

**OPTIMIZING ROAD MAINTENANCE MANAGEMENT THROUGH DATA-DRIVEN
PRIORITIZATION FRAMEWORK IN ADAMA CITY**



ESMAEL TOLOLA GELCHU

A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

**PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF MASTER OF
SCIENCE IN CIVIL ENGINEERING (SPECIALIZATION IN CONSTRUCTION
ENGINEERING AND MANAGEMENT)**

OFFICE OF GRADUATE STUDIES

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

JUNE, 2024

ADAMA, ETHIOPIA

**Optimizing Road Maintenance Management Through Data-Driven
Prioritization Framework in Adama City**

Esmael Tolola Gelchu

Advisor: Bahiru Bewket Mitike (Ph.D.)

**A Thesis Submitted to the Department of Civil Engineering
School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment of the Requirement of Master of Science
in Civil Engineering (Specialization in Construction Engineering and
Management)**

**Office of Graduate Studies
Adama Science and Technology University**

June, 2024

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis “**Optimizing Road Maintenance Management Through Data-Driven Prioritization Framework in Adama City**” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Esmael Tolola Gelchu

Name of the student

Signature

Date

APPROVA PAGE OF THE ADVISOR

I, the advisor of the thesis entitled, and developed “**Optimizing Road Maintenance Management Through Data-Driven Prioritization Framework in Adama City**” by Esmael Tolola Gelchu, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Bahiru Bewket Mitike (Ph.D.)

Major Advisor/Supervisor

Signature

Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Reviewers of the thesis by Esmael Tolola have read and evaluated the thesis entitled “**Optimizing Road Maintenance Management Through Data-Driven Prioritization Framework in Adama City**” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management)

_____	_____	_____
Chairperson	Signature	Date

_____	_____	_____
Internal Examiner	Signature	Date

_____	_____	_____
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

_____	_____	_____
Department Head	Signature	Date

_____	_____	_____
School Dean	Signature	Date

_____	_____	_____
Office of PG Studies, Dean	Signature	Date

ACKNOWLEDGEMENT

This research has become a reality due to the generous help and support of many individuals. It is my pleasure to acknowledge and thank them for their contributions. First of all, I would like to express my deepest appreciation to my advisor Bahiru Bewket (Ph.D.) for his time and effort in reviewing the progress of this paper and providing valuable feedback, guidance, and encouragement. And I would like to express my appreciation to all organizations and individuals who contributed directly or indirectly to this paper especially by sacrificing their time in filling the questionnaires and provided the necessary materials and support for the realization of this paper. Finally, Special thanks and love go to my family for their encouragement and support through the tough times.

ABSTRACT

Efficient and safe transportation infrastructure is crucial for a nation's economic development and social well-being. However, traditional reactive road maintenance approaches struggle with limited budgets, inefficient resource allocation, and lack of reliable data. This study is aimed to comprehensively evaluate the effectiveness of current road maintenance management practices in Adama City, and develop a data-driven approach for improvement. The research employed a mixed-methods approach, utilizing surveys and interviews with road construction and maintenance professionals. The Relative Importance Index (RII) assessed the effectiveness of current practices, revealing weaknesses in cost-effectiveness, time efficiency, and quality of materials/techniques. Financial constraints were identified as the most significant challenge. A data-driven prioritization framework, based on the Weighted Average Score (WAS) method, is proposed to address these issues. The framework emphasizes investing in staff capacity building and crew training programs as the most impactful strategy. This aligns with the study's conclusion that a well-trained workforce can optimize resource allocation, improve time efficiency, and ensure the effective use of high-quality materials and techniques. The study recommends addressing weaknesses through data-driven budgeting, training programs, exploring cost-efficient techniques, and ensuring quality materials and techniques. Strategic resource allocation and alternative financing mechanisms can address financial limitations. This data-driven approach offers a valuable model for Adama City and other municipalities facing similar challenges in optimizing road maintenance management practices.

Key Words: Road maintenance management, data-driven approach, prioritization framework, Weighted Average Score, Improvement Strategies.

TABLE OF CONTENTS

DECLARATION	III
APPROVA PAGE OF THE ADVISOR.....	IV
APPROVAL OF BOARD OF REVIEWERS	V
ACKNOWLEDGEMENT	VI
ABSTRACT.....	VII
CHAPTER ONE	12
INTRODUCTION	12
1.1 Background of the Study.....	12
1.2 Statement of the Problem.....	15
1.3 Objective of the Study.....	16
1.3.1 General Objective	16
1.3.2 Specific Objectives	16
1.4 Research Questions	17
1.5 Significance of the Study	17
1.6 Scope of the Study.....	17
1.7 Limitations of the Study.....	18
CHAPTER TWO	20
LITERATURE REVIEW	20
2.1 Introduction	20
2.2 Overview of Road Maintenance.....	20
2.2.1 Concept of Maintenance and Road Maintenance	21
2.2.2 The Value of Maintaining Roads	22
2.2.3 The Purpose of Maintaining Roads.....	22

2.3	Road Maintenance Management: An Overview	23
2.4	Elements of Road Maintenance Management Process	24
2.5	Data-Driven MCDM Approaches in Road Maintenance Management	25
2.6	Prioritization Frameworks in Road Maintenance Management.....	26
2.7	Effectiveness of Current Road Maintenance Management Practices	26
2.8	Challenges Facing the Road Maintenance Management Practices	27
2.8.1	Budget and Funding Related Challenges.....	28
2.8.2	Human Resources and Capacity Related Challenges	29
2.8.3	Legislative Level Issues.....	29
2.8.4	Administrative Level Issues.....	30
2.8.5	Technical Challenges	30
2.9	Enhancing Road Maintenance Management Practices	31
2.9.1	Road Maintenance Management Practices: Ethiopian Experience	32
2.10	Summary of Literature Review and Research Gaps.....	34
CHAPTER THREE		37
RESEARCH METHODOLOGY.....		37
3.1	Introduction	37
3.2	Study Area.....	37
3.3	Research Design and Approach.....	38
3.4	Population of the Study	39
3.5	Sample Size	41
3.6	Sampling Technique	42
3.7	Sources of Data	43
3.7.1	Secondary Sources	43

3.7.2	Primary Sources	43
3.8	Data Collection Instruments	44
3.8.1	Questionnaire Survey	44
3.8.2	Interviews.....	46
3.9	Data Analysis and Presentation	47
3.9.1	Relative Importance Index	47
3.9.2	Weighted Average Score	49
3.10	Reliability of the Data.....	50
3.11	Validity of the Study.....	51
3.11.1	Construct Validity	51
3.11.2	Internal Validity	52
3.11.3	External Validity	52
3.12	. Ethical Considerations	53
CHAPTER FOUR.....		54
RESULTS AND DISCUSSIONS		54
4.1	Introduction	54
4.2	Respondent’s Profile	55
4.2.1	Respondent’s respective Organizations	55
4.2.2	Respondents Job Position	56
4.2.3	Respondent’s Educational Background	57
4.2.4	Respondent’s Educational Background	58
4.3	Effectiveness of Road maintenance Management Practices	60
4.4	Challenges of Road Maintenance Management Practices.	62
4.5	A Data-Driven Prioritization Framework for Improvement Strategies.....	65

4.5.1	Prioritization Framework for Improvement Strategies (Ease of Execution)	66
4.5.2	Prioritization Framework for Improvement Strategies (Cost-Effectiveness)	69
4.5.3	Prioritization Framework for Improvement Strategies (Potential Impact)	73
4.5.4	Prioritization Framework - Integrated Analysis.....	77
4.6	Discussions and Implications of Key Findings	81
4.6.1	Discussion and Implications of Performance of Road Maintenance Management Findings.....	81
4.6.2	Discussion and Implications of Challenges of Road Maintenance Management Findings.....	84
4.6.3	Discussion and Implications of Prioritization Framework for Improvement Strategies Findings.....	85
CHAPTER FIVE		87
CONCLUSIONS AND RECOMMENDATIONS		87
5.1	Conclusions	87
5.2	Recommendations	88
5.3	Further Research	89
REFERENCES		90
APPENDIX A		96
APPENDIX A		

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Efficient and safe transportation of people and goods is not just a convenience, but a vital component for a nation's economic development and social well-being. Well-maintained roads form the backbone of this transportation system, facilitating the movement of goods and services, fostering trade, and connecting communities (Queiroz & Gautam, 1992). Roads are the arteries through which the economy pulses, linking producers to markets, workers to jobs, students to school, and the sick to hospitals (Berg et al., 2017).

However, the burden on road infrastructure is constantly increasing. Aging roads, coupled with rising traffic volumes due to population growth and urbanization, place significant strain on existing maintenance practices (Ai et al., 2024). The need for maintenance increases as road infrastructure ages, since it becomes more fragile, less resilient and journeys are more susceptible to disruption (Ivanova & Masarova, 2013). If insufficient maintenance is carried out, roads can need replacing or major repairs after just a few years. That deterioration spread across a road system very quickly results in soaring costs and a major financial impact on the economy and citizens (World Highways, 2021)

Moreover, higher traffic volumes are associated with a net increase in crashes. However, the crash increase is less than proportional to traffic volume increases, indicating a lower risk for each road user (Hesjevoll and Elvik, 2016). Faced with the contradiction between the increasing traffic volume and the aging road infrastructures, it is crucial to propose feasible strategies to enhance the level of service and safety (Ali et al., 2024).

The importance of road infrastructure and its maintenance cannot be overstated. As the demand for efficient transportation grows, so does the need for robust and well-maintained roads. Therefore, it is imperative to develop effective strategies for road maintenance that can keep pace with the increasing demands placed on our road infrastructure (Ali et al., 2024; Ivanova & Masarova, 2013).

Traditional road maintenance management often relies on reactive approaches. This involves waiting for visible signs of deterioration, such as potholes or cracks, before taking action. While seemingly straightforward, reactive maintenance has several drawbacks (Saarenketo & Männistö, 2021).

Decisions are based on subjective observations or experience of maintenance crews, potentially leading to uneven prioritization of repairs across the road network. The key problem with a reliance on physical visual surveys is that the recorded condition of the road will, by its very nature, be a subjective exercise based on opinion and/or interpretation. Errors in evaluation of the road condition and the mechanisms of distress will lead to either under design of remedial interventions, with resultant premature failure, or an overly robust design with associated wasteful expenditure in additional design and construction costs (Mbiyana et al., 2023). In addition, effective planning is hampered by a lack of comprehensive data on road conditions, traffic patterns, and past maintenance history. This makes it difficult to predict future needs and prioritize interventions. Common hurdles in applying machine learning algorithms to predictive maintenance include data scarcity, data imbalance due to few failure instances, and the temporal dependence nature of predictive maintenance data (Hakami, A2024; Myakala & Shankar, 2023).

Moreover, budgetary limitations and inefficient resource allocation can prevent timely maintenance (Sandamal & Pasindu, 2024). This can lead to postponing necessary repairs, further exacerbating road deterioration. The construction, maintenance, and operation of transportation infrastructures are subject to five major types of constraints. Physical and environmental constraints impose higher construction and maintenance costs that can only be justified by higher economic and social opportunities the infrastructure may confer. Allocating scarce resources for transportation infrastructure requires careful consideration of the expected economic and social benefits. If these benefits are uncertain, infrastructure development could be impaired, which is particularly the case for peripheral areas (Pinha & Ahluwalia, 2019). While reactive maintenance may seem cost-effective in the short run, the long-term costs can be considerably higher due to potential collateral damage upon equipment failure, emergency repair costs, and the costs incurred due to unplanned downtime (Saarenketo & Männistö, 2021).

Given the limitations of current road maintenance management practices, there is an urgent need for a comprehensive evaluation to identify areas for improvement. Inadequate road maintenance can lead to a host of problems, including increased accidents, vehicle damage, and longer travel times, thereby impacting the overall efficiency of the transportation system (Diaz et al., 2021). Road maintenance authorities face several key challenges. Limited budgets often hinder the implementation of necessary maintenance interventions. This lack of funding can lead to inefficient resource allocation, preventing timely maintenance interventions and allowing minor issues to escalate into major problems, thereby increasing overall costs (Juma 2022). Moreover, the lack of reliable data can make it difficult for these authorities to prioritize projects effectively. Without accurate and comprehensive data on road conditions, traffic patterns, and maintenance history, planning and decision-making processes may be compromised (Nautiyal & Sharma, 2022).

Deteriorated roads can lead to increased travel time and accidents. When roads are not properly maintained, they can become safety hazards, leading to increased accident rates and vehicle damage. This not only disrupts traffic flow but also poses significant safety risks to road users. Furthermore, resources might be directed towards less critical repairs while neglecting more pressing needs. This misallocation of resources can exacerbate road conditions, leading to premature road failures and inefficient resource allocation (Nautiyal & Sharma, 2022). In conclusion, addressing these challenges requires a shift in approach towards road maintenance management.

The current state of road maintenance in Adama City exemplifies the need for a data-driven prioritization framework. Similar to findings by Nautiyal & Sharma (2022), existing practices often lack a systematic approach to prioritizing maintenance strategies. While factors like pavement condition, traffic volume, and connectivity are considered, these methods might not capture the city's specific challenges. Rapid road deterioration due to heavy traffic volume and inadequate maintenance plagues the city's road network. This manifests as potholes, cracks, and uneven surfaces. Limited budgetary resources further restrict the ability to comprehensively address these issues. The current reactive approach, focusing on repairs after significant damage, fails to prioritize preventive measures. These factors contribute to a decline in the overall health of the road network, negatively impacting safety, traffic flow, and economic activity in Adama.

This research aims to address this gap by developing a data-driven prioritization framework specifically tailored to Adama City. The framework utilizes the Weighted Average Score (WAS) method (Anjasromo & Sangkawati, 2017) to systematically analyze potential maintenance improvement strategies. By prioritizing strategies based on these locally relevant criteria, the framework aims to optimize resource allocation and maximize the effectiveness of road maintenance efforts in Adama City. This aligns with recent research advocating for data-driven approaches to road maintenance management (Zhao et al., 2022; Nautiyal & Sharma, 2022).

In conclusion, this data-driven prioritization framework represents a significant advancement in road maintenance management practices. By incorporating a systematic, objective, and data-driven approach, this framework has the potential to greatly improve the efficiency and effectiveness of road maintenance efforts.

1.2 Statement of the Problem

In the rapidly urbanizing city of Adama, the management of road maintenance presents a critical challenge to sustainable urban development. The ideal scenario envisions a city where road infrastructure is maintained efficiently, ensuring safety, economic vitality, and the well-being of its inhabitants. However, the reality deviates significantly from this ideal. Current road maintenance management practices in Adama are often reactive rather than proactive, leading to deteriorating road conditions, increased vehicle operating costs, and heightened safety risks (Shewatatek, 2022).

The research gap lies in the lack of a systematic, data-driven approach to prioritize road maintenance that considers local conditions and resource constraints. This study aims to bridge this gap by developing a Weighted Average Score (WAS) based framework that systematically analyzes improvement strategies with respect to ease of execution, cost-effectiveness, and potential impact. The absence of such a framework result in suboptimal allocation of resources, where critical road sections remain neglected, and funds may not be utilized where they are most needed.

The consequences of not addressing this gap are far-reaching. Inefficient road maintenance can lead to increased accident rates, hinder economic growth by affecting the transportation of goods and people, and result in higher environmental impacts due to poor road conditions leading to increased emissions (Nautiyal & Sharma, 2022).

In conclusion, the current reactive road maintenance practices in Adama are demonstrably inadequate, leading to a significant decline in road quality and posing safety and economic challenges. The absence of a data-driven prioritization framework further exacerbates this issue by hindering the optimal allocation of resources. This study addresses this critical gap by proposing a WAS-based framework to systematically evaluate improvement strategies and prioritize road maintenance interventions. By implementing this framework, Adama City can transition towards a more proactive and sustainable approach to road maintenance, promoting public safety, economic prosperity, and environmental well-being.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of the study is to evaluate the effectiveness of current road maintenance management practices in Adama City, and develop a data-driven strategy for improvement.

1.3.2 Specific Objectives

The specific objectives of the study are:

- To assess the effectiveness of current road maintenance management practices.
- To examine the key challenges that hinder the performance of road maintenance management practices.
- To develop a data-driven prioritization framework as a strategy to alleviate the identified challenges and improve the practices of road maintenance management.

1.4 Research Questions

The research questions for this study are:

- How effective are the current road maintenance management practices?
- What are the key challenges that hinder the performance of road maintenance management practices?
- How can a data-driven prioritization framework be developed for strategies to overcome the identified challenges and improve the overall road maintenance management practices?

1.5 Significance of the Study

This study holds significant value due to its comprehensive evaluation of current road maintenance practices in Adama City and the subsequent development of a data-driven prioritization framework for improvement. The research addresses a critical need by providing a clear understanding of the effectiveness of existing practices, highlighting key challenges that hinder performance, and proposing a novel solution. The framework utilizes Weighted Average Score (WAS) to objectively assess the ease of execution, cost-effectiveness, and potential impact of various improvement strategies. This empowers decision-makers to prioritize interventions that optimize resource allocation, enhance road conditions, and ultimately promote transportation efficiency and safety within Adama City.

The study's findings and the proposed framework extend beyond Adama City. Road authorities in other Ethiopian cities facing similar challenges can adapt the methodology and utilize the framework to improve their own road maintenance practices. Additionally, policymakers can leverage the study's insights to inform policy development related to road maintenance funding, resource allocation, and the establishment of best practices. In conclusion, this research has the potential to make a significant contribution to improving road infrastructure and transportation efficiency not only in Adama City, but also across Ethiopia, leading to a more sustainable transportation system.

1.6 Scope of the Study

This study's scope encompassed two thematic areas within road maintenance management for Adama City, Ethiopia. The first theme assessed the effectiveness of current practices through the

Relative Importance Index (RII), evaluating their strengths, weaknesses, and overall impact on road maintenance. The second theme focused on developing a data-driven prioritization framework utilizing the Weighted Average Score (WAS) method. This framework aimed to prioritize improvement strategies based on ease of implementation, cost-effectiveness, and potential impact.

Geographically, the study was confined to Adama City to ensure a comprehensive investigation of its specific context, including infrastructure, traffic patterns, and existing maintenance practices. While this context may limit the generalizability of findings to other cities, the framework provides a foundation for adaptation in similar settings. The data collection and analysis were conducted within a defined timeframe, encompassing January 2024 to May 2024, capturing a snapshot of Adama City's current road maintenance landscape and its associated challenges. The study acknowledges the limitation of generalizability due to its focus on a single city. Future research could explore the applicability of the framework in other Ethiopian cities or similar contexts. Additionally, implementing pilot projects or long-term monitoring could further illuminate the effectiveness of specific improvement strategies identified within this study.

1.7 Limitations of the Study

This study, while providing a comprehensive evaluation of road maintenance practices in Adama City, acknowledged certain inherent limitations. These limitations pertained to the generalizability of the findings, the data collection methods employed, the developed framework itself, the scope of the research, and the time constraints encountered during the study.

The focus on Adama City restricted the applicability of the findings to other cities with differing infrastructure characteristics (road types, materials, traffic volume) and maintenance practices (policies, budgeting, resources). The data-driven prioritization framework may necessitate adjustments for use in other contexts. The multifaceted approach utilizing surveys and stakeholder consultations might have been susceptible to self-reported bias, where participant responses may not always have reflected reality. Additionally, the sample size of surveys or interviews might not have captured the perspectives of the entire stakeholder population.

The WAS method within the framework assigned equal weight to ease of execution, cost-effectiveness, and potential impact. However, the relative importance of these factors can vary depending on specific situations. The framework's effectiveness also relied on data availability and the accuracy of assigned weights. Limited data or subjective weighting could have influenced the prioritization of improvement strategies. The study's focus was on evaluating current practices and developing a framework, not on implementing and evaluating specific improvement strategies. The effectiveness of identified strategies may require further investigation through pilot projects or long-term monitoring.

The study timeframe might have limited the depth of data collection and analysis. A longer duration could potentially have provided more comprehensive insights. By acknowledging these limitations, the study demonstrated a critical understanding of its methodological approach and strengthened the credibility of its findings. This transparency highlighted areas for future research, paving the way for further exploration and refinement of the proposed framework for optimizing road maintenance management practices.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The field of road maintenance management is a critical area of study, particularly in the context of developing countries like Ethiopia where infrastructure development and maintenance are key to economic growth and societal well-being. This literature review aims to provide a comprehensive overview of the current practices, challenges, and potential strategies for optimizing road maintenance management.

The primary objective of this review is to evaluate the effectiveness of existing road maintenance management practices. This involves a thorough examination of various methodologies and techniques currently in use, as well as their outcomes in terms of road quality, cost-effectiveness, and overall efficiency. In addition, this review seeks to identify and analyze the key challenges that hinder the performance of road maintenance management practices. These challenges may encompass a wide range of issues, from technical and logistical constraints to policy-related obstacles and resource limitations. Finally, this review aims to explore the potential of a data-driven prioritization framework as a strategy to overcome these challenges and improve overall road maintenance management practices. The use of data-driven approaches in infrastructure management is a burgeoning field of study, and this review will delve into the various ways in which such approaches can be applied to road maintenance management.

In the following sections, we delved deeper into each of these areas, providing a detailed analysis of the current state of knowledge and identifying gaps where further research is needed. The final section summarized the key findings from the literature and highlight the research gaps that this study aims to address.

2.2 Overview of Road Maintenance

Before assessing the situation in the road maintenance management system, it is important to address the issue of the term "maintenance." It is done to ensure that the road that has been constructed or improved is maintained in its original condition. It is accepted that over the life of the road, it will deteriorate due to factors with which maintenance activities cannot deal.

Nevertheless, maintenance is intended to begin on the first day after the road improvement works are completed.

2.2.1 Concept of Maintenance and Road Maintenance

According to Mulmi (2016), the definition of maintenance varies among agencies. In a physical sense, maintenance consists of a set of activities directed towards keeping a structure in a serviceable state. Patil and Kulkarni (2019) describes maintenance as a combination of technical and management work done on a specific asset or structure to ensure the structure is in good condition and is functioning at its maximum capacity. There are two types of maintenance: repair work and prevention work. Reparation can be described as the rehabilitation or replacement of spoiled components, while prevention is to prevent defects from occurring.

According to Henok and Mohamed (2020), the definition of maintenance can be described as methods and techniques used to restore or maintain a specified level of service and to prolong road life by slowing its deterioration rate. As a summary, the main and only objective of maintenance is to ensure the specific structure being maintained is in a good and acceptable condition and will not cause inconvenience to the users.

The World Road Association in 1994 defined road maintenance as the operations necessary to maintain the road, shoulders, slopes, waterways, and all other structures and properties within the limits for the road as close to their originally or upgraded status as possible. This includes modest improvements and repairs to eliminate problem areas and prevent overly frequent upkeep. Activities such as road widening, shoulder construction, and rehabilitation are not included in maintenance (Hoban et al., 1994).

The Ethiopian Roads Authority (ERA) in 2013 defined road maintenance as regular, sporadic, and emergency works to maintain shoulders, slopes, drainage systems, and structures as close to their original state as possible in order to ensure that the road's design life is fulfilled³. This definition emphasizes the importance of maintaining the integrity of the road infrastructure to ensure its longevity and functionality (ERA, 2013).

2.2.2 The Value of Maintaining Roads

Building new roads is essential to a country's development. However, there is a problem with road maintenance negligence that is widespread around the world. While constructing new roads is expensive, they deteriorate rapidly if they are not adequately maintained. Roads with a decades-long design life may require replacement or extensive repair work after only a few years if nothing is done (Levik, 2008).

Heggie and Vickers (1998) assert that in many nations, roads rank among the most significant public resources. Improved comfort, speed, and safety; reduced vehicle running costs; and easier access to schools, hospitals, and markets are just a few of the obvious advantages that come with road upgrades for drivers. Road improvements can have longer-term effects on development, such as higher agricultural output and higher school enrollment, but they cannot be realized without continuous maintenance, as roads can quickly deteriorate (Mulmi, 2016).

By making the running surface better, it reduces the cost of operating cars on the road and maintains uninterrupted road access. According to Robinson et al. (1998), in their book "Road Maintenance Management Concepts and Systems," the importance of maintenance lies in its ability to reduce road deterioration through timely and effective maintenance, lower vehicle operating costs through proper and timely maintenance, and lower transportation, fuel, and other user costs. However, operational expenses for vehicles will probably rise by roughly 15% if maintenance funding is cut. A paved road will soon begin to deteriorate if maintenance is completely neglected, and annual vehicle running costs would rise by roughly 50%.

2.2.3 The Purpose of Maintaining Roads

Road maintenance is a critical aspect of infrastructure management and has significant implications for the socio-economic development of a region (Nautiyal & Sharma, 2022). The primary objective of road maintenance is to ensure that the constructed or improved road is maintained in its original condition as much as possible. Over the life of the road, it will inevitably deteriorate due to various factors, but maintenance activities aim to mitigate this deterioration as much as possible (Donnges et al., 2007).

Timely maintenance of roads offers many benefits for the preservation of road assets. Good and effective road maintenance not only reduces vehicle operation cost and accident rates but also improves the service life of the road by reducing the rate of deterioration of pavements (Nautiyal & Sharma, 2022). Regular road maintenance activities save budgetary expenditure of restoration of roads. The economic rate of return due to timely maintenance of the road can be as high as 15 to 20 percent, depending upon the traffic volume and category of the road (Nautiyal & Sharma, 2022).

An effective pavement maintenance program becomes necessary for reducing hazardous impacts on the environment because poor quality of pavements increases vehicle operation cost and energy and environmental (i.e., emissions) impacts become very high (Nautiyal & Sharma, 2022). Many road authorities consider contracting out road maintenance to the private sector based on performance measures as an alternative and better solution than traditional methods of contracting (Sultana et al., 2013).

In conclusion, road maintenance is a crucial aspect of infrastructure management that contributes significantly to socio-economic development. It helps preserve road assets, reduce vehicle operation costs, accident rates, and environmental impacts, and improve the service life of roads. Therefore, it is essential to prioritize road maintenance and develop effective strategies for its implementation.

2.3 Road Maintenance Management: An Overview

Road maintenance management is the process of preserving and keeping the road structure as normal as possible and practicable (Nautiyal & Sharma, 2022). This involves regular inspections and timely repairs to ensure the road's optimal performance (Mbiyana et al., 2023). The goal is to prevent the deterioration of roads, extend their lifespan, and ensure they are safe and comfortable for user (Nautiyal & Sharma, 2022).

Roads are vital for a nation's growth and development. They provide access to employment, social, health, and education services, making a road network crucial in fighting against poverty. By opening up more areas, roads stimulate economic and social development (Sally and Natalya, 2005).

Road infrastructure is one of the most important public assets. Adequate maintenance is essential to preserve these assets and prevent them from depreciating in value. Without proper maintenance, roads can deteriorate quickly, leading to soaring costs and a major financial impact on the economy and citizens.

Well-maintained roads offer smooth rides and easy navigation, with fewer hazards that could lead to accidents. This results in less congestion and fewer accidents, saving both time and lives. Regular maintenance helps identify and address potential hazards, minimizing the risk of accidents (Mbiyana et al., 2023). Regular road maintenance can prevent the need for major repairs or replacements, which are often more costly. By investing in maintenance, future costs for citizens, road users, taxpayers, and road owners can be significantly reduced (Burrow et al., 2013).

In conclusion, road maintenance management plays a crucial role in ensuring the safety, comfort, and economic well-being of a community. It is a critical aspect of infrastructure management that requires careful planning and execution. This means less congestion and fewer accidents, which in turn saves both time and lives (Robinson et al., 1998).

2.4 Elements of Road Maintenance Management Process

Effective road maintenance management processes are crucial for ensuring safe, efficient, and sustainable transportation infrastructure. This review examines the key components and strategies involved in this process, drawing on insights from scholarly articles and reliable references. Road maintenance extends the lifespan of roadways, minimizes safety hazards, and reduces user costs associated with vehicle repairs due to poor road conditions (Rastegari & Salonen, 2015). A well-defined management process optimizes resource allocation, prioritizes maintenance activities, and facilitates data-driven decision-making for cost-effective road network upkeep (Jafari et al., 2008).

Road maintenance management is a comprehensive and systematic approach that ensures the longevity and functionality of road networks. It involves a series of interconnected phases, each with its unique focus and objectives.

The planning phase of road maintenance management is a comprehensive process that involves the establishment of policies, considerations for the network, and the delineation of responsibilities among staff. It also encompasses the determination of the level of data detail required and the methods for estimating costs.

The programming phase is characterized by the selection of treatments for different road sections. This selection is based on the current condition of these sections and the budget available for maintenance activities (Robinson et al., 1998).

The preparation phase involves the prioritization of road sections for maintenance. This prioritization is based on a variety of factors, including the distress level of the road, the condition of the pavement, the utility value of the road, the total traffic on the road, the climatic conditions of the area, and the type of road (Nautiyal & Sharma, 2022). The operations phase involves the actual execution of the maintenance activities. These activities can include routine maintenance, periodic maintenance, and emergency maintenance (Robinson et al., 1998).

Effective road maintenance management is crucial for the sustainability of road networks. It involves a complex process of planning, programming, preparation, and operations. By understanding these key elements and utilizing appropriate models, road maintenance management can be optimized to ensure the longevity and functionality of road networks.

2.5 Data-Driven MCDM Approaches in Road Maintenance Management

Data-driven approaches are increasingly being used in various fields, including road maintenance management. These approaches involve the use of data to make informed decisions. In the context of road maintenance management, data-driven approaches can involve the use of various techniques and models for data collection and decision making (Nautiyal & Sunil Sharma, 2022).

A multi-criteria decision-making (MCDM) approach is one such data-driven approach that has been applied in various studies (Alshamsi et al., 2023). This approach assigns various scores of weights to alternatives, then the best-scored alternative is passed through a recommendation model. The benefits of implementing data-driven MCDM approaches in road maintenance management include enhanced decision-making processes and improved road maintenance outcomes (Sun & Yan, 2023). However, there are also challenges associated with implementing these approaches. These can include issues related to data collection, the need for advanced technological infrastructure, and the requirement for skilled personnel to analyze and interpret the data (Merk, 2021).

In summary, MCDM approaches offer a promising avenue for improved road maintenance management. By leveraging data to analyze various factors and prioritize interventions, these approaches can lead to more informed decisions and ultimately, better road conditions. While challenges exist in data collection, infrastructure, and personnel expertise, the potential benefits of data-driven MCDM outweigh these hurdles. By investing in data collection methods, technological advancements, and personnel training, road maintenance authorities can reap the rewards of a data-driven approach, ensuring a more efficient and effective road network.

2.6 Prioritization Frameworks in Road Maintenance Management

Prioritization frameworks are essential tools in road maintenance management. These frameworks help in determining the order in which roads should be maintained based on various factors. Factors considered in these frameworks can include the condition of the pavement, the utility value of the road, total traffic on the road, climatic conditions of the area, and the type of road (Nautiyal & Sharma, 2016).

The importance of prioritization in road maintenance management cannot be overstated. Prioritization helps in the efficient allocation of resources, ensuring that roads most in need of maintenance are attended to first. It also aids in planning and scheduling maintenance activities, thereby improving the overall effectiveness of road maintenance programs (Sun and Yan, 2023).

In conclusion, prioritization frameworks play crucial roles in road maintenance management. While they offer numerous benefits, their implementation also comes with certain challenges that need to be addressed for successful outcomes.

2.7 Effectiveness of Current Road Maintenance Management Practices

Hussain et al. (2022) explored the awareness of Pavement Management System (PMS) in Pakistan and proposes a low-cost model and pavement maintenance indicators for developing countries. The study found that while experts are aware of PMS for new roads, there is no PMS in place for road rehabilitation. The study suggests that the proposed framework can significantly assist in facilitating sustainable infrastructure in developing countries (Hussain et al., 2022).

Nautiyal & Sharma, 2022) reviewed various factors, techniques, and models used by researchers for prioritizing roads for maintenance. The study found that major factors responsible for pavement deterioration include distress, condition of pavement, utility value of road, total traffic on road, climatic conditions of area, and type of road.

A study conducted by Klockow & Hofer (1991) focused on improving road maintenance practices in developing countries, with a case study from Nepal. The study provides valuable insights into the challenges faced by developing countries in maintaining their road networks. Another study by Dengeso (2021) evaluates the management system of road maintenance construction in Jimma zones, Ethiopia. The study investigates the poor management system, determines the significant factor for the poor management system, and the consequences on road maintenance construction projects.

These studies provide a comprehensive overview of the current practices and challenges in road maintenance management. They highlight the need for effective pavement management systems and prioritization methods to ensure the sustainability and effectiveness of road maintenance practices. They also underscore the importance of context-specific strategies, considering the unique challenges faced by developing countries.

2.8 Challenges Facing the Road Maintenance Management Practices

Road infrastructure forms the backbone of any nation's economic development and prosperity. It facilitates the movement of goods and people, fostering social interaction and economic integration. However, maintaining this critical asset in an optimal condition is a complex task fraught with numerous challenges (Khahro et al., 2022). This empirical review aims to explore these challenges, focusing specifically on road maintenance management practices.

The importance of road maintenance cannot be overstated. It ensures the longevity of road infrastructure, enhances safety, and promotes efficient transportation. Despite its significance, road maintenance management often faces numerous hurdles, ranging from financial constraints, technological gaps, to human resource issues. These challenges can severely impact the productivity and efficiency of road maintenance activities, leading to deteriorating road conditions and, ultimately, economic losses. This review will delve into the various challenges that impede effective road maintenance management. It will draw upon a wealth of data and insights from

numerous studies and reports, providing a comprehensive overview of the current state of affairs in road maintenance management.

2.8.1 Budget and Funding Related Challenges

The funding gap in road maintenance management is a major issue due to competing priorities, underestimating needs, and short-term budget cycles. This leads to delayed maintenance, escalating road deterioration, and higher costs in the long run. To address this, proactive maintenance is crucial, even if it requires higher upfront costs, and alternative funding mechanisms like user fees or public-private partnerships can help bridge the gap between needs and resources (Setyawan et al., 2024). Incomplete maintenance systems can hinder effective road management by limiting data collection, adopting a reactive approach, and relying on skilled personnel. Budget constraints can lead to delayed interventions, compromised road conditions, and a short-term focus on short-term fixes, resulting in costly repairs and a cycle of deterioration (Matjane, 2023).

Similarly, reduced financing for capital and maintenance is a significant challenge in road management. This leads to deteriorating existing roads, safety concerns, traffic congestion, delayed maintenance, shorter road lifespans, and increased operational costs. Striking a balance between capital investment and ongoing maintenance is crucial for saving money, improving the road network, and ensuring safety and efficiency. Proper maintenance can reduce costs, attract businesses and residents, and reduce accidents (Matjane, 2023). Creating an objective priority program for road maintenance budget support is crucial due to challenges such as limited or outdated data availability, subjective weighting of factors, and public perception vs. objective data. Factors such as traffic volume, pavement condition, and economic impact can impact funding decisions. Balancing factors and public perception can also impact the decision-making process, as public pressure to fix roads may not align with objective data (Mostafa, 2018).

Budget requests significantly affect the future condition of road networks. Adequate funding ensures road network preservation, improves safety, enhances traffic flow, and stimulates economic activity. Insufficient budgets lead to deteriorating infrastructure, increased repair costs, safety hazards, and economic downturn. Challenges in budget requests include short-term vs. long-term thinking, competition for funds, and unrealistic budget expectations. Adequate funding allows for regular preventative maintenance, reducing accidents and reducing healthcare costs.

Insufficient budgets can also lead to a decline in road quality, increased repair costs, and safety hazards (Gould et al., 2013).

Moreover, road maintenance management faces challenges in justifying budget proposals, setting priorities, and balancing public and political pressures. Effective justifications should consider economic benefits, safety improvements, and long-term cost savings. Priorities should be based on data-driven decision-making, ensuring resources are directed towards areas with the greatest need. Balancing public expectations and political pressures with technical requirements is crucial, and transparency and communication are key to addressing public concerns and ensuring budget decisions are based on objective data and technical expertise (Brushett, 2005).

2.8.2 Human Resources and Capacity Related Challenges

Road maintenance management faces several challenges, including personnel issues due to limited capacity building, skilled worker shortages, and competition from private construction firms. Insufficient training can lead to subpar repair work, reduced efficiency, and a decline in road network quality. Investment in capacity building initiatives is crucial for road maintenance organizations to ensure staff have the necessary knowledge and skills to utilize advanced technologies, implement innovative maintenance strategies, and make informed decisions. (Burningham and Natalya, 2010).

Skilled worker shortages and competition also pose a significant challenge, as private firms may offer higher salaries, benefits packages, and faster career advancement opportunities. To mitigate these challenges, road maintenance agencies can offer competitive salaries and benefits packages, create clear career development pathways, and offer competitive salaries and benefits to attract and retain skilled workers (Mostafa, 2018).

2.8.3 Legislative Level Issues

The administrative and technical levels must acknowledge the rather broad nature of the issues at the legislative level. These consist of the following: the rationale behind the budget proposal; the impact of reduced financing for capital and upkeep; the results of postponing projects or reducing standards; the impact of the budget request on the network's future condition; and the results of higher load limitations.

2.8.4 Administrative Level Issues

Budget and programming priorities are two topics that are related to the decision-making process at the administrative level. These concerns include a summary evaluation of the network's existing state in graphical and tabular form, as well as an objectively based priority program to support budget demands. Assessing the network's future status for the projected investment and quantitatively calculating the effects of reducing spending and delaying maintenance while accounting for average serviceability, quality, and safety.

2.8.5 Technical Challenges

Road management raises many different problems and queries from a technical standpoint. If technical operations are to have any significance, it is also necessary to understand the questions and problems that arise at the administrative level. Some of the most important queries at this stage, which take into account both network and project factors, are as follows: The design, functionality, procedures, and sufficiency of the inventory database. Models for reliably forecasting a variety of variables, including traffic, performance, skid, and distress.

Nuru (2010) asserts that because of the discrepancy between repair need and maintenance fund, budget is the most important issue with the road maintenance management system. The maintenance system cannot be completed without the necessary budget, and the road will eventually need to be dismantled, resulting in the highest cost. The difficulties in road maintenance also include project delivery, data collection on the roads that need care, and the lack of a standard handbook. Additionally, he said that a lack of capacity building initiatives has resulted in personnel problems that are less trained.

Nuru (2010) asserts that because of the discrepancy between repair needs and maintenance funds, budget is the most important issue with the road maintenance management system. The maintenance system cannot be completed without the necessary budget, and the road will eventually need to be dismantled, resulting in the highest cost. The difficulties in road maintenance also include project delivery, data collection on the roads that need care, and the lack of a standard handbook. Additionally, he observed that fewer capacity-building initiatives had resulted in personnel problems that were less trained.

2.9 Enhancing Road Maintenance Management Practices

Every system in use today has both strengths and weaknesses due to advancements in technology. Thus, the Road Maintenance Management System was not left out and would gradually need to be improved. A systematic approach to maintenance management is required for several reasons, such as providing information on the condition of roads today and predicting their future state, offering objective alternatives for maintenance policies, offering a solid foundation for allocating resources and making the best use of funds, enhancing management effectiveness and generating cost savings, and offering an impartial, quick, and repeatable method for making decisions (Patil and Kulkarni, 2019).

Nuru (2010) did a case study in Malaysia and found that the fundamental strategies for resolving issues with the road maintenance management system include systematic database storage, whether for hard copy or soft copy, and monitoring the completed road maintenance work. Most of the time, it will be challenging to calculate the maintenance budget due to data loss on road conditions. Failure to closely monitor the road maintenance work may have an impact on the project's completion and maintenance quality.

Enhancing road maintenance management practices is crucial for optimizing road infrastructure and ensuring safe and efficient transportation. Nautiyal and Sharma (2022) explored factors, techniques, and models used by researchers in different studies related to road maintenance. It discusses major factors responsible for pavement deterioration, such as distress, pavement condition, utility value of the road, total traffic, climatic conditions, and road type. The paper also categorizes pavement maintenance models into three major categories: deterministic, probabilistic, and biologically inspired models. A study conducted by Hafez et al (2019) focused on innovative practices in road pavement maintenance management. It covers topics such as sustainable materials, construction practices, life cycle assessment, and applications of AI and ML for pavement sustainability. Another paper proposed a framework for improved road maintenance and rehabilitation. Decision-makers can use this framework to make better decisions and policies. It aligns with UN Sustainable Development Goals (SDGs) related to sustainable infrastructure and affordable transport systems.

2.9.1 Road Maintenance Management Practices: Ethiopian Experience

It was acknowledged that one of the main obstacles to actions made to boost Ethiopia's economy was the road network's small size and bad condition. Merely 11% of asphalted roads and 19% of unpaved roads were in a suitable state in 1995. The government started the 10-year Road Sector Development Program (RSDP) in 1997 to address these issues. It was acknowledged that better funding for road repair was required as part of the RSDP. By the Road Maintenance Initiative (RMI) funded by the World Bank, Ethiopia's parliament declared the establishment of a road fund in 1997.

The fund was created with the intention of using a specific road user payment fund to support road maintenance and safety initiatives. The government budget was determined to be one of the fund's revenue sources. It may be necessary to fix fuel levies, vehicle license renewal fees based on axle weight and configuration, overloading fines, and other road tariffs. The Board has the authority to examine the road agencies' yearly programs for road repair and to recommend projects to the government that would be funded by the Fund (Nagawoo, 2008).

In 2004, the Ethiopian Road Authority established the Highway Maintenance Management Manual system. It is meant to serve as a manual that system operators can refer to for organizing, planning, scheduling, managing, and assessing maintenance tasks. Its purpose was to prepare work plans and report work progress to the ERA headquarters from the district level.

A road network's fundamental engineering and traffic features are described in detail in a road inventory (ERA, 2013). It provides an overview of the salient characteristics of every road segment and displays the volume of traffic. The inventory's contents ought to be specifically pertinent to maintenance management. In the initial drawing, it ought to be as straightforward as feasible.

Many challenges arise during the road inventory and condition survey process. The three main issues that cause challenges in road maintenance practice are inadequate funds, a lengthy period required to gather data on road conditions, and a large amount of paperwork (Njeri, 2015). Due to the lengthy process and subpar district forms, over half of the district engineers employed their methods to gather data for condition surveys and road inventories, which had an impact on the project's final cost and completion date (Chebon, 2011).

The inspection and ranking of possible roads in a program area according to a predetermined set of common criteria is the aim of the prioritization activity. The physical state of a road, the amount of investment, and the socioeconomic impact of the proposed investment are typically taken into account when ranking roads. A streamlined set of guidelines should be used in the selection and prioritization process for road investments on low-traffic routes. The majority of the criteria used to choose routes should be based on data that is easily obtainable, such as population, road conditions, etc., or data that can be gathered with little trouble. To make comparing different evaluation factors easier, each selection criterion should include a numerical value and weight (Overseas Road Note 1, 2003). Roads are prioritized differently in different countries. In Ghana, for instance, road maintenance work is prioritized based on technical and community inputs; in India, on the other hand, road maintenance work is prioritized based on both technical and social factors (Hoban, 1994); in Kenya, road maintenance work is prioritized primarily on the basis of political influence and district engineers' own methods (Chebon, 2011).

In 2004, the Ethiopian Road Authority created a set of guidelines for conducting a condition survey and prioritization of roads. Six fundamental criteria were used to rank the maintenance tasks in order of importance: urgent, regular drainage work, recurrent work, periodic work, and exceptional work (HMS, 2004). The roads with the highest maintenance priorities within the neighborhood should be 23. It is best to split all routes into two or three priority groups for simplicity and clarity. These groups should be based on the following recommended criteria: strategic inter-community or main road links; maintainability; amount of traffic; population served; value of volume of crops extracted annually; serving markets; and healthcare or educational facilities (ERA, 2011).

Roads are designated for maintenance based on the ranking of upkeep and the availability of funding. Depending on the state of the roads and the availability of money, the maintenance engineer and his team conduct field inspections to ascertain what has to be done. Following the identification of a list of maintenance tasks and their locations, the estimated quantities of each task are measured, and the estimated cost of completion is calculated based on market prices. This is done in order to prevent deviations when performing maintenance tasks (Robinson, 2005). Following the acceptance of the work order, the federal contractors completed the road maintenance work, and they were paid according to their performance (ERA, 2003). This includes timetables for contracts, tracking the advancement of physical work, measuring and paying for completed work, and reporting on financial success.

A maintenance engineer can track the progress of contracts according to schedule with the aid of these schedules. Contract management heavily relies on progress reports on the actual job being completed. This makes it easy for an engineer to identify which maintenance tasks are falling behind schedule in terms of physical labor to identify causes and potential solutions. Since financial progress allows an engineer to track how money is used in a contract, it is also a crucial component of contract management.

Numerous scheduling tasks, including dates for tendering, evaluation, contract durations, defects liability periods, and so on, are completed from the beginning of the contract to the end. As of right now, each engineer records and monitors contract schedules according to their own methodology; no specific standards are followed in the districts (Robinson, 2005). There are two primary uses for monitoring: first, it lets the maintenance engineer verify the caliber and efficiency of the job being done; second, it gives data that can be utilized to enhance future maintenance operations' performance and management. The duty consists of two parts: desk reviews and location inspections (Overseas Road, 2003).

In addition, site Inspections highlighted the value of on-site inspections for the maintenance engineer's job as well as the benefits of participating in the inspection process firsthand. Inspection visits will necessitate the use of a motor vehicle, which should be driven slowly along the stretch being examined due to the length of the road to be covered. The maintenance engineer should be given enough time to conduct several thorough on-foot checks. He needs to take a detailed look at the soil, culverts, side drains, and road surfaces. It is ideal for him to travel as a passenger so that he can focus on his examination and his driver may follow the car when he ventures out to observe the road.

2.10 Summary of Literature Review and Research Gaps

Road maintenance management plays a pivotal role in ensuring the longevity, safety, and efficiency of road infrastructure. This review synthesizes key findings from various studies, shedding light on the current practices, challenges, and potential enhancements in this critical field.

Several studies have shed light on current practices and challenges in pavement management, particularly in developing countries. Hussain et al. (2022) investigated Pavement Management System (PMS) awareness in Pakistan, highlighting the need for a more cost-effective model suited to the constraints of developing nations. Their research revealed that while experts possess a strong understanding of PMS for new road construction, a systematic approach for road rehabilitation is lacking.

Furthermore, Nautiyal & Sharma (2022) identified various factors that significantly contribute to pavement deterioration. These factors include pavement distress, overall pavement condition, its utility value, traffic volume, local climatic conditions, and the type of road itself. Adding to these challenges, Klockow & Hofer (1991) and Dengeso (2021) emphasized the specific difficulties faced by developing countries in maintaining their road networks. These studies underscore the need for tailored solutions that consider the resource limitations often encountered in developing nations.

Road maintenance management faces numerous challenges, including budgetary constraints, short-term funding cycles, human resource limitations, legislative and administrative hurdles, and technical complexities. These factors can lead to delayed maintenance, deteriorating infrastructure, and the need for proactive maintenance strategies and alternative funding mechanisms. Skilled workers shortages and competition from the private sector further complicate the process. Legislative and administrative hurdles, such as justifying budget proposals and prioritizing maintenance, also pose significant challenges. Technical complexities, such as road asset characteristics, regional variations, and forecasting future needs, further complicate the process.

To improve road maintenance management, a systematic approach, data-driven methods, and long-term planning are essential. Consistent monitoring of maintenance work and the creation of comprehensive databases are crucial for efficient management. Innovative practices like sustainable materials, life cycle assessments, and AI/ML applications can enhance pavement maintenance. A decision-making framework aligned with the UN Sustainable Development Goals can help policymakers create sustainable and impactful policies, considering social, economic, and environmental factors alongside traditional infrastructure concerns.

Current road maintenance management practices in Adama City lack a systematic and data-driven approach for prioritizing improvement strategies. Existing methods often rely on subjective assessments or prioritize immediate needs over long-term solutions. The application of the Weighted Average Score (WAS) method, a Multi-Criteria Decision Making (MCDM) technique, is underexplored in the context of road maintenance management within Adama City. This gap presents an opportunity to leverage a data-driven approach for weighting and aggregating various factors that influence the effectiveness of improvement strategies. While existing research emphasizes the importance of context-specific solutions and effective pavement management systems, limited studies have explored their implementation within the specific context of Adama City.

This study addresses critical research gaps in road maintenance management for Adama City by developing a data-driven prioritization framework and demonstrating its application.

Firstly, the framework utilizes the Weighted Average Score (WAS) method, a Multi-Criteria Decision Making (MCDM) technique. This innovative approach evaluates and prioritizes improvement strategies specific to Adama City's context. By considering factors like ease of execution, cost-effectiveness, and potential impact, the framework ensures data-driven prioritization over subjective assessments or short-term solutions.

Secondly, this study demonstrates the application of WAS in prioritizing context-specific improvement strategies for Adama City. This practical application will contribute to a broader understanding of how MCDM methods can be effectively utilized to optimize road maintenance practices in developing cities. By showcasing the WAS method's effectiveness in Adama, the study paves the way for its adaptation in similar urban environments.

Finally, through a comprehensive evaluation of current practices and challenges, the study provides data-driven recommendations for enhancing road maintenance management in Adama City. These recommendations can directly inform future policy decisions and contribute to a more sustainable and efficient road network. Overall, this study bridges the critical gap of data-driven prioritization and context-specific solutions, aiming to deliver valuable scientific contributions that can be applied and adapted in similar developing cities, fostering more sustainable and efficient road maintenance practices.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter explores the methods used to investigate road maintenance practices in Adama City, Ethiopia. It details the research design, data collection methods, and analysis techniques used. A mixed-methods approach combined surveys and interviews for a comprehensive understanding. Surveys assessed effectiveness, challenges, and improvement strategies from road maintenance professionals. Interviews with key stakeholders provided in-depth insights. Purposive sampling ensured participation from diverse stakeholders in interviews. The survey sample size was statistically representative using Yamane's formula. Data analysis employed the Relative Importance Index (RII) and Weighted Average Score (WAS) to evaluate practices, challenges, and improvement strategies. This mixed-methods approach with purposive sampling and robust analysis techniques aims to provide a thorough evaluation of road maintenance management in Adama City.

3.2 Study Area

This research focuses on optimizing road maintenance management practices in Adama City, Ethiopia. Adama lies 99 kilometers southeast of Addis Ababa, the national capital, within the East Shewa Zone. The city boasts a population of approximately 435,000 inhabitants residing in an area of 29.5 square kilometers (See Figure 3.1). Adama serves as a crucial transportation hub, situated along the major road and railway routes connecting Addis Ababa with Dire Dawa and Djibouti. The city's diverse road infrastructure, including viaducts and bridges, necessitates consistent maintenance activities. However, Adama also faces transportation-related challenges like traffic congestion, road safety concerns, and environmental impacts.

The main objective of this study is to evaluate and enhance road maintenance management practices within Adama City. This will be achieved by employing a benchmarking methodology that compares existing practices against established best practices in the field. The research will identify areas for improvement and opportunities to optimize the efficiency, cost-effectiveness, and safety of road operations and maintenance within the city.

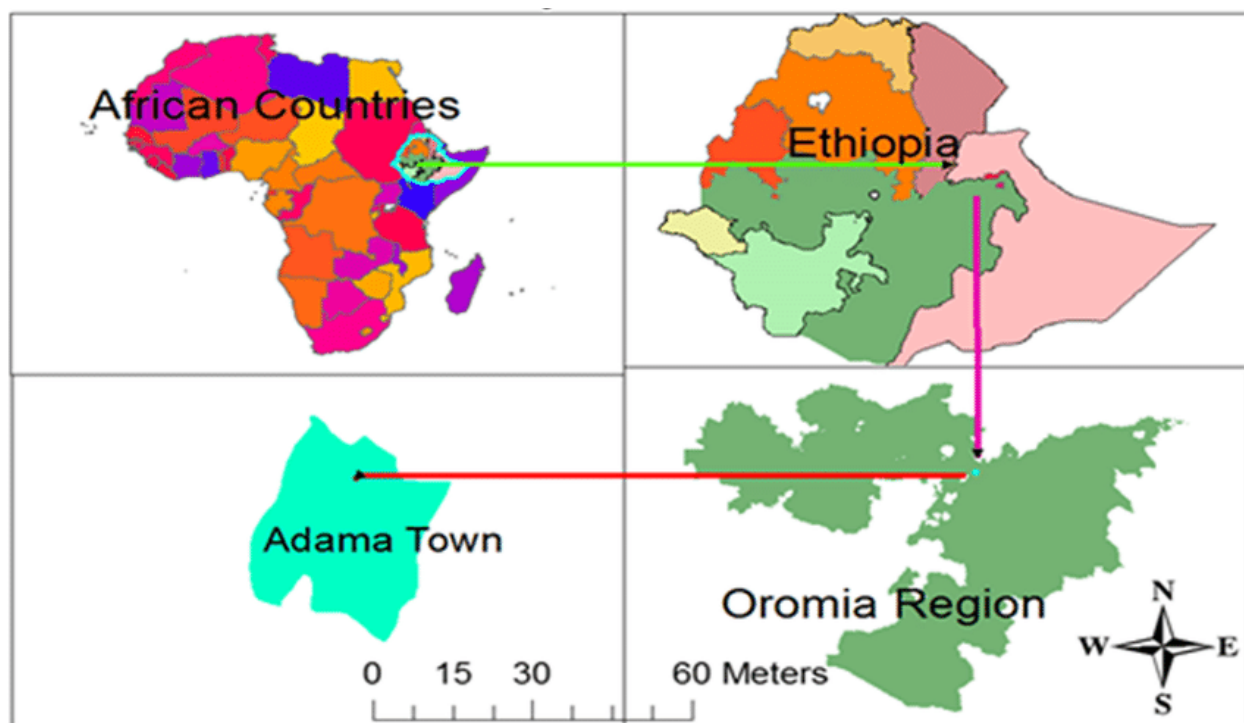


Figure 3.1. Study area

3.3 Research Design and Approach

The study adopts a mixed-methods approach, integrating quantitative and qualitative data collection techniques. Quantitative data was gathered through a structured questionnaire survey and analyzed using statistical methods. This data provided insights into the effectiveness of current practices, the prevalence of challenges, and the perceived value of proposed improvement strategies. Qualitative data was collected via semi-structured interviews with key stakeholders and through expert consultations. This data provided a deeper understanding of the lived experiences of professionals involved in road maintenance, the nuances of identified challenges, and detailed perspectives on potential improvement strategies. The combination of quantitative and qualitative data collection methods strengthens the research by offering a well-rounded and comprehensive understanding of road maintenance management practices in Adama City. Figure 3.2 depicts the overall research methodology flow.

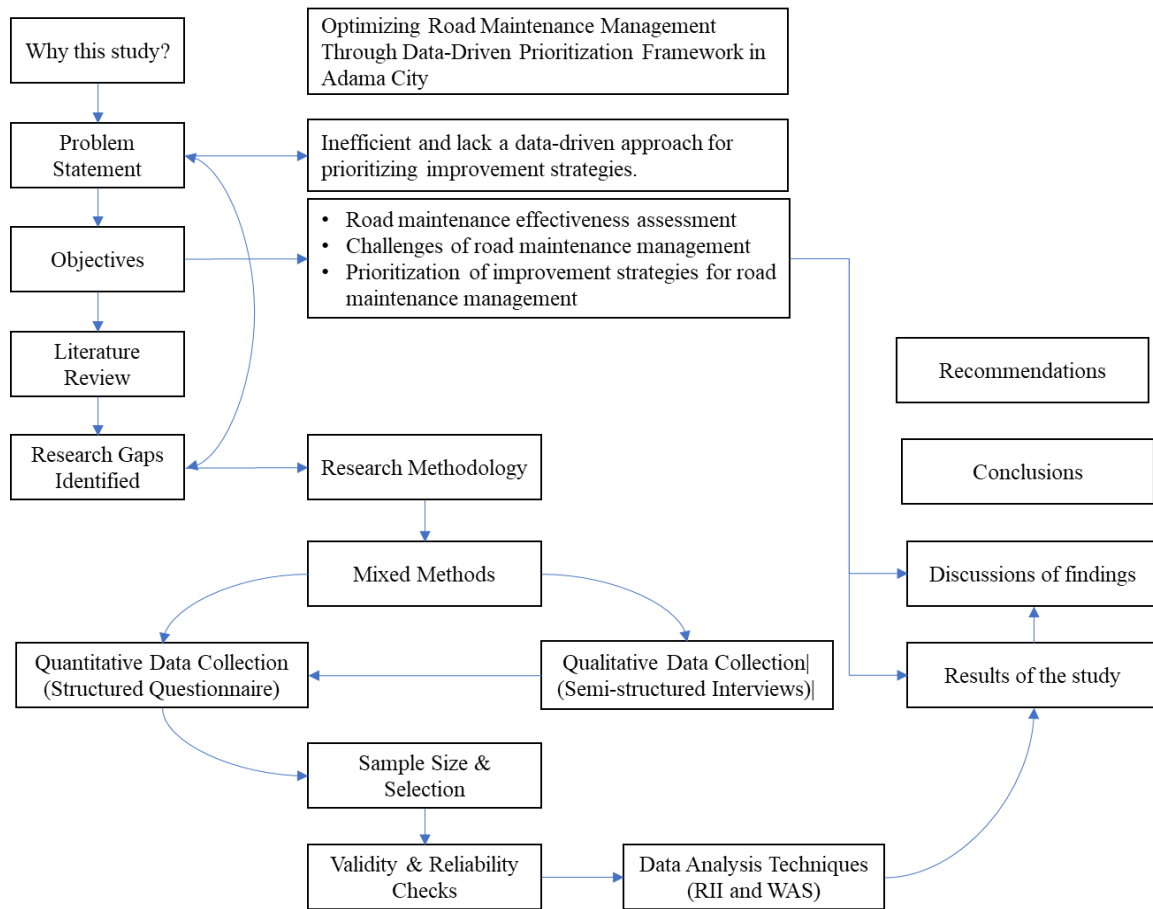


Figure 3.2. Research methodology flow

3.4 Population of the Study

The target population for this study comprises road construction and maintenance professionals within Adama City Administration, Ethiopia. This encompasses individuals from various sectors with crucial roles in road projects. The first category includes personnel from the regulatory body, likely responsible for establishing and enforcing road design and construction standards. The client sector involves representatives from both the city administration and sub-cities who oversee and commission road projects. Additionally, consultants, who are professionals offering expert advice and design services, are included. Finally, the target population extends to contractors, encompassing both companies and individuals directly responsible for the physical construction and maintenance of roads within Adama.

These road construction and maintenance professionals were chosen as the target population due to their unique and complementary expertise across the entire lifecycle of a road project in Adama. Their involvement in design, construction, and ongoing maintenance equips them with a comprehensive understanding of the existing road maintenance management practices within the city administration. This deep knowledge base makes them invaluable sources of information for evaluating the effectiveness of current practices, identifying any challenges that hinder optimal road maintenance, and proposing potential improvements for a more efficient and sustainable system. The target population was thus strategically defined based on their professional roles, ensuring a well-rounded perspective on all aspects of road maintenance management in Adama.

The selection of professionals based on their role within road construction and maintenance provided a strong foundation for the target population. However, to gain even richer insights, further stratification based on additional participant characteristics could be beneficial. These characteristics include level of education, years of experience, job title, and specific role within the road maintenance management process.

Analyzing the correlation between educational background and perspectives on road maintenance practices could reveal knowledge gaps or areas where specific educational emphasis might be advantageous. Similarly, years of experience can influence how individuals perceive challenges and suggest improvements. Seasoned professionals may identify issues stemming from historical practices, while those newer to the field can offer fresh perspectives.

Furthermore, within each professional category (e.g., regulatory body), different job titles hold varying levels of responsibility and offer diverse viewpoints. For instance, a project manager within a contracting firm would have a different experience than a quality control inspector. Finally, understanding the specific role each participant plays in the road maintenance management process can provide a more nuanced perspective on the effectiveness of current practices. By capturing these details during the data collection phase, the research can achieve a more comprehensive understanding of the existing practices and how different stakeholders within the system interact. This will ultimately allow for a more robust analysis of the effectiveness of current road maintenance management practices in Adama City Administration.

3.5 Sample Size

In this study, Yamane's formula was employed to calculate an appropriate sample size that balances precision with practicality. Yamane's formula is a widely recognized statistical tool specifically designed for situations involving finite populations. Given the total population for this study is known to be 126 professionals, Yamane's formula can be effectively utilized to determine a representative sample size. The formula is delineated as follows:

$$n = \frac{N}{1 + N(e^2)}$$

Where:

- (n) represents the sample size to be determined,
- (N) denotes the total population size, which, in this context, is 126 professionals,
- (e) signifies the level of precision, which is conventionally set at 0.05 for a 95% confidence level.

Upon the application of the aforementioned values into Yamane's formula, the calculation proceeds thusly:

$$n = \frac{126}{1 + 126(0.05^2)}$$

$$n = \frac{126}{1 + 126(0.0025)}$$

$$n = \frac{126}{1 + 0.315}$$

$$n = \frac{126}{1.315}$$

$$n \approx 96$$

Given that the sample size cannot encompass a fractional individual, it is rounded to the nearest whole number, yielding a sample size of **96**. This figure represents a statistically significant subset of the total population, ensuring that the study's conclusions are reflective of the broader community of professionals engaged in road infrastructure projects within Adama city.

The precision level of 0.05 is indicative of a 95% confidence interval, suggesting that if the study were to be replicated multiple times, the results would be consistent 95% of the time.

3.6 Sampling Technique

Considering the stratified nature of the target population, this study adopted stratified random sampling as the most appropriate technique to ensure representativeness and capture the diverse perspectives within the road construction and maintenance sector of Adama City Administration. The target population, while focused on professionals involved in road projects, comprises distinct subgroups based on their professional roles: regulatory body, client (city administration and sub-cities), consultants, and contractors. These subgroups likely possess varying experiences and viewpoints on road maintenance practices.

Stratified random sampling addresses this heterogeneity by ensuring each subgroup (stratum) has a fair chance of being included in the final sample. This is achieved by first clearly defining the strata based on the identified professional roles. Following this, the total sample size (determined using Yamane's formula in this case) is then proportionally allocated across the strata.

The total population size is 126 professionals. Yamane's formula, with a desired precision level of 0.05 (resulting in a 95% confidence interval), yielded a sample size of 96. To ensure proportional representation of each stratum in the final sample, we applied the following allocation strategy:

- Regulatory Body: 20% of the 96-sample size translates to approximately 19 individuals.
- Client: 40% of the sample size translates to approximately 39 individuals. However, due to rounding limitations of sample sizes.
- Consultants & Contractors: Since both consultants and contractors represent 40% of the population each, they can be allocated 19 individuals each (remainder from the total sample size of 96 after allocating to the regulatory body and client strata).

Once the sample size for each stratum is established (Regulatory Body: 19, Client: 39, Consultants: 19, Contractors: 19), random sampling techniques will be employed within each subgroup. This ensures that every individual within a stratum has an equal probability of being selected for the survey.

By implementing stratified random sampling, the research can achieve a representative sample that incorporates the diverse perspectives of the various professional roles within the target population. This approach will ultimately lead to a more robust analysis of the effectiveness of current road maintenance management practices in Adama City Administration.

3.7 Sources of Data

This research adopted a multi-source approach to data collection, drawing on both primary and secondary sources to achieve a comprehensive understanding of road maintenance management practices in Adama City Administration.

3.7.1 Secondary Sources

The research commenced with a thorough review of existing literature on road maintenance management practices. This included scholarly articles, technical reports, industry publications, and relevant government documents.

The focus of this review was on established frameworks and best practices, common challenges faced by municipalities, existing MCDM techniques such as WAS used in road maintenance decision-making, and successful applications of MCDM approaches in similar contexts. The insights gleaned from these secondary sources provided a strong theoretical foundation and helped refine the research questions.

3.7.2 Primary Sources

To complement the theoretical grounding and gather practical insights from key stakeholders, primary data collection was conducted. A structured questionnaire survey was developed and administered to professionals from various sectors within the road construction and maintenance industry in Adama City. This target population included personnel from the regulatory body, representatives from the city administration and sub-cities (clients), consultants offering expert advice, and individuals and companies directly responsible for road construction and maintenance (contractors). A stratified random sampling technique ensured a representative sample across these professional categories.

The survey data was further enriched by conducting semi-structured interviews with key informants and experts in the field. These interviews explored unforeseen challenges, potential solutions, and practical considerations for implementing a data-driven MCDM approach within the local context.

By employing this multifaceted approach to primary and secondary sources, the research ensured a comprehensive understanding of the research question, triangulating findings from established knowledge with the perspectives and experiences of key stakeholders within Adama City.

3.8 Data Collection Instruments

3.8.1 Questionnaire Survey

The data for this research was collected through a self-administered questionnaire survey distributed to professionals involved in road maintenance management within Adama City, Ethiopia. The survey aimed to achieve a comprehensive evaluation of current practices and identify areas for improvement, challenges, improvement strategies for road maintenance management practices.

The target population for this survey included individuals working within organizations involved in road maintenance management in Adama City. These organizations could be clients (government agencies responsible for road infrastructure), contractors responsible for road construction and maintenance projects, consultants providing technical expertise, or regulatory bodies overseeing road maintenance practices (city administration). From the 126 total population of the study, the sample size was determined using Yamane's formula to ensure sufficient representation of the target population. The final sample size achieved was 96 participants.

The data collection instrument for this research was a four-part questionnaire designed to gather information on current road maintenance management practices in Adama City, Ethiopia. The first section focused on acquiring general demographic details about the respondents. This aimed to understand the diversity of perspectives and expertise within the participant pool. It included questions regarding the highest level of educational attainment, current organizational affiliation (client, regulatory body, contractor and consultant), job title and primary responsibilities, total construction industry experience, experience specifically in maintenance management, and any other relevant information the respondents felt was pertinent to the study.

The second section employed a five-point Likert scale to assess the current level (or effectiveness) of road maintenance management practices. Statements were developed through meticulous research and addressed various criteria critical for successful road maintenance management. The Likert scale ranged from "Strongly Disagree" (indicating practices do not effectively meet the criterion) to "Strongly Agree" (indicating practices are highly effective in meeting the criterion). (See Appendix A).

Section three aimed to identify key challenges hindering optimal performance in road maintenance practices. Statements were presented that addressed common road maintenance hurdles. Respondents then rated their level of agreement on how much each statement hindered optimal performance using a five-point scale. This scale ranged from "Strongly Disagree" (indicating the challenge is rarely or never an issue) to "Strongly Agree" (indicating the challenge is a major barrier that significantly hinders performance).

Finally, the fourth section presented potential strategies for improving road maintenance practices. Respondents were asked to rate their level of agreement on three key factors for each strategy: Ease of Implementation (measured on a scale from "Very Easy" to "Very Difficult"), Cost Effectiveness (measured on a scale from "Highly Cost-Effective" to "Likely Quite Costly"), and Potential Impact (measured on a scale from "Significant Potential" to "Limited Potential"). This section aimed to gather insights into the feasibility, economic viability, and potential effectiveness of various improvement strategies.

The survey was distributed through email to relevant organizations and physical distribution at professional offices. Participation was voluntary and anonymous. A pilot test of the questionnaire was conducted with a small group of individuals from the target population to assess clarity, comprehensiveness, and response time. Feedback from the pilot test was used to refine the questionnaire before full-scale distribution.

3.8.2 Interviews

Semi-structured interviews were conducted alongside the questionnaire survey to help refine the instrument and gain a better understanding of specific aspects of road maintenance practices in Adama City, Ethiopia. A purposive sampling strategy ensured the participation of key stakeholders such as client organization engineers, contractors with road maintenance experience, and field consultants. Six interviewees (2 from consultants and contractors, 2 from regulatory bodies, and another two from clients in roughly equal proportions) provided a wide range of perspectives on the questionnaire and road maintenance practices in general.

The selection criteria included extensive experience, diverse roles, and a broad range of perspectives from various professional categories. Participants included regulatory body, clients, consultants, and contractors. The pilot interview was conducted with a relevant expert to refine the interview guide and ensure clarity and focus.

The sample size was flexible, allowing for additional interviews if saturation was not reached. The final number of interviews will be reported in the findings section of this thesis. The purposive sampling strategy ensured the collection of rich qualitative data from a diverse range of stakeholders with extensive experience in road maintenance management. This data will complement the quantitative findings from the questionnaire survey and provide valuable insights into the effectiveness and challenges of current practices, ultimately informing the development of a data-driven MCDM approach for improvement

The interviews served two primary objectives. First, they aimed to refine the questionnaire by assessing its clarity, comprehensiveness, and effectiveness in capturing stakeholder perspectives on current practices, challenges, and improvement strategies. Second, they sought to gain deeper insights into specific aspects of these practices. This included exploring participants' lived experiences, the nuances of identified challenges, and detailed perspectives on potential improvement strategies and their feasibility.

A semi-structured interview protocol facilitated flexibility while guiding the discussions. It covered key areas such as initial impressions of the questionnaire, participants' experiences with current practices, their views on identified challenges, and their insights into potential improvement strategies. Prior to the interview, informed consent was obtained, explaining the research purpose, interview process, and participant confidentiality. The interviews were conducted face-to-face.

Thematic analysis of the transcribed interviews focused on three key areas: questionnaire refinement based on participant feedback, deeper understanding of practices and challenges through lived experiences and detailed perspectives, and evaluation of improvement strategies based on participant insights. By incorporating these valuable contributions, the questionnaire was refined to better capture the complexities of road maintenance management in Adama City. The interview data further enriched the quantitative survey results by providing context and depth, leading to a more comprehensive understanding of the research topic.

3.9 Data Analysis and Presentation

3.9.1 Relative Importance Index

The Relative Importance Index (RII) analysis, performed using Microsoft Excel version 2019, was employed to evaluate three key sections of the survey data. The first section focuses on Performance (Effectiveness), where the current level of effectiveness in road maintenance practices is assessed. The second section, Challenges, aims to identify the key obstacles hindering optimal performance. Finally, the Improvement Strategies section explores potential strategies for improvement, considering factors like ease of implementation, cost-effectiveness, and potential impact on overall road maintenance practices.

The RII is calculated for each factor within each section using the following formula:

$$RII = (\Sigma W_i / A) / N$$

Where:

- **RII:** The Relative Importance Index (0 to 1, with higher values indicating greater importance)
- **ΣW_i :** The sum of the weights given to the factor by all respondents (W_i represents the weight assigned by each respondent, ranging from 1 to 5 based on the Likert scale)
- **A:** The highest weight possible on the Likert scale (in this case, 5)
- **N:** The total number of respondents

The RII score for each factor serves as a numerical representation of its relative importance based on respondent ratings. A higher RII value indicates a factor perceived as more critical within its respective category. This applies to:

- **Performance (Effectiveness):** Practices with higher RII scores are perceived as more effective in current road maintenance.
- **Challenges:** Factors with higher RII scores are considered more significant obstacles hindering optimal performance in road maintenance.
- **Improvement Strategies:** Strategies with higher RII scores are viewed as more impactful, cost-effective, and easier to implement compared to those with lower RII scores.

By analyzing the RII scores alongside the corresponding survey statements for each factor, we can gain valuable insights into:

- The most effective practices currently employed in road maintenance.
- The most significant challenges hindering optimal performance within the road maintenance system.
- The improvement strategies perceived as most impactful, cost-effective, and feasible for implementation.

This analysis will inform the discussion on the current state of road maintenance practices, the key challenges that need to be addressed, and the most promising avenues for improvement.

3.9.2 Weighted Average Score

The study employed the Weighted Average Score (WAS) technique, a Multi-Criteria Decision-Making (MCDM) method, performed using Microsoft Excel version 2019. WAS was used to rank potential strategies for enhancing road maintenance management practices. The WAS approach considers three key factors for each strategy identified in the survey:

- Ease of Implementation: Measured on a scale from "Very Easy" (5) to "Very Difficult" (1). Higher scores indicate easier implementation.
- Cost Effectiveness: Measured on a scale from "Highly Cost-Effective" (5) to "Likely Quite Costly" (1). Higher scores represent higher cost-effectiveness.
- Potential Impact: Measured on a scale from "Significant Potential" (5) to "Limited Potential" (1). Higher scores indicate a greater potential impact on improving road maintenance practices.

The WAS is calculated for each strategy using the following formula, where the weights are pre-determined:

$$\text{WAS} = (0.3 * \text{Ease_Score}) + (0.3 * \text{Cost_Score}) + (0.4 * \text{Impact_Score})$$

Where:

- WAS: Weighted Average Score for the strategy
- Ease_Score: Average score assigned by respondents for Ease of Implementation (1 to 5)
- Cost_Score: Average score assigned by respondents for Cost Effectiveness (1 to 5)
- Impact_Score: Average score assigned by respondents for Potential Impact (1 to 5)

The weights assigned to each factor reflect their relative importance in the decision-making process. In this study, the weights were determined through a literature review and expert consultation:

- Ease of Implementation (weight = 0.3): Represents the importance of implementing the strategy without significant disruptions or challenges.
- Cost Effectiveness (weight = 0.3): Reflects the need for strategies that are cost-conscious and provide value for the resources invested.

- Potential Impact (weight = 0.4): Emphasizes the importance of strategies with the greatest potential to improve the overall efficiency and effectiveness of road maintenance practices.

WAS is interpreted as follows: strategies with higher WAS scores are considered more favorable because they represent a combination of easier implementation, increased cost-effectiveness, and greater potential impact.

The most promising options for enhancing road maintenance practices are identified by ranking the improvement strategies based on their WAS scores. This ranking is considered alongside the qualitative data from the survey responses (specific strengths and weaknesses of each strategy) to provide a comprehensive evaluation for decision-making.

3.10 Reliability of the Data

To ensure the reliability and internal consistency of the data collected through the questionnaire survey, Cronbach's alpha coefficient was employed. This widely used statistical test evaluates the extent to which the various items within each section of the questionnaire measure the same underlying construct. In simpler terms, it assesses whether the questions within a section are all capturing the same information or concept. Cronbach's alpha is calculated using the following formula:

$$\alpha = (k / (k - 1)) * (1 - \sum \sigma^2_i / \sigma^2_t)$$

where:

- α = Cronbach's alpha coefficient (ranging from 0 to 1)
- k = number of items in the questionnaire section
- $\sum \sigma^2_i$ = sum of the variances of each individual item
- σ^2_t = total variance of the sum of scores for all items

Cronbach's alpha is calculated using a specific formula that considers the number of items in the questionnaire section (k), the individual variances of each item ($\sum \sigma^2_i$), and the total variance of the sum of scores for all items (σ^2_t). The resulting alpha coefficient (α) ranges from 0 to 1, with higher values indicating greater internal consistency.

In this study, Cronbach's alpha was calculated for each section of the questionnaire. All sections achieved a Cronbach's alpha value greater than 0.7, which is generally considered a benchmark for acceptable internal consistency. This result provides strong evidence that the data collected through the questionnaire is reliable and provides a consistent measure of perceptions and experiences related to road maintenance management practices in Adama City.

3.11 Validity of the Study

This section addresses the validity of the research design and data collection methods employed in this study. The breakdown of the efforts undertaken to ensure the construct, internal, and external validity of the research is presented.

3.11.1 Construct Validity

Construct validity refers to the degree to which the research instruments accurately measure the intended constructs. In this study, a multi-pronged approach was adopted to ensure construct validity. Firstly, the target population selection focused on road construction and maintenance professionals within Adama City Administration. This group possesses the relevant expertise across the entire lifecycle of road projects, encompassing design, construction, and ongoing maintenance. Their comprehensive understanding of existing practices equips them to provide valuable insights for evaluating effectiveness, identifying challenges, and proposing improvements.

Secondly, the data collection instruments were meticulously designed and piloted. The questionnaire underwent a pilot test with a small sample group to assess clarity, comprehensiveness, and its effectiveness in capturing stakeholder perspectives. Feedback from this pilot test was then used to refine the questionnaire before full-scale distribution. Similarly, the interview protocol for semi-structured interviews was designed to facilitate flexibility while guiding discussions on key areas, including experiences with current practices, perceived challenges, and potential improvement strategies. This approach ensured the interviews delved deeper into specific aspects and lived experiences, enhancing the understanding of the constructs being investigated.

3.11.2 Internal Validity

Internal validity concerns the extent to which the research design minimizes the influence of extraneous variables on the findings. In this study, internal validity was strengthened through the design of the questionnaire survey. The use of a Likert scale with established criteria for road maintenance management practices ensured consistency in data collection. Furthermore, Cronbach's Alpha coefficient was employed to assess the internal consistency of the questionnaire. This statistical test, as detailed previously, evaluates whether the various items within each section of the questionnaire measure the same underlying construct. A high Cronbach's Alpha value (presented in Section 2.10) indicates strong internal consistency, minimizing the risk of misinterpretations or inconsistencies in responses due to poorly worded questions or ambiguous items.

3.11.3 External Validity

External validity refers to the generalizability of the research findings to a broader population. This study employed several strategies to enhance external validity. Firstly, Yamane's formula was utilized to calculate a statistically significant sample size ($n=96$) from the known target population size ($N=126$) of road construction and maintenance professionals within Adama City Administration. This approach ensures the findings are generalizable to the broader population of professionals engaged in road infrastructure projects within the city. Secondly, stratified random sampling was employed as the sampling technique. This method acknowledges the heterogeneity within the target population, which encompasses distinct professional roles such as regulatory body, client, consultant, and contractor. By ensuring each subgroup has a fair chance of being included in the final sample (as detailed in Section 1.3), the research captures the diverse perspectives within the road maintenance sector, enhancing the external validity of the findings.

In conclusion, by employing a multi-source approach for data collection (questionnaires and interviews), conducting pilot tests of the instruments, and implementing a purposive sampling strategy with considerations for both internal and external validity, this research design aimed to collect reliable and valid data. This data considered ultimately contribute to a comprehensive understanding of road maintenance management practices in Adama City Administration, paving the way for the development of a data-driven MCDM approach for improvement.

3.12. Ethical Considerations

The study followed the ethical principles and guidelines of the Adama Science and Technology University and the Adama City Administration. The study obtained the necessary permissions and approvals from the relevant authorities and institutions before conducting the data collection. The study also ensured the confidentiality, anonymity, and informed consent of the participants and respect their rights and dignity. Moreover, the study acknowledged the sources of data and avoid plagiarism and falsification.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the findings of our investigation into the effectiveness and challenges of current road maintenance management practices in Adama City, alongside the development of a data-driven framework for improvement. The specific objectives guiding this exploration were evaluating the effectiveness of existing practices; identifying key challenges hindering performance; and constructing a prioritization framework for improvement strategies.

The chapter unfolds in several sections. The first two sections delve into the effectiveness of current practices and the key challenges faced by road maintenance management in Adama. The Relative Importance Index (RII) served as the primary tool for these assessments, with the resulting scores and rankings presented in Tables 4.5 and 4.6, respectively. Analyzing these findings allows us to gain a comprehensive understanding of the strengths and weaknesses within the current system, paving the way for targeted discussions on improvement.

Following the evaluation of existing practices, the chapter progresses to the development of a data-driven prioritization framework. This framework aims to identify the most effective strategies for addressing the identified challenges and enhancing overall road maintenance practices within resource constraints. The construction of this framework involved a three-step process, each focusing on a critical factor for successful implementation.

Ease of Execution (Table 4.7): This section prioritizes strategies based on their swift implementation potential, allowing for quicker improvements. The RII was again utilized to evaluate each strategy's ease of execution, with rankings presented in the table. **Cost-Effectiveness (Table 4.8):** Here, the focus shifts to identifying strategies that offer the most significant improvement while considering associated costs. The RII scores and rankings associated with each strategy's cost-effectiveness are provided in Table 4.8. **Potential Impact (Table 4.9):** This section prioritizes strategies with the greatest transformative power to significantly enhance road maintenance practices. Similar to the previous analyses, the RII is employed, with scores and rankings reflecting each strategy's potential impact presented in Table 4.9.

The final section of the chapter integrates the findings from the three individual analyses (ease of execution, cost-effectiveness, and potential impact) by employing the Weighted Average Score (WAS) Multi-Criteria Decision-Making (MCDM) approach. This method considers the relative importance of each factor through assigned weights, ultimately generating a comprehensive prioritization framework for resource allocation and improvement (Table 4.10). By analyzing the WAS scores and rankings, we can identify the strategies that offer the most well-rounded combination of the evaluated factors, leading to a prioritized list for effective implementation within Adama's context.

4.2 Respondent's Profile

4.2.1 Respondent's respective Organizations

To gain a holistic understanding of road maintenance management practices in Adama City, the study surveyed representatives from a variety of organizations directly involved in this crucial aspect of urban infrastructure. This section delves into the breakdown of respondents by their respective organizations, as presented in the Table 4.1. Through this exploration, we aim to shed light on the valuable perspectives each stakeholder group brings to the table.

Table 4.1. respondent's respective organizations

Respective Organization	Frequency	Percent
Regulatory Body	19	20
Client (City & Sub-city)	39	40
Construction companies (Consultants and contractors)	38	40
Total	96	100.0

This study sought to comprehensively evaluate road maintenance management practices in Adama City. To achieve this, a survey was distributed to representatives from various organizations with a vested interest in this domain. The final sample included 96 complete responses, ensuring a well-rounded perspective on the current practices. Notably, the breakdown of respondents by organization type reveals a balanced distribution, Regulatory Body (20%); Client (City & Sub-city) (40%); and Construction Companies (Consultants and Contractors) (40%)

This inclusion of diverse stakeholders is critical for a thorough understanding of the existing road maintenance landscape in Adama City. Representatives from the valid regulatory body provide valuable insight into the role of regulations in shaping maintenance practices. Client representatives, encompassing City and Sub-city entities, can illuminate budgetary and prioritization challenges faced by city authorities. Finally, construction companies, including consultants and contractors, offer perspectives on the technical aspects of road maintenance, along with the practical challenges they encounter during project execution.

The participation of all three respondent groups significantly strengthens the study's credibility. By capturing the viewpoints of key stakeholders across the spectrum of road maintenance, the research has identified a comprehensive set of strengths and weaknesses within current practices. This comprehensive understanding will prove invaluable in Chapter 5, where a data-driven approach for improvement will be developed. Recognizing the diverse priorities and perspectives of each stakeholder group will allow for the creation of a plan that effectively addresses the needs of all parties involved in Adama City's road maintenance efforts.

4.2.2 Respondents Job Position

Having explored the range of organizations represented in our survey, here is the examination of specific job titles of the respondents. This information, presented in the table below (Table 4.2), offers valuable insights into the professional expertise shaping road maintenance practices in Adama City. Through this lens, we can gain a better understanding of the unique perspectives each respondent brings to the table.

4.2. Respondent's job position

Job Position	Frequency	Percent
Office Engineer	48	50
Site Engineer	32	33.3
Project Manager	10	10.4
Maintenance Engineer	6	6.3
Total	96	100.0

The distribution of job titles among respondents provides valuable insights into the professional backgrounds of those involved in road maintenance practices in Adama City.

The majority of respondents (83.3%) hold engineering titles, with a relatively even split between Office Engineers (50%) and Site Engineers (33.3%). This suggests a strong presence of engineering expertise at the implementation level of road maintenance projects. A smaller percentage of respondents hold project management (10.4%) and maintenance engineering (6.3%) titles. This indicates that there is also involvement from professionals focused on the broader planning and oversight of maintenance activities.

The dominance of engineering titles among respondents (particularly Office and Site Engineers) reflects the hands-on nature of road maintenance works in Adama City. Having a high proportion of respondents directly involved in the execution of these projects provides a detailed understanding of the ground-level challenges and realities faced by maintenance crews. The presence of project managers and maintenance engineers, though smaller in number, ensures that the perspectives of those responsible for planning and overseeing maintenance activities are also captured in this study.

This mix of job titles strengthens the comprehensiveness of the findings presented in this chapter. By incorporating the viewpoints of those directly involved in maintenance work, along with those who manage and oversee these activities, the study provides a well-rounded picture of the strengths and weaknesses of current practices in Adama City.

4.2.3 Respondent's Educational Background

In addition to organizational affiliation and job titles, understanding the educational background of our respondents provides valuable insight. This information, presented in the table below (Table 4.3), sheds light on the knowledge base that shapes road maintenance practices in Adama City. By exploring the educational landscape, we can gain a deeper appreciation for the expertise brought to the table by each respondent.

The survey achieved a good representation of educational backgrounds among the respondents. The majority of respondents (79.2%) hold at least a Bachelor's degree (BSc), with nearly half (47.9%) possessing this qualification. A significant portion (32.3%) also hold a college diploma. There were a small number (19.8%) with a Master's degree (MSc), and no respondents with a Ph.D.

Table 4.3. Respondent’s educational background

Education Level	Frequency	Percent
College Diploma	31	32.3
BSc	46	47.9
MSc	19	19.8
Ph.D.	-	-
Total	96	100.0

The strong presence of respondents with Bachelor’s degrees (BSc) and college diplomas suggests a workforce with a solid foundation in technical knowledge relevant to road maintenance. This educational background equips them with the skills and understanding necessary to effectively execute and oversee maintenance tasks.

The inclusion of a small number of respondents with Master’s degrees (MSc) ensures that the survey also captured the perspectives of those with more advanced knowledge and expertise in road maintenance practices. While their presence is limited, their insights can be particularly valuable in informing the development of data-driven approaches and best practices.

The absence of respondents with Ph.D. s is not unexpected, given the practical and applied nature of road maintenance work. However, it is important to acknowledge that ongoing research and development in civil engineering and related fields can inform best practices in road maintenance. Future studies may benefit from including stakeholders with a research background.

Overall, the educational background of the respondents strengthens the credibility of the findings presented in this chapter. The data suggests a workforce with a strong mix of theoretical knowledge and practical experience, which is essential for effective road maintenance.

4.2.4 Respondent’s Educational Background

The table below (Table 4.4) details the distribution of respondents by their years dedicated to road maintenance in Adama City. This information sheds light on the accumulated knowledge and expertise shaping current practices. By exploring the experience landscape, we can gain a deeper understanding of the diverse perspectives brought to the table by each respondent.

Table 4.4. Respondent's year of experience

Year of experience	Frequency	Percent
< 5 years	20	20.8
5 - 9 years	35	36.5
10 - 14 years	28	29.2
> 14 years	13	13.4
Total	96	100.0

As the table shows, the survey respondents possess a variety of experience levels in road maintenance. A significant portion (57.3%) have between 5 and 14 years of experience, with nearly equal representation in the 5-9 year (36.5%) and 10-14 year (29.2%) categories. A fifth of the respondents (20.8%) have less than 5 years of experience, and a smaller group (13.4%) have more than 14 years of experience.

The distribution of experience levels among respondents suggests a workforce with a healthy mix of experience. The substantial presence of those with 5-14 years of experience (57.3%) indicates a core group with a solid understanding of the practical aspects of road maintenance in Adama City. This experience equips them to effectively identify and address the challenges encountered during maintenance projects.

The inclusion of respondents with less experience (20.8% with less than 5 years) provides valuable insights from those who are new to the field. Their perspectives can help to identify areas where improvements can be made to onboarding and training programs for new personnel.

A smaller group of respondents with extensive experience (13.4% with more than 14 years) brings valuable knowledge and historical perspective to the table. Their insights can be particularly beneficial in informing the development of long-term maintenance strategies and best practices.

Overall, the range of experience levels among respondents strengthens the comprehensiveness of the findings in this chapter. By capturing the perspectives of those at various stages in their careers, the study provides a well-rounded picture of the strengths and weaknesses of current road maintenance practices in Adama City.

4.3 Effectiveness of Road maintenance Management Practices

This section delves into the quantitative assessment of current performance level (or effectiveness) road maintenance management based on various practice areas employed by Adama City Administration. The Relative Importance Index (RII) served as the primary tool for this evaluation. The RII scores, reflecting the current performance level or effectiveness, are presented in Table 4.5 alongside rankings for each practice area.

Through this analysis, we aim to gain a comprehensive understanding of the strengths and weaknesses within the existing road maintenance management system. The results will guide further discussion on potential areas for improvement and the development of recommendations for enhancing the overall effectiveness of road maintenance practices.

Table 4.5: RII Scores and Rankings of Road Maintenance Management Practices

Road Maintenance Management Practice Areas	RII Scores	Rank
Public opinion on road condition and safety	0.65	1
Functionality (drainage, signage visibility, lane markings)	0.64	2
Economic benefits of well-maintained roads	0.624	3
Road surface conditions (smoothness, cracks, potholes)	0.623	4
Satisfaction with maintenance responsiveness and efforts	0.61	5
Traffic safety (accident rates, guardrails, road lighting)	0.58	6
Effective distribution of budget and manpower	0.56	7
Effectiveness in budget allocation and minimizing waste	0.54	8
Prioritization of preventative measures over major repairs	0.53	9
Long-term cost reduction through proactive maintenance	0.49	10
Reduction in road deterioration rate	0.48	11
Performance metrics for contracted maintenance work	0.472	12
Improvement in road performance post-maintenance	0.473	13
Impact of maintenance activities on the environment	0.46	14
Quick response to reported road problems like potholes	0.444	15
Regular inspections and standardized road condition indexes	0.443	16
Use of sustainable practices and recycled materials	0.441	17

Quality of materials and techniques used	0.433	18
Time efficiency in completing maintenance activities	0.431	19
Cost-effectiveness of maintenance operations	0.39	20

An analysis of the RII scores and rankings within the table reveals several potential weaknesses in the Adama City Administration's Road maintenance management system. The lowest RII score (0.39) pertains to the cost-effectiveness of maintenance operations, suggesting that current practices may be incurring unnecessary expenses or failing to deliver optimal improvements in road conditions. Furthermore, time efficiency in completing maintenance activities ranks second-to-last (RII = 0.43), indicating potential delays in project completion. This could be attributed to factors such as inadequate planning, inefficient work practices, or resource limitations. Finally, the quality of materials and techniques employed in maintenance activities also ranks low (RII = 0.43), raising concerns about the durability of repairs and the potential for premature road deterioration necessitating more frequent interventions. It is crucial to acknowledge that these are potential weaknesses, and further investigation is warranted for definitive confirmation. However, the RII results strongly suggest that these areas merit closer examination to identify and implement improvement strategies.

An examination of the RII results also unveils opportunities for significant improvement in specific areas of Adama City Administration's Road maintenance management system. Firstly, the tied 16th rank for "Use of sustainable practices and recycled materials" suggests a potential need to either implement such practices more extensively or develop a more robust system to measure their impact. Secondly, the equally low ranking (16th) for "Regular inspections and standardized road condition indexes" indicates that the current inspection regime might be insufficient for timely problem identification.

Furthermore, the lack of standardized road condition indexes could hinder the ability to effectively track trends in road health. Thirdly, the 15th ranking for "Quick response to reported road problems like potholes" underscores the potential for delays in addressing these issues. Such delays can lead to the need for more extensive and costly repairs, while also posing safety risks to road users. Finally, the 14th position for "Impact of maintenance activities on the environment" highlights the possibility of negative environmental consequences arising from current practices.

Prioritizing a reduction in environmental impact is essential for ensuring the long-term sustainability of the road maintenance program.

By addressing these shortcomings, the Adama City Administration has the opportunity to enhance the effectiveness of its road maintenance program. This could result in multiple benefits, including improved road quality, reduced maintenance costs, and a more environmentally responsible transportation system.

Conversely, an analysis of the RII scores and rankings reveals strengths in three key practice areas of Adama City Administration's Road maintenance management system. Public opinion on road condition and safety ranks highest (1st) with a score of 0.65, indicating a relatively high level of resident satisfaction. Furthermore, the system achieves a strong ranking (2nd) with a score of 0.64 for functionality, ensuring proper drainage, clear signage visibility, and well-defined lane markings. Finally, the economic benefits of well-maintained roads secure a commendable position (3rd) with a score of 0.62, demonstrating the city administration's recognition of the importance of good road conditions for economic activity. These top three rankings suggest that Adama City Administration effectively addresses these crucial aspects of road maintenance.

4.4 Challenges of Road Maintenance Management Practices.

Following the assessment of current practices, this section focuses on identifying the key challenges that hinder the optimal performance of road maintenance management within Adama City Administration. The RII was once again employed to evaluate these challenges. The RII scores, reflecting the relative significance of each challenge, are presented in Table 4.6 alongside their rankings.

By analyzing these results, we aim to shed light on the most pressing obstacles faced by road maintenance management practices. This will allow for a targeted discussion on potential solutions and recommendations to address these challenges and ultimately achieve optimal performance.

Table 4.6: RII Scores and Rankings of Challenges in Road Maintenance Management

Challenges of Road Maintenance Management Performance	RII Scores	Rank
Discrepancy between repair needs and maintenance funds	0.89	1
Incompletion of maintenance system due to inadequate budget	0.87	2
Quantifying effects of reduced spending and delayed maintenance on serviceability, quality, and safety	0.86	3
Difficulty in incorporating climate change impacts into forecasting models	0.85	4
Impact of reduced financing for capital and maintenance	0.83	5
Developing an objectively based priority program for budget support	0.82	6
Effect of budget requests on future network condition	0.79	7
Rationale behind budget proposals	0.78	8
Establishing budget and programming priorities	0.77	9
Public and political pressure on budget allocation	0.74	10
Personnel issues due to fewer capacity-building initiatives	0.712	11
Outcomes of implementing higher load limitations	0.711	12
Consequences of postponing projects or reducing standards	0.693	13
High costs resulting from the dismantling of roads	0.692	14
Skilled worker shortages and competition from the private sector	0.68	15
Assessing future network status for projected investment	0.67	16
Challenges in project delivery	0.664	17
Lack of standardized data collection methods at different period	0.663	18
Environmental regulations impacting project timelines and costs	0.662	19
Absence of a standard maintenance handbook	0.661	20
Data collection for roads requiring maintenance	0.652	21
Design and functionality of the inventory database	0.651	22
Evaluating the network's current state (graphical and tabular	0.644	23
Forecasting models for traffic, performance, skid, and distress	0.642	24
Procedures and sufficiency of the inventory database	0.63	25

Relevance of technical operations to administrative level questions and problems	0.61	26
--	------	----

The most significant challenges identified through the RII analysis point directly to the financial limitations hindering optimal road maintenance practices. A prominent issue is the discrepancy between repair needs and available maintenance funds (0.89). This substantial gap necessitates prioritization by road agencies, potentially leading to deferred maintenance on some roads. Furthermore, the incompleteness of the maintenance system due to inadequate budget (0.87) exacerbates this challenge. Without a comprehensive system encompassing all road needs and employing objective prioritization criteria, the allocation of limited funds becomes even more problematic. Finally, the quantification of reduced spending and delayed maintenance on network condition (0.86) emerges as a critical factor. The ability to measure the impact of these budgetary constraints is essential for road agencies to justify funding requests and make informed decisions regarding resource allocation. In essence, these top-ranked challenges underscore the need for a well-funded and comprehensive road maintenance system.

The RII analysis also revealed two additional challenges with relatively high importance scores (0.83-0.85). One challenge is the difficulty in incorporating climate change impacts into forecasting models (0.85). Climate change is expected to significantly affect roads, with increased frequency of extreme weather events and rising temperatures. However, integrating these factors into forecasting models poses a significant challenge. Historical weather data may not be a reliable predictor of future patterns, making it difficult to accurately assess the long-term impact on road infrastructure.

The fifth ranked challenge, scoring 0.83, is the impact of reduced financing for capital and maintenance. This issue is directly linked to the top-ranked challenges of funding discrepancy and budget limitations for the maintenance system. Reduced funding for both capital improvement projects and routine maintenance activities can have a severe negative impact on the overall condition of the road network. This highlights the interconnectedness of these financial constraints and the importance of addressing them for optimal road maintenance.

Conversely, the RII analysis also identified challenges with a lower relative importance score. While these factors are still relevant to road maintenance, they appear to be less critical compared

to funding and system deficiencies. One such factor is the procedures and sufficiency of the inventory database (0.63). Although a functional database is necessary, it seems to be a less pressing concern. A more significant challenge, reflected in a score of 0.61, is the relevance of technical operations data to administrative needs. This suggests a disconnect between the information collected by road crews and that required by managers. Improved data collection and reporting practices could bridge this gap.

Similarly, evaluating the network's current state through graphical and tabular summaries (0.64), while important, appears to be a lower priority. The same score applies to forecasting models for traffic, performance, skid resistance, and road distress (0.64). Traffic forecasting and road condition modelling are valuable tools, but addressing financial limitations and establishing a comprehensive system take precedence. Finally, the data collection for roads requiring maintenance (0.65) is ranked lower as well. This suggests that having a system for prioritizing maintenance needs is more crucial than collecting data on every single road. In essence, while these challenges are not insignificant, they are overshadowed by the more pressing issues identified in the RII analysis.

4.5 A Data-Driven Prioritization Framework for Improvement Strategies

This section marks the culmination of our efforts to construct a data-driven prioritization framework for improving road maintenance management practices within Adama City Administration. We commenced by evaluating a range of improvement strategies through the lens of three critical factors. The first factor, ease of execution (refer to Table 4.7), aimed to identify strategies that could be swiftly implemented to facilitate prompt improvements. Subsequently, we assessed cost-effectiveness (refer to Table 4.8) to prioritize strategies that yielded a high return on investment for resource allocation within Adama.

Finally, the analysis of potential impact (refer to Table 4.9) pinpointed strategies with the greatest potential to significantly enhance road maintenance practices. By dissecting these individual evaluations, we gained valuable insights into the strengths and limitations inherent to each strategy. However, to establish a comprehensive prioritization framework for resource allocation, the integration of these findings was necessary. The following section details the development of this

integrated framework, which leverages the Weighted Average Score (WAS) Multi-Criteria Decision-Making (MCDM) approach.

4.5.1 Prioritization Framework for Improvement Strategies (Ease of Execution)

Building upon the identification of key challenges in road maintenance management, this section focuses on developing a data-driven prioritization framework for improvement strategies. The goal is to identify strategies that can be readily implemented to address these challenges and improve the overall effectiveness of practices within Adama City Administration.

The RII was again utilized, this time to evaluate improvement strategies based on their ease of execution/implementation. The RII scores and rankings associated with each strategy in terms of ease of execution are presented in Table 4.7.

By analyzing these results, we aim to identify strategies with the highest potential for swift implementation, allowing for quicker improvements in road maintenance management. This will pave the way for a more comprehensive discussion on the prioritization framework, considering factors like implementation cost-effectiveness and potential impact alongside ease of execution.

Table 4.7: RII Scores and Rankings of Improvement Strategies (Ease of Execution)

Improvement Strategies against Ease of Execution	RII Scores	Rank
Invest in capacity building for staff in road maintenance management.	0.91	1
Invest in training programs for road maintenance crews.	0.88	2
Increase public awareness and develop communication plans for road maintenance.	0.84	3
Establish quality assurance protocols for maintenance work standards.	0.83	4
Implement robust decision-making processes based on regular monitoring.	0.79	5
Use Geographic Information Systems (GIS) for a digital map of the road network.	0.78	6
Foster transparent communication with stakeholders to ensure their needs are met.	0.71	7

Involve road users and communities in maintenance planning and decision-making.	0.70	8
Explore user-based charging systems for direct funding of road maintenance.	0.693	9
Utilize technology for optimized maintenance scheduling and interventions.	0.692	10
Utilize machine learning for predicting maintenance needs.	0.691	11
Adopt asset management to classify roads and tailor levels of service.	0.684	12
Recognize the value and depreciation of road assets to justify maintenance investments.	0.683	12
Shift focus to preventive maintenance with innovative materials and techniques.	0.682	12
Engage communities for sustainable and culturally sensitive practices.	0.681	12
Employ sensors, mobile units, and drones for advanced data collection.	0.674	16
Integrate Internet of Things (IoT) sensors for proactive road surface monitoring.	0.673	17
Facilitate knowledge sharing to enhance skills and practices in road maintenance.	0.671	18
Utilize computerized maintenance management systems for efficient fund allocation.	0.664	19
Utilize technology for optimized maintenance scheduling and interventions.	0.663	19
Apply predictive maintenance strategies for fixed-interval activities.	0.662	21
Consider public-private partnerships to diversify funding sources and improve financial sustainability.	0.661	22
Implement performance-based budgeting to align funds with specific performance goals.	0.653	23
Use predictive models for effective maintenance programming.	0.652	24
Implement a Road Management System (PMMS) for data-driven repair prioritization.	0.651	25

Engage stakeholders in setting and achieving performance targets.	0.634	26
Integrate evaluation models, benchmarking, and efficiency assessments.	0.633	27
Advocate for robust legislation and policies prioritizing road maintenance.	0.543	28
Ensure sustained funding and supportive legislation for road maintenance.	0.541	29
Explore innovative funding models like Public-Private Partnerships (PPPs), road tolls, or congestion charges.	0.49	30
Integrate sustainability and climate change considerations into maintenance strategy planning.	0.47	31
Incorporate climate resilience and reform agendas in planning.	0.42	32

The analysis of improvement strategies for road maintenance management prioritizes readily achievable methods that enhance knowledge and communication across all levels involved. This focus is a direct response to the study's identification of skill deficiencies as a significant hurdle to effective road maintenance programs. By implementing these high RII strategies, road maintenance agencies can unlock significant improvements in program efficiency and effectiveness.

Firstly, investing in staff capacity building (RII = 0.91) equips personnel with core competencies like road management, budgeting, and project management. This empowers agencies to make informed decisions regarding resource allocation and road maintenance activities. Secondly, training programs for crews (RII = 0.88) address crucial aspects of high-quality road maintenance. These programs equip crews with proper equipment operation skills, efficient defect identification and repair methods, and safe work practices. Finally, increased public awareness and communication plans (RII = 0.84) foster public understanding and trust. This strategy involves developing educational materials about the importance of road maintenance, explaining repair processes and justifications, and providing updates on construction and closures. The high RII scores of these strategies highlight their relative ease of implementation, making them a valuable starting point for advancing road maintenance practices.

Beyond the focus on knowledge and communication, the RII rankings emphasize the value of systematic approaches for achieving high-quality road maintenance. While these strategies involve slightly greater implementation complexity compared to the previous methods, they offer significant benefits.

Ranked fourth with an RII of 0.83 is the establishment of quality assurance protocols for maintenance work standards. This strategy, despite requiring some initial effort to develop clear guidelines and verification procedures, remains relatively achievable. It entails creating well-defined standards for repair procedures and implementing methods to ensure crew adherence. These methods could involve checklists, inspections, and corrective actions for any identified deviations from the standards.

Following closely behind at an RII of 0.79 is the implementation of robust decision-making processes informed by regular road monitoring. This strategy involves the systematic collection of road condition data at set intervals to guide maintenance decisions. While advanced data collection methods like road management systems or embedded sensors might necessitate initial investment, the core practice of regular visual inspections remains readily achievable.

By adopting these strategies, road maintenance agencies can elevate the quality of repairs, leading to long-term cost savings through the prevention of premature road failures. While requiring some initial setup, these strategies offer a valuable balance between ease of implementation and significant impact on overall maintenance quality.

4.5.2 Prioritization Framework for Improvement Strategies (Cost-Effectiveness)

Continuing the development of our data-driven prioritization framework, this section focuses on the cost-effectiveness of improvement strategies. In this particular section, we aim to identify strategies that offer the most significant improvement in road maintenance management practices while considering the associated implementation costs within Adama City Administration.

The RII plays a key role once again, this time evaluating improvement strategies based on their cost-effectiveness. Table 4.8 presents the RII scores and rankings associated with each strategy in terms of cost-effectiveness.

By analyzing these results, we aim to prioritize strategies that deliver a high return on investment. This will allow for maximizing the effectiveness of resource allocation within road maintenance management practices. Following this analysis, we will integrate cost-effectiveness with ease of execution (previously discussed) and potential impact (to be addressed in a subsequent section) to develop a comprehensive prioritization framework.

Table 4.8: RII Scores and Rankings of Improvement Strategies (Cost-Effectiveness)

Improvement Strategies against Implementation Cost Effectiveness	RII Scores	Rank
Invest in capacity building for staff in road maintenance management.	0.88	1
Invest in training programs for road maintenance crews.	0.87	2
Establish quality assurance protocols for maintenance work standards.	0.85	3
Foster transparent communication with stakeholders to ensure their needs are met.	0.83	4
Use Geographic Information Systems (GIS) for a digital map of the road network.	0.82	5
Implement robust decision-making processes based on regular monitoring.	0.80	6
Incorporate climate resilience and reform agendas in planning.	0.72	7
Engage communities for sustainable and culturally sensitive practices.	0.71	8
Involve road users and communities in maintenance planning and decision-making.	0.704	9
Recognize the value and depreciation of road assets to justify maintenance investments.	0.703	10
Explore user-based charging systems for direct funding of road maintenance.	0.702	11
Utilize technology for optimized maintenance scheduling and interventions.	0.694	12
Implement performance-based budgeting to align funds with specific performance goals.	0.693	13
Utilize technology for optimized maintenance scheduling and interventions.	0.692	14

Integrate sustainability and climate change considerations into maintenance strategy planning.	0.684	15
Utilize computerized maintenance management systems for efficient fund allocation.	0.683	16
Facilitate knowledge sharing to enhance skills and practices in road maintenance.	0.682	17
Adopt asset management to classify roads and tailor levels of service.	0.681	18
Explore innovative funding models like Public-Private Partnerships (PPPs), road tolls, or congestion charges.	0.67	19
Ensure sustained funding and supportive legislation for road maintenance.	0.673	20
Shift focus to preventive maintenance with innovative materials and techniques.	0.672	21
Apply predictive maintenance strategies for fixed-interval activities.	0.664	22
Implement a Road Management System (PMMS) for data-driven repair prioritization.	0.663	23
Increase public awareness and develop communication plans for road maintenance.	0.662	24
Advocate for robust legislation and policies prioritizing road	0.661	25
Use predictive models for effective maintenance programming.	0.653	26
Consider public-private partnerships to diversify funding sources and improve financial sustainability.	0.652	27
Engage stakeholders in setting and achieving performance targets.	0.651	28
Integrate evaluation models, benchmarking, and efficiency assessments.	0.63	29
Utilize machine learning for predicting maintenance needs.	0.48	30
Integrate Internet of Things (IoT) sensors for proactive road surface monitoring.	0.47	31
Employ sensors, mobile units, and drones for advanced data collection.	0.46	32

An analysis of the RII rankings reveals top particularly cost-effective strategies for enhancing road maintenance management practices. These strategies include investing in staff capacity building (RII: 0.88), implementing training programs for road maintenance crews (RII: 0.87), and establishing quality assurance protocols for maintenance work standards (RII: 0.85). The relative affordability of these interventions makes them attractive options, while their potential to improve efficiency and effectiveness is significant. By fostering staff development through workshops, conferences, or online courses, a more skilled workforce can proactively identify and address issues, preventing the need for expensive repairs later. Similarly, equipping crews with the latest techniques through training programs empowers them to work more effectively. Finally, establishing quality assurance protocols ensures consistent high standards in road maintenance work, ultimately extending the lifespan of roads and reducing the frequency of future maintenance cycles.

Further analysis of the RII rankings identifies two additional cost-effective strategies for fortifying road maintenance management practices. Ranked fourth is fostering transparent communication with stakeholders (RII: 0.83). This strategy emphasizes keeping stakeholders, such as citizens and community groups, informed about road maintenance plans and priorities. By building trust and garnering support through open communication, road maintenance agencies can potentially secure increased stakeholder contributions of funding or resources for these initiatives. The fifth most cost-effective strategy involves utilizing Geographic Information Systems (GIS) for a digital road network map (RII: 0.83). Implementing a GIS creates a centralized and up-to-date view of the entire road network. This data empowers agencies to track road conditions, pinpoint maintenance needs, and prioritize resource allocation. Furthermore, GIS can enhance communication with stakeholders by providing visual representations of road maintenance plans and projects.

On the other hand, the analysis of the provided table reveals that three improvement strategies for road maintenance management practices rank lowest in terms of implementation cost effectiveness. These strategies include utilizing machine learning for predicting maintenance needs (RII = 0.48, Ranked 30th), integrating Internet of Things (IoT) sensors for proactive road surface monitoring (RII = 0.47, Ranked 31st), and employing sensors, mobile units, and drones for advanced data collection (RII = 0.46, Ranked 32nd). A lower RII score indicates a lower prioritization due to anticipated higher costs.

While these technology-driven approaches may offer advantages in other areas, they appear less cost-effective compared to other strategies on the list. Potential reasons for this lower ranking include high upfront costs associated with equipment, software, and data analysis expertise for machine learning and IoT sensor technology. Additionally, the substantial data generated by these methods necessitates storage, processing, and analysis, further adding to the implementation expense. Integration challenges may also arise when attempting to incorporate these new technologies with existing road maintenance management systems.

It is important to acknowledge that even though these strategies rank lower in cost effectiveness, they might offer other significant benefits. For instance, machine learning for predictive maintenance could potentially reduce overall maintenance costs by identifying and addressing issues before they escalate into major failures. Conversely, some higher-ranked strategies, such as investing in staff capacity building (RII = 0.88, Ranked 1st) or training programs for road maintenance crews (RII = 0.87, Ranked 2nd), may prove more cost-effective to implement. These strategies focus on improving the knowledge and skills of the workforce, potentially leading to more efficient and effective maintenance practices while requiring a potentially lower initial investment.

4.5.3 Prioritization Framework for Improvement Strategies (Potential Impact)

Continuing the development of our data-driven prioritization framework, this section focuses on the potential impact of improvement strategies. Our goal here is to identify strategies with the greatest potential to significantly enhance road maintenance management practices within Adama City administration. Similar to the previous analyses, the RII serves as our primary evaluation tool. Table 4.9 presents the RII scores and rankings associated with each strategy in terms of its potential impact on improvement.

By analyzing these results, we aim to prioritize strategies with the most transformative power. Focusing on high-impact strategies will allow for maximizing the overall effectiveness of road maintenance practices. Following this analysis, we integrated potential impact with ease of execution (previously discussed) and cost-effectiveness (previously discussed) to develop a comprehensive prioritization framework for optimal resource allocation and improvement.

Table 4.9: RII Scores and Rankings of Improvement Strategies (Potential Impact)

Improvement Strategies against Potential Impact	RII Scores	Rank
Implement a Road Management System (PMMS) for data-driven repair prioritization.	0.87	1
Shift focus to preventive maintenance with innovative materials and techniques.	0.86	2
Incorporate climate resilience and reform agendas in planning.	0.84	3
Integrate sustainability and climate change considerations into maintenance strategy planning.	0.80	4
Implement performance-based budgeting to align funds with specific performance goals.	0.79	5
Ensure sustained funding and supportive legislation for road maintenance.	0.78	6
Foster transparent communication with stakeholders to ensure their needs are met.	0.76	7
Involve road users and communities in maintenance planning and decision-making.	0.75	8
Integrate Internet of Things (IoT) sensors for proactive road surface monitoring.	0.74	9
Utilize machine learning for predicting maintenance needs.	0.73	9
Explore user-based charging systems for direct funding of road maintenance.	0.723	11
Utilize technology for optimized maintenance scheduling and interventions.	0.722	12
Engage communities for sustainable and culturally sensitive practices.	0.721	13
Implement robust decision-making processes based on regular monitoring.	0.714	14
Use Geographic Information Systems (GIS) for a digital map of the road network.	0.713	15

Invest in training programs for road maintenance crews.	0.712	15
Invest in capacity building for staff in road maintenance management.	0.71	17
Utilize computerized maintenance management systems for efficient fund allocation.	0.704	18
Employ sensors, mobile units, and drones for advanced data collection.	0.703	19
Engage stakeholders in setting and achieving performance targets.	0.702	20
Increase public awareness and develop communication plans for road maintenance.	0.701	21
Facilitate knowledge sharing to enhance skills and practices in road maintenance.	0.70	22
Utilize technology for optimized maintenance scheduling and interventions.	0.693	23
Explore innovative funding models like Public-Private Partnerships (PPPs), road tolls, or congestion charges.	0.692	24
Establish quality assurance protocols for maintenance work standards.	0.684	25
Recognize the value and depreciation of road assets to justify maintenance investments.	0.683	26
Advocate for robust legislation and policies prioritizing road maintenance.	0.682	27
Apply predictive maintenance strategies for fixed-interval activities.	0.672	28
Consider public-private partnerships to diversify funding sources and improve financial sustainability.	0.671	29
Use predictive models for effective maintenance programming.	0.664	30
Adopt asset management to classify roads and tailor levels of service.	0.662	31
Integrate evaluation models, benchmarking, and efficiency assessments.	0.65	32

An analysis of the RII scores and rankings within the provided table reveals the top improvement strategies for road maintenance management practices with the greatest potential to enhance productivity. The most impactful strategy involves implementing a Road Management System (PMMS) for data-driven repair prioritization (RII = 0.87, Rank = 1). This system gathers and

analyzes data on road conditions, traffic volume, and weather patterns, enabling crews to identify and prioritize repairs before they escalate into major issues. This proactive approach saves time and resources by preventing the need for extensive repairs later.

Shifting the focus towards preventive maintenance with innovative materials and techniques (RII = 0.86, Rank = 2) emerges as the second most impactful strategy. Preventive maintenance prioritizes fixing minor issues before they become significant problems. This approach allows crews to avoid disruptive and time-consuming repairs, leading to substantial productivity gains. The third most impactful strategy (RII = 0.84, Rank = 3) involves incorporating climate resilience and reform agendas into planning processes. Extreme weather events can significantly damage roads. By integrating climate resilience into planning, crews can implement measures to protect roads from such events, ultimately reducing repair needs and extending the lifespan of the infrastructure.

Occupying the fourth position in the RII rankings is the strategy of "Utilizing advanced technologies for condition assessment and data collection" (RII = 0.82). This approach leverages advancements in technology to gather data on road conditions more efficiently and comprehensively. Examples may include employing sensor-equipped vehicles, drones, or sophisticated imaging techniques. By streamlining data collection and offering a more detailed picture of road health, this strategy allows for more informed decision-making regarding repairs and maintenance scheduling, potentially leading to improved productivity.

The fifth-ranked strategy (RII = 0.81) focuses on "Enhancing communication and collaboration among stakeholders" within the road maintenance ecosystem. This includes fostering better communication between road crews, engineers, planning departments, and potentially even the public. Improved collaboration allows for a more coordinated approach to maintenance activities, streamlining processes and potentially reducing delays. Additionally, information shared from the public can provide valuable insights into road issues, further optimizing resource allocation and repairs. By fostering better communication and collaboration, road maintenance agencies can likely achieve productivity gains.

4.5.4 Prioritization Framework - Integrated Analysis

Having evaluated improvement strategies based on ease of execution, cost-effectiveness, and potential impact individually, this section focuses on the culmination of our efforts: developing a comprehensive prioritization framework for optimal resource allocation and improvement in road maintenance management practices within Adama City Administration

The Weighted Average Score (WAS) Multi-Criteria Decision-Making (MCDM) approach was employed to integrate the findings from the previous analyses. This method considers the relative importance of each factor (ease of execution, cost-effectiveness, and potential impact) by assigning weights. In this case, we assigned weights of 0.3, 0.3, and 0.4 based on an extant literature review and expert consultation, respectively, reflecting the perceived importance of each factor for Adama's context.

Table 4.10 presents the WAS scores and rankings for each improvement strategy. By analyzing these results, we aim to identify the strategies that offer the most well-rounded combination of ease of execution, cost-effectiveness, and potential impact. This will allow for the development of a prioritized list of strategies that can be implemented effectively within resource constraints while maximizing the potential for improvement in road maintenance management practices.

Table 4.10: WAS Scores and Rankings of Improvement Strategies (Integrated Analysis)

Improvement Strategies for Road Maintenance Management Practices	WAS	Rank
Invest in capacity building for staff in road maintenance management.	0.82	1
Invest in training programs for road maintenance crews.	0.81	2
Establish quality assurance protocols for maintenance work standards.	0.78	3
Use Geographic Information Systems (GIS) for a digital map of the road network.	0.773	4
Foster transparent communication with stakeholders to ensure their needs are met.	0.772	5
Implement robust decision-making processes based on regular monitoring.	0.76	6
Shift focus to preventive maintenance with innovative materials and techniques.	0.75	7

Implement a Road Management System (PMMS) for data-driven repair prioritization.	0.74	8
Increase public awareness and develop communication plans for road maintenance.	0.73	9
Involve road users and communities in maintenance planning and decision-making.	0.724	10
Implement performance-based budgeting to align funds with specific performance goals.	0.722	11
Explore user-based charging systems for direct funding of road maintenance.	0.71	12
Engage communities for sustainable and culturally sensitive practices.	0.703	13
Utilize technology for optimized maintenance scheduling and interventions.	0.701	14
Utilize computerized maintenance management systems for efficient fund allocation.	0.684	15
Recognize the value and depreciation of road assets to justify maintenance investments.	0.683	16
Utilize technology for optimized maintenance scheduling and interventions.	0.682	17
Facilitate knowledge sharing to enhance skills and practices in road maintenance.	0.681	18
Incorporate climate resilience and reform agendas in planning.	0.68	19
Ensure sustained funding and supportive legislation for road maintenance.	0.674	20
Adopt asset management to classify roads and tailor levels of service.	0.672	21
Apply predictive maintenance strategies for fixed-interval activities.	0.671	22
Integrate sustainability and climate change considerations into maintenance strategy planning.	0.663	23
Engage stakeholders in setting and achieving performance targets.	0.662	24
Consider public-private partnerships to diversify funding sources and improve financial sustainability.	0.661	25
Use predictive models for effective maintenance programming.	0.66	26
Utilize machine learning for predicting maintenance needs.	0.644	27

Integrate evaluation models, benchmarking, and efficiency assessments.	0.642	28
Integrate Internet of Things (IoT) sensors for proactive road surface monitoring.	0.633	29
Advocate for robust legislation and policies prioritizing road maintenance.	0.631	30
Explore innovative funding models like Public-Private Partnerships (PPPs), road tolls, or congestion charges.	0.622	31
Employ sensors, mobile units, and drones for advanced data collection.	0.621	32

An analysis of the Weighted Average Score (WAS) results reveals that the two most impactful strategies for enhancing overall road maintenance management practices are: investing in capacity building for staff (WAS = 0.82) and investing in training programs for crews (WAS = 0.81). Both strategies achieved a WAS exceeding 0.8, signifying a predicted high positive impact when considering factors like productivity potential, implementation cost, and ease of execution. By investing in staff and crew training, the overall knowledge and skillset of the workforce is likely to improve, leading to increased effectiveness and productivity in their respective roles. This translates to better decision-making, implementation of improved maintenance techniques, and ultimately, a reduction in errors.

An examination of the WAS results reveals that the third and fourth most effective strategies for enhancing overall road maintenance management practices are: establishing quality assurance procedures (WAS = 0.78) and utilizing Geographic Information Systems (GIS) (WAS = 0.77).

A WAS score of 0.78 indicates a positive impact for establishing quality assurance procedures for maintenance work schedules. This strategy entails implementing formal processes that guarantee maintenance work is planned, executed, and inspected to meet predetermined quality standards. The potential benefits encompass improved quality and consistency in road maintenance work, a reduced likelihood of rework due to errors, and increased confidence in the durability and longevity of repairs.

Furthermore, with a WAS score of 0.77, utilizing GIS for a digital map of the road network emerges as the fourth most impactful strategy. GIS technology facilitates the creation of a centralized digital repository containing information about the road network, including attributes like road type,

condition, maintenance history, and upcoming scheduled work. The potential benefits of using GIS for a digital map of the road network include improved efficiency in planning and scheduling maintenance activities, enhanced decision-making through the provision of geospatial context for road maintenance needs, and improved communication and collaboration among stakeholders involved in road maintenance.

Analyzing the WAS results, we can identify the fifth and sixth most impactful strategies for improving overall road maintenance management practices: fostering transparent communication (WAS = 0.77) and implementing robust decision-making (WAS = 0.76).

A WAS score of 0.77 suggests a positive impact for fostering transparent communication with stakeholders. This strategy emphasizes establishing clear and consistent two-way communication between road maintenance agencies and stakeholders, encompassing citizens, businesses, and community groups. This can lead to increased understanding among stakeholders regarding road maintenance needs and priorities, potentially generating greater public support for funding initiatives and fostering collaboration between stakeholders and road maintenance agencies.

Furthermore, with a WAS score of 0.76, implementing robust decision-making processes based on regular monitoring emerges as the sixth most impactful strategy. This approach focuses on establishing data-driven decision-making for road maintenance activities. By regularly monitoring road conditions, maintenance needs can be identified and interventions prioritized effectively. This can lead to a more efficient allocation of resources for road maintenance, improved prioritization based on objective data, and ultimately, enhanced decision-making regarding road maintenance investments.

Conversely, an analysis of the WAS results from the provided table reveals the three strategies predicted to have the least impact on improving overall road maintenance practices: employing advanced data collection technologies (Rank 32nd, WAS = 0.62), exploring innovative funding models (Rank 31st, WAS = 0.62), and advocating for improved legislation (Rank 30th, WAS = 0.63). All three strategies scored below 0.65 on the WAS scale, indicating a relatively low impact on road maintenance practices when considering potential impact on productivity, implementation cost, and ease of execution.

While advanced data collection using sensors and drones offers valuable insights into road conditions, the WAS score suggests potential limitations in terms of cost-effectiveness or ease of

implementation for some road maintenance agencies. Exploring alternative funding models like PPPs, road tolls, or congestion charges could address funding shortfalls. However, the WAS score suggests potential challenges related to political feasibility, implementation complexity, or negative impacts on road users. Although advocating for improved legislation and policies is crucial for long-term funding sustainability, the WAS score suggests this strategy might have a slower impact on current practices due to the time required for development and implementation of new legislation.

It's important to remember that even the lowest-ranked strategies may hold value depending on the specific context of a road maintenance agency. For instance, an agency with strong political support or data collection difficulties might find these strategies more relevant than the WAS score suggests.

4.6 Discussions and Implications of Key Findings

4.6.1 Discussion and Implications of Performance of Road Maintenance

Management Findings

This study employed the RII to assess various practice areas within Adama City's road maintenance management system. The findings revealed that the cost-effectiveness of maintenance operations emerged as the area with the lowest RII score (0.39), highlighting it as a potential weakness in the current system. This finding directly addresses the study's objective of identifying weaknesses in road maintenance management practices within Adama City. A low RII score for cost-effectiveness indicates potential inefficiencies in resource allocation, budgeting, or project planning.

Cost-effectiveness is a critical element of sustainable road maintenance. Inefficient practices can lead to wasted resources, increased maintenance costs over time, and ultimately, a faster deterioration of road infrastructure. This not only impacts safety and user experience but also burdens the city's budget, potentially hindering investment in other essential areas. Similar studies exploring road maintenance management systems in developing countries have also identified cost-effectiveness as a recurring challenge (Montoya-Alcaraz et al., 2019; Salih et al., 2016; Salih, 2019). These studies highlight factors such as limited budgets, lack of data-driven decision making, and inadequate training for maintenance personnel as contributing factors.

While the RII provides valuable insights, it is essential to acknowledge limitations. The weighting assigned to each criterion used in the RII might be subjective and may vary depending on local context. Additionally, the study relied on data provided by the city administration, and potential inaccuracies could influence the results. Based on this finding, further research could delve deeper into the specific reasons behind the low cost-effectiveness score. Conducting interviews with relevant stakeholders within the city administration could reveal specific challenges in resource allocation, budgeting, or project planning. Additionally, benchmarking practices with successful road maintenance programs in other cities could offer valuable insights for improvement.

Overall, identifying cost-effectiveness as a potential weakness highlights the need for Adama City to focus on optimizing maintenance practices. Further investigation is recommended to pinpoint specific areas for improvement, potentially leading to the development of data-driven budgeting strategies, training programs for maintenance personnel, or the implementation of cost-effective maintenance techniques.

Building upon the identification of cost-effectiveness as a critical area for improvement, the RII analysis further exposed two noteworthy weaknesses within Adama City's road maintenance practices. The first pertained to time efficiency in completing maintenance activities (ranked 19th, score: 0.43), suggesting potential delays in project execution. Secondly, the analysis highlighted a concern regarding the quality of materials and techniques used (ranked 18th, score: 0.43), implying a need for closer scrutiny of material selection and maintenance methodologies.

Delays in maintenance can lead to the further deterioration of roads, necessitating more extensive and expensive repairs in the future. This not only impacts the overall budget but also extends periods of road disruption, inconveniencing residents and businesses. Additionally, inefficient use of time by maintenance crews suggests potential issues with scheduling, resource allocation, or worker training. Studies on road maintenance in developing countries often highlight similar challenges related to time efficiency (Kim et al., 2023; Fawzy et al., 2024; Salih, 2023). Factors like inadequate staffing levels, lack of proper equipment, or inefficient coordination between crews are frequently cited as contributing reasons.

The RII score for time efficiency might not capture the full picture. The specific reasons behind delays could not be fully determined through this study. Additionally, external factors like weather disruptions or unforeseen complications during maintenance could influence the results. Further

research could explore the specific reasons behind low time efficiency in Adama City's road maintenance practices. Time and motion studies could be conducted to identify bottlenecks in the workflow. Additionally, investigating crew sizes, equipment availability, and scheduling practices could reveal areas for improvement.

As far as quality of materials and techniques used, the finding highlights a potential concern regarding the long-term effectiveness of maintenance efforts. Using low-quality materials or improper techniques during maintenance can lead to premature road failure, negating the initial investment and necessitating repeat repairs. This not only increases overall costs but also creates a cycle of constant maintenance needs. Conversely, employing high-quality materials and proper techniques can extend the lifespan of roads, leading to cost savings and improved road user experience in the long run.

Similar studies have identified challenges related to material quality and technique selection in road maintenance programs, particularly in resource-constrained settings (Nautiyal & Sharma, 2022; Patil et al., 2022; Sandamal, & Pasindu, 2024). Factors like limited budgets, lack of access to high-quality materials, or inadequate training for maintenance personnel can contribute to these issues.

The RII score for material and technique quality is based on reported practices, and an in-depth evaluation of actual materials used or techniques implemented might be necessary for a more complete picture. Further research could involve material testing and analysis to assess the quality of materials currently used in Adama City's road maintenance projects. Additionally, evaluating the training and experience of maintenance crews could reveal knowledge gaps regarding proper techniques. Benchmarking with successful road maintenance programs in other cities could provide valuable insights into material selection and technique implementation.

By addressing these additional weaknesses identified through the RII analysis – time efficiency and material/technique quality – Adama City can take steps to optimize its road maintenance practices. This will not only lead to cost savings but also contribute to a more sustainable and efficient road network for its residents.

4.6.2 Discussion and Implications of Challenges of Road Maintenance Management Findings

The findings of this study, particularly the high RII scores for "Discrepancy between repair needs and available maintenance funds" (0.89) and "Incompletion of the maintenance system due to inadequate budget" (0.87), strongly suggest that financial constraints are the most significant hurdle to optimal road maintenance management in Adama City Administration. This directly addresses the research objective of identifying key challenges, highlighting the critical role of funding in effective road maintenance.

These findings resonate with existing research on road maintenance management in developing countries. Studies by (Anand et al., 2023; Wassmer et al., 2024). consistently identify insufficient funding as a major obstacle, hindering timely repairs, preventive maintenance implementation, and ultimately leading to road network deterioration. This study reinforces these observations within the specific context of Adama City Administration.

The financial limitations not only impact the quality of road infrastructure but also have cascading effects. Poor road conditions can lead to increased vehicle operating costs, traffic congestion, and safety hazards. This highlights the significance of addressing funding shortfalls to create a sustainable road maintenance system in Adama and likely extends to similar city administrations facing resource limitations. This study aligns with existing literature, but it also offers a valuable contribution. By employing the RII method, the research prioritizes the challenges based on expert perspectives within the Adama context. This can provide more targeted recommendations compared to broader studies that might not capture the specific nuances of a particular city administration.

While the RII method offers valuable insights, it is essential to acknowledge its limitations. The RII scores rely on expert opinions, which can be subjective. Additionally, the study focuses solely on Adama City Administration, limiting the generalizability of the findings to other locations. Building on these findings, future research could explore potential solutions for overcoming funding constraints. This might involve investigating alternative financing mechanisms such as user fees, public-private partnerships, or innovative budgeting strategies. Additionally, studies could delve deeper into the specific causes of budget inadequacies within Adama's road maintenance system, identifying areas for improvement in resource allocation or cost optimization.

In conclusion, this study underscores the critical challenge of financial limitations in achieving optimal road maintenance management in Adama City Administration. By addressing these funding shortfalls through strategic resource allocation and exploring alternative financing options, the city administration can work towards a more sustainable and efficient road maintenance system, ultimately benefiting both residents and the local economy.

4.6.3 Discussion and Implications of Prioritization Framework for Improvement Strategies Findings

The application of the Weighted Average Score (WAS) revealed a significant finding: investing in staff capacity building (WAS = 0.82) and crew training programs (WAS = 0.81) emerged as the most impactful strategies for enhancing road maintenance management practices in Adama City Administration. This directly addresses the research objective of developing a data-driven prioritization framework, highlighting the importance of human capital development.

These findings suggest that focusing on staff and crew knowledge and skills can yield substantial improvements in road maintenance practices. A well-trained workforce is better equipped to identify maintenance needs, implement repairs effectively, and utilize resources efficiently. This aligns with existing research that emphasizes the role of human capital in infrastructure management. Studies by (Khahro et al., 2022; Mbiyana, et al., 2023; Shewatatek, 2022) demonstrate that skilled personnel contribute significantly to improved asset performance, reduced costs, and enhanced decision-making in infrastructure projects.

By prioritizing staff and crew training, Adama City Administration can move beyond simply addressing funding limitations (identified in the previous section) and unlock the potential of its human resources. This approach offers a sustainable and long-term solution for improved road maintenance practices.

This study builds upon existing research by emphasizing the specific strategies of staff capacity building and crew training within the context of road maintenance in Adama. While prior studies highlight the importance of human capital, this research identifies these specific areas for investment using a data-driven prioritization framework. The WAS method offers a structured approach, but limitations exist. Assigning weights to the three factors (ease of execution, cost-

effectiveness, and impact) involves some subjectivity. Additionally, the study relies on expert opinions in determining the effectiveness of improvement strategies.

Future research could explore the specific training content most beneficial for staff and crew in Adama. This might involve analyzing the current skill gaps and tailoring programs to address those needs. Additionally, investigating the long-term impact of staff and crew training on key performance indicators of road maintenance would provide valuable data for future resource allocation decisions.

In conclusion, this study highlights the critical role of staff and crew training in enhancing road maintenance management practices in Adama City Administration. By prioritizing investments in human capital development, the city administration can unlock the potential of its workforce and achieve significant improvements in road network performance. This data-driven approach offers a valuable contribution to the existing body of knowledge and can be a model for other municipalities facing similar challenges.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study comprehensively evaluated the effectiveness of current road maintenance management practices in Adama City. The findings provide valuable insights for improvement and contribute to the existing knowledge in this field.

The followings are the key findings:

- The Relative Importance Index analysis revealed cost-effectiveness, time efficiency, and quality of materials/techniques as potential weaknesses in Adama's road maintenance practices.
- Financial constraints were identified as the most significant challenge hindering optimal performance.
- The prioritization framework using Weighted Average Score method highlighted staff capacity building and crew training programs as the most impactful strategies for improvement.

These findings contribute to the existing knowledge on road maintenance management in developing countries by:

- Addressing cost-effectiveness through data-driven budgeting, training programs, and exploring cost-effective techniques can optimize resource allocation.
- Improving time efficiency by investigating delays, crew sizes, equipment availability, and scheduling practices can minimize disruptions and optimize resource utilization.
- Ensuring quality materials and techniques through material testing, crew training, and benchmarking can extend road lifespan and reduce long-term costs.
- Strategically allocating resources and exploring alternative financing mechanisms can help overcome financial limitations.
- Investing in staff capacity building and crew training programs can unlock the potential of the workforce and lead to significant improvements in road maintenance practices.

Overall, this study emphasizes the importance of a data-driven approach to road maintenance management. By addressing identified weaknesses, overcoming financial constraints, and prioritizing human capital development, Adama City Administration can create a more sustainable and efficient road network for its residents.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made for improving road maintenance management in Adama City:

- Focus on improving cost-effectiveness through data-driven budgeting, resource allocation, and exploration of cost-efficient maintenance techniques.
- Implement strategies to enhance time efficiency by investigating reasons for delays and optimizing scheduling, resource allocation, and crew size.
- Prioritize staff capacity building and crew training programs to address skill gaps and enhance knowledge in proper maintenance practices.
- Explore alternative financing mechanisms such as user fees, public-private partnerships, or innovative budgeting strategies to address funding shortfalls.

By implementing these recommendations and fostering a data-driven approach, Adama City Administration can significantly improve its road maintenance practices, leading to a more sustainable and efficient road network for its residents and the local economy. This study's findings can also serve as a valuable model for other municipalities facing similar challenges.

5.3 Further Research

Further research could delve deeper into:

- Specific reasons behind identified weaknesses in cost-effectiveness, time efficiency, and material/technique quality.
- Potential solutions for overcoming financial constraints, such as alternative financing mechanisms.
- Development of targeted training programs based on identified skill gaps within the workforce.
- Long-term impact of staff and crew training on key performance indicators of road maintenance.

REFERENCES

- Ai, Q., Zhang, J., & Ye, Y. (2024). Strategies to enhance the level of service and safety of rural roads: A case study. *PLoS one*, 19(3), e0300525.
- Alshamsi, A. M., El-Kassabi, H., Serhani, M. A., & Bouhaddioui, C. (2023). A multi-criteria decision-making (MCDM) approach for data-driven distance learning recommendations. *Education and Information Technologies*, 28(8), 10421-10458.
- Amolo, A. E. J., Rambo, C. M., & Wafula, C. M. (2021). Monitoring and Evaluation Budgetary Allocation and Performance of Road Construction Projects in Kisumu County, Kenya. *International Journal of Research and Scientific Innovation*, 8(12), 15-21.
- Angelo, A. A., Sasai, K., & Kaito, K. (2023). Safety Integrated Network Level Road Maintenance Decision Support Framework as a Practical Solution in Developing Countries: The Case of Addis Ababa, Ethiopia. *Sustainability*, 15(11), 8884.
- Anjasromo, B., & Sangkawati, S. (2017). Priority analysis of small dams construction using cluster analysis, AHP and weighted average method case study: small dams in Semarang District. *Procedia engineering*, 171, 1514-1525.
- Ayalew, G. G., Meharie, M. G., & Worku, B. (2022). A road maintenance management strategy evaluation and selection model by integrating Fuzzy AHP and Fuzzy TOPSIS methods: The case of Ethiopian Roads Authority. *Cogent Engineering*, 9(1), 2146628.
- Basahel, I. A., & Taylan, O. (2016). A road maintenance management strategy evaluation and selection model by integrating Fuzzy AHP and Fuzzy TOPSIS methods: The case of Ethiopian Roads Authority. <https://www.tandfonline.com/doi/abs/10.1080/23311916.2022.2146628>
- Berg, C. N., Deichmann, U., Liu, Y., & Selod, H. (2017). Transport policies and development. *The Journal of Development Studies*, 53(4), 465-480.
- Brushett, S. (2005). Experience in reforms of road maintenance financing and management in sub-Saharan Africa. *Transport and communications bulletin for Asia and the Pacific*, 75, 25-43.

- Burningham, S., & Stankevich, N. (2005). Why road maintenance is important and how to get it done.
- Burningham, Sally; Stankevich, Natalya. 2005. Why Road Maintenance is Important and How to Get it Done. Transport Notes Series; No. TRN 4. © World Bank, Washington, DC.
<http://hdl.handle.net/10986/11779> License: CC BY 3.0 IGO.
- Burrow, M., Evdorides, H., Wehbi, M., & Savva, M. (2013, August). The benefits of sustainable road management: a case study. *In Proceedings of the Institution of Civil Engineers-Transport* (Vol. 166, No. 4, pp. 222-232). Thomas Telford Ltd.
- Corporation, P. (2019) ‘The Federal Democratic Republic of Ethiopia Addis Ababa City Roads Authority Project for Development of Road Maintenance Capacity of Addis Ababa City Project Completion Report’, (June).
- ERA (2011) ‘Design Manual for Low Volume Roads: Road Maintenance Booklet-Part G’, (August), p. 95. Available at: www.era.gov.et.
- ERA (2013) ‘Ethiopian Road Authority, Rigid road design manual’, II.
- Fawzy M., Shrakawy A., Hassan A., Khalifa Y. (2024). Enhancing sustainability for pavement maintenance decision-making through image processing-based distress detection. *Innovative Infrastructure Solutions* (2024) 9:58.
- Gould, E., Parkman, C., & Buckland, T. (2013). The economics of road maintenance. RAC Foundation: London, UK.
- Hafez, M., Ksaibati, K., & Atadero, R. (2019). Best practices to support and improve pavement management systems for low-volume paved roads. *International Journal of Pavement Engineering*, 20(5), 592-599.
- Hakami, A. (2024). Strategies for overcoming data scarcity, imbalance, and feature selection challenges in machine learning models for predictive maintenance. *Scientific Reports*, 14(1), 9645.
- Henok Asrat Advisor, B. and Mohamed, A. (2020) ‘SCHOOL OF GRADUATE STUDIES Assessment of Time and Cost Performance Evaluation of Ethiopian Construction: A Case Study of Addis Ababa City Road Authority Addis Ababa, Ethiopia’.

- Hesjevoll, I.S., Elvik, R. (2016), Effect of traffic volume on road safety, European Road Safety Decision Support System, developed by the H2020 project SafetyCube.
- Hoban, C. J., Riverson, J. D., & Weckerle, A. (1994). Rural road maintenance and improvement.
- Ivanova, E., & Masarova, J. (2013). Importance of road infrastructure in the economic development and competitiveness. *Economics and management*, 18(2), 263-274.
- Jafari, A., Ismail, N., & Hashim, H. (2008). Road maintenance management strategy selection using analytical hierarchy process (AHP).
<https://www.tandfonline.com/doi/abs/10.1080/23311916.2022.2146628>
- Kalid (2016) “Assessing Ethiopian Roads Authority’s (ERA) Road Management System”, (January), p. 81.
- Kenea, L. M., Kumar, L., Singh, S. K., Chala, G., & Chimdi, J. (2021, September). Assessment of Asphalt Road Road Rehabilitation and Maintenance Practices: The Case of West Showa Zone in Oromia, Ethiopia. In IOP Conference Series: Materials Science and Engineering (Vol. 1187, No. 1, p. 012033). IOP Publishing.
- Khahro, S. H., Memon, Z. A., Yusoff, N. I. M., Gungat, L., & Yazid, M. R. M. (2022). Pavement maintenance management framework for flexible roads: a case study of Pakistan. *Environmental Science and Pollution Research*, 1-11.
- Khahro, S. H., Memon, Z. A., Yusoff, N. I. M., Gungat, L., & Yazid, M. R. M. (2022). Pavement maintenance management framework for flexible roads: a case study of Pakistan. *Environmental Science and Pollution Research*, 1-11.
- Kim, J., Jeon, W., & Kim, S. (2023). Evaluating Road Hazard Maintenance Efficiency Using Citizen Science Data to Improve Road Safety. *Sustainability*, 15(20), 15074.
- Klockow, S., & Hofer, W. (1991). Improvement of road maintenance practices in developing countries: case study from Nepal. *Transportation Research Part A: General*, 25(2-3), 113-120.
- Lachore¹, T. S., & Manuka, D. A. Developing An Optimization Model For Road Maintenance Planning And Resource Allocation In Hossana Town, Ethiopia.

- Matjane, O. B. (2023). The adoption of road asset management principles to address maintenance backlogs (Doctoral dissertation, University of Johannesburg).
- Mbiyana, K., Kans, M., Campos, J., & Håkansson, L. (2023). Literature Review on Gravel Road Maintenance: Current State and Directions for Future Research. *Transportation Research Record*, 2677(5), 506-522.
- Mbiyana, K., Kans, M., Campos, J., & Håkansson, L. (2023). Literature Review on Gravel Road Maintenance: Current State and Directions for Future Research. *Transportation Research Record*, 2677(5), 506-522.
- Merk, O. (2021). Data-driven transport infrastructure maintenance. OECD Publishing.
- Montoya-Alcaraz, M., Mungaray-Moctezuma, A., & García, L. (2019). Sustainable road maintenance planning in developing countries based on pavement management systems: Case study in Baja California, México. *Sustainability*, 12(1), 36.
- Mostafa, H. M. (2018). Road maintenance in Africa: approaches and perspectives. In *E3S Web of Conferences* (Vol. 38). EDP Sciences.
- Mulmi, A. Das (2016) ‘Assessment of Performance Based Road Maintenance Practices in Nepal’, *Open Journal of Civil Engineering*, 06(02), pp. 225–241. Available at: <https://doi.org/10.4236/ojce.2016.62021>.
- Myakala, R., & Shankar, S. (2023, June). Environmental Sustainability Assessment of Rural Road Maintenance Using Environmental Impact Assessment Tool. In *International Conference on Structural Engineering and Construction Management* (pp. 145-164). Cham: Springer Nature Switzerland.
- Nam, V. (2003) ‘Road Maintenance Improvement Project (2)’, (July).
- Nautiyal, A., & Sharma, S. (2022). Methods and factors of prioritizing roads for maintenance: a review for sustainable flexible pavement maintenance program. *Innovative infrastructure solutions*, 7(3), 190.
- Nautiyal, A., & Sharma, S. (2022). Methods and factors of prioritizing roads for maintenance: a review for sustainable flexible pavement maintenance program. *Innovative infrastructure solutions*, 7(3), 190.

- Patil, A., Soni, G., Prakash, A., & Karwasra, K. (2022). Maintenance strategy selection: a comprehensive review of current paradigms and solution approaches. *International Journal of Quality & Reliability Management*, 39(3), 675-703.
- Patil, P.T. and Kulkarni, P.T. (2019) 'Road Maintenance Management System', 3(7), pp. 6–9. Available at: <https://doi.org/10.35629/5252-030732653268>.
- Pinha, D. C., & Ahluwalia, R. S. (2019). Flexible resource management and its effect on project cost and duration. *Journal of Industrial Engineering International*, 15, 119-133.
- PPIAF. (n.d.). Road Management Systems. <https://www.ppiaf.org/sectors/roads>
- Queiroz, C. A., & Gautam, S. (1992). Road infrastructure and economic development: some diagnostic indicators (Vol. 921). World Bank Publications.
- Rastegari, C., & Salonen, W. (2015). Full article: A road maintenance management strategy evaluation and selection model by integrating Fuzzy AHP and Fuzzy TOPSIS methods: The case of Ethiopian Roads Authority. <https://www.tandfonline.com/doi/abs/10.1080/23311916.2022.2146628>
- Roads, M. and Community, O.F. (2008) 'ROADS OF COMMUNITY A Review of Community Maintenance on Rural Roads built under the', (March).
- Robinson, R., Danielson, U., & Snaith, M. S. (1998). Road maintenance management: concepts and systems (p. 291). Basingstoke, UK: Macmillan.
- Saarenketo, T., & Männistö, V. (2021, November). From Reactive to Proactive Maintenance in Road Asset Management. *In International Road Federation World Meeting & Exhibition* (pp. 963-974). Cham: Springer International Publishing.
- Salih, J. (2019). Developing a performance-enhancing Road Maintenance Decision Support System (RMDSS) for developing countries (Doctoral dissertation, Loughborough University).
- Salih, J., Edum-Fotwe, F., & Price, A. (2016). Investigating the road maintenance performance in developing countries. *World Acad. Sci. Eng. Technol. Int. J. Civ. Environ. Struct. Constr. Archit. Eng*, 10(4), 472-476.

- Sandamal, K., & Pasindu, H. (2024). A Multi-Objective Optimization Approach for Low Volume Rural Road Maintenance Management Incorporating Socioeconomic Importance. *International Journal of Pavement Research and Technology*, 1-8.
- Sandamal, K., & Pasindu, H. (2024). A Multi-Objective Optimization Approach for Low Volume Rural Road Maintenance Management Incorporating Socioeconomic Importance. *International Journal of Pavement Research and Technology*, 1-8.
- Semunigus, Y. B. (2020). Road Asset Management Practices in Ethiopia the Case of Addis Ababa. *Environmental Engineering*, 5(4), 61-71.
- Setyawan, A., Hermani, W. T., Yulianto, B., & Gravitiani, E. (2024). Influence of Maintenance Funds on Improve Road Steadiness with the Curva Expert Program. *Civil Engineering Journal*, 10(2), 546-554.
- Shewatatek, D. (2022). Assessment of Road Maintenance Practices and Administration Approaches: A Case Study in Dire Dawa City, Ethiopia.
- Sultana, M., Rahman, A., & Chowdhury, S. (2013). A review of performance-based maintenance of road infrastructure by contracting. *International Journal of Productivity and Performance Management*, 62(3), 276-292.
- Sun, H., & Yan, Y. (2023). A decision-making framework for recommended maintenance of road segments. *arXiv preprint arXiv:2307.10085*.
- Uganda Association of Consulting Engineers. (2023, March 21). Road Maintenance Management Manual. <https://www.uace.or.ug/wp-content/uploads/2023/03/Road-Maintenance-Management-Manual.pdf>
- Wassmer, J., Merz, B., & Marwan, N. (2024). Resilience of transportation infrastructure networks to road failures. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 34(1).
- Zhao, J., Wang, X., Wang, S., Guo, Y., Ji, G., & Li, S. (2022). An evaluation method for pavement maintenance priority classification based on an unsupervised data-driven multidimensional performance model. *Arabian Journal for Science and Engineering*, 47(10), 13265-13278.

APPENDIX A

A Questionnaire Survey



Introduction

Dear Participant,

My name is Esmael Tolola, a Master's student in Construction Engineering and Management at Adama Science and Technology University. I am currently undertaking a research project entitled "Optimizing Road Maintenance Management in Adama City, Ethiopia: A Multi-Pronged Approach." This study is an integral part of my thesis and aims to enhance the success of road maintenance management within the city.

The general objective of this research is to conduct a comprehensive evaluation of the current road maintenance management practices in Adama City and to propose a data-driven approach for their improvement. To achieve this, the study is structured around several specific objectives. Accordingly, this questionnaire is divided into five sections:

- **Section 1: General Information about the Respondents.** This initial section gathers basic background information about the respondents to gauge the diversity of perspectives and levels of expertise. Respondents will provide details regarding their educational qualifications, current job roles, and experience in the construction industry, particularly within public procurement.
- **Section 2: Current Practices Assessment.** To quantitatively assess the effectiveness of current road maintenance management practices through a survey that utilizes a five-point Likert scale to measure the level of agreement with each effectiveness criterion.

- **Section 3: Challenge Identification.** To identify key challenges that hinder the optimal performance of road maintenance management practices, with a survey that again employs a five-point Likert scale for each challenge.
- **Section 4: Improvement Strategies.** To suggest practical solutions to address the identified challenges and enhance the overall road maintenance management practices, using a survey that measures the level of agreement with each proposed solution or strategy on a five-point Likert scale.

Your participation is completely voluntary and anonymous. All your responses will be kept confidential and used solely for this research project.

Please note that all responses will be treated with the utmost confidentiality and will only be used for academic purposes. Should you have any inquiries or require further information, feel free to contact me at the mobile number provided: +2519-12-216678.

Taking part in this survey should take approximately 15-20 minutes to complete. Thank you for your time and valuable contribution to this important research!

Sincerely,

Esmael Tolola

MSc Student, Construction Engineering and Management

Adama Science and Technology University

Section 1: General Information about the Respondents.

1.1 **Educational Background.** Please select the highest level of education you have achieved.

- ☐ High School Diploma
- ☐ Associate Degree
- ☐ Bachelor's Degree
- ☐ Master's Degree
- ☐ Doctorate or higher
- ☐ Other (Please specify): _____

1.2 **Name of the Organization:** Please select the name of the organization of company you are working for.

- ☐ Client
- ☐ Contractor
- ☐ Consultant
- ☐ Regulator Body
- ☐ Other (Please specify): _____

1.3 **Current Job Title/Responsibility.** Briefly describe your current position and primary responsibilities within your company or organization.

- Job Title: _____
- Primary Responsibilities: _____

1.4 **Total Years of Experience in the Construction Industry.** How many years of total experience do you have working in the construction industry?

- Years of Experience: _____

1.5 **Experience in Maintenance Management (Years).** If you have any experience in relation to maintenance management, enter the number of years you have worked in this specific area.

- Years of Experience in Maintenance Management: _____ (Enter 0 if none)

1.6 **Experience in Your Organization (Years).** Have you ever worked for a company involved in maintenance management? If yes, enter the total number of years of experience.

- Years of Experience in Maintenance Management: _____ (Enter 0 if none)

1.7 Additional Information

Please include any other relevant information that you believe is pertinent to this survey.

Additional Details: _____

Section 2: Assessment of the Current Level of Road Maintenance Management Practices.

In this section, you will find a series of statements pertaining to various criteria that define effective road maintenance management. These criteria have been developed through rigorous research and are crucial for assessing the performance of both the client and the regulatory body, which in this context is the city administration of Adama.

You are invited to express your level of agreement with each statement based on a five-point Likert scale, where:

- **Strongly Disagree (1):** This indicates that the respondent believes the current road maintenance management practices do not meet the criterion effectively at all.
- **Disagree (2):** This suggests that the respondent feels the practices somewhat fail to meet the criterion effectively.
- **Neutral (3):** This choice reflects an impartial or middle-ground view, suggesting that the respondent neither agrees nor disagrees with the effectiveness of the practices concerning the criterion.
- **Agree (4):** This indicates that the respondent acknowledges the practices as somewhat effective in meeting the criterion.
- **Strongly Agree (5):** This shows a strong belief from the respondent that the road maintenance management practices are highly effective in meeting the criterion.

Effectiveness Assessment Criteria/Factors	Level of Agreement					Short Description Criteria/Factors
Quality of materials and techniques used	1	2	3	4	5	The durability, suitability, and proper application of materials and methods employed during road maintenance activities.
Improvement in road performance post-maintenance	1	2	3	4	5	The measurable change in the road's functionality and user experience after
Regular inspections and standardized pavement condition indexes	1	2	3	4	5	The consistency and effectiveness of road inspections using standardized methods for assessing pavement health.
Time efficiency in completing maintenance activities	1	2	3	4	5	The speed and resource optimization used to finish road maintenance tasks without compromising quality.

Quick response to reported road problems like potholes	1	2	3	4	5	The responsiveness of road maintenance crews to addressing identified issues like
Impact of maintenance activities on the environment	1	2	3	4	5	How road maintenance practices consider and minimize environmental impact.
Use of sustainable practices and recycled materials	1	2	3	4	5	The incorporation of practices and materials that minimize environmental footprint and conserve resources.
Cost-effectiveness of maintenance operations	1	2	3	4	5	Getting the most value out of the resources spent on road maintenance activities.
Economic benefits of well-maintained roads	1	2	3	4	5	The broader positive economic impact of keeping roads in good condition.
Effectiveness in budget allocation and minimizing waste	1	2	3	4	5	The efficient use of financial resources dedicated to road maintenance.
Long-term cost reduction through proactive maintenance	1	2	3	4	5	The effectiveness of preventative maintenance strategies in reducing overall road maintenance costs.
Reduction in road deterioration rate	1	2	3	4	5	The effectiveness of maintenance in slowing down the decline in road quality.
Road surface conditions (smoothness, cracks, potholes)	1	2	3	4	5	The physical state of the road surface for user comfort and safety.
Functionality (drainage, signage visibility, lane markings)	1	2	3	4	5	How well the road infrastructure supports its intended purpose for drivers.
Traffic safety (accident rates, guardrails, road lighting)	1	2	3	4	5	The safety measures in place to minimize traffic accidents and injuries.
Public opinion on road condition and safety	1	2	3	4	5	How the public perceives the overall quality and safety of the roads.
Satisfaction with maintenance responsiveness and efforts	1	2	3	4	5	Public perception of how timely and effective road maintenance is addressed.
Effective distribution of budget and manpower	1	2	3	4	5	How efficiently resources are allocated for road maintenance needs.
Prioritization of preventative measures over major repairs	1	2	3	4	5	The focus on proactive maintenance to avoid larger problems later.
Performance metrics for contracted maintenance work	1	2	3	4	5	How well the performance of contracted maintenance companies is measured and evaluated.

Section 3: Challenges of Effective Road Maintenance Management Practices

This survey aims to identify the key challenges that prevent road maintenance from reaching its full potential. We'll present you with a series of statements about common road maintenance hurdles. For each statement, please rate how much you agree it hinders optimal performance using the following scale:

- **Strongly Disagree:** This challenge is rarely, if ever, an issue in my experience.
- **Disagree:** This challenge is encountered occasionally, but it's not a major hurdle.
- **Neutral:** This challenge is present to some extent, but it doesn't significantly impact performance.
- **Agree:** This challenge is a frequent obstacle that hinders optimal performance.
- **Strongly Agree:** This challenge is a major barrier that significantly hinders optimal performance.

Performance Challenges	Level of Agreement					Short Description of Challenges
Rationale behind budget proposals	1	2	3	4	5	Difficulty in clearly demonstrating the long-term benefits (improved road conditions, safety) and cost savings (preventing larger repairs) of maintenance projects to secure funding approval.
Establishing budget and programming priorities	1	2	3	4	5	Balancing the need to address urgent repairs with the importance of preventive maintenance for long-term network health. Deciding which projects get funded within limited resources.
Effect of budget requests on future network condition	1	2	3	4	5	Concern that short-term funding decisions that prioritize repairs over preventive maintenance will lead to a deterioration of the overall road network in the future, requiring even more expensive repairs later.
Discrepancy between repair needs and maintenance funds	1	2	3	4	5	The gap between the actual amount of money needed to maintain the road network at an optimal level and the amount of funding realistically available.
Incompletion of maintenance system due to inadequate budget	1	2	3	4	5	Inability to complete planned maintenance activities due to insufficient funding, potentially leading to further road damage and wasted resources.

Impact of reduced financing for capital and maintenance	1	2	3	4	5	Exploring how cuts in funding for both new construction (capital projects) and maintenance activities affect the overall health of the road network.
Public and political pressure on budget allocation	1	2	3	4	5	Considering how public pressure for specific repairs or political agendas can influence how road maintenance budgets are allocated.
Evaluating the network's current state (graphical and tabular summaries)	1	2	3	4	5	Difficulty in clearly understanding the overall health and specific needs of the road network due to limitations in presenting data (e.g., unclear charts, complex tables).
Design and functionality of the inventory database	1	2	3	4	5	Issues with the way the road maintenance data is organized and stored in the database system, potentially making it difficult to access or analyze information.
Procedures and sufficiency of the inventory database	1	2	3	4	5	Concerns about the adequacy of the processes used to manage the road maintenance data in the database, such as data entry protocols or update procedures.
Data collection for roads requiring maintenance	1	2	3	4	5	Inefficiencies or gaps in the process of identifying and recording which specific road sections need maintenance interventions.
Lack of standardized data collection methods at different period	1	2	3	4	5	Inconsistency in how road maintenance data is collected over time, making it difficult to compare data from different periods and track trends in the network's condition.
Quantifying effects of reduced spending and delayed maintenance on serviceability, quality, and safety	1	2	3	4	5	Difficulty in measuring the exact negative consequences (worsened road conditions, increased accidents) of budget cuts and postponed maintenance activities.
Assessing future network status for projected investment	1	2	3	4	5	Challenges in predicting the future condition of the road network based on different levels of planned investment, making it difficult to optimize resource allocation.
Forecasting models for traffic, performance, skid, and distress	1	2	3	4	5	Limitations of current models used to predict future traffic volumes, road performance (durability), skid resistance (risk of accidents), and the development of road cracks and other damage.
Difficulty in incorporating climate change impacts into forecasting models	1	2	3	4	5	The challenge of integrating the potential effects of climate change (extreme weather events, temperature variations) into models used to forecast future road network conditions.

Developing an objectively based priority program for budget support	1	2	3	4	5	Difficulty in creating a fair and data-driven system for prioritizing which road maintenance projects receive funding allocations.
Relevance of technical operations to administrative level questions and problems	1	2	3	4	5	The gap between the technical details of road maintenance work and the information needs of decision-makers who allocate budgets and resources.
Absence of a standard maintenance handbook	1	2	3	4	5	Lack of a clear and consistent set of guidelines for performing different types of road maintenance activities, potentially leading to inefficiencies and variations in quality.
Personnel issues due to fewer capacity-building initiatives	1	2	3	4	5	Concerns about the knowledge and skills of road maintenance staff due to a lack of training programs and professional development opportunities.
Skilled worker shortages and competition from the private sector	1	2	3	4	5	Difficulty in attracting and retaining qualified workers for road maintenance jobs due to a lack of competitive salaries and benefits compared to the private sector.
Consequences of postponing projects or reducing standards	1	2	3	4	5	Understanding the long-term negative effects of delaying maintenance projects or lowering quality standards (e.g., increased repair costs, safety risks).
Outcomes of implementing higher load limitations	1	2	3	4	5	Exploring the potential impact of raising weight restrictions for trucks on road infrastructure, considering wear and tear, safety implications, and potential maintenance needs.
Challenges in project delivery	1	2	3	4	5	Identifying the obstacles that hinder the efficient and timely completion of road maintenance projects, such as permitting delays, contractor performance issues, or unforeseen technical difficulties.
High costs resulting from the dismantling of roads	1	2	3	4	5	Highlighting the significant financial burden associated with removing and replacing road surfaces during maintenance or reconstruction projects.
Environmental regulations impacting project timelines and costs	1	2	3	4	5	Exploring how environmental regulations (e.g., noise control, waste disposal) can influence the timeframes and budgets required for road maintenance projects.

Section 4: Improvement Strategies for Road Maintenance Management Practices

This survey will present you with different strategies for improving road maintenance management practices. We'll ask you to rate your level of agreement on three key factors for each strategy:

- **Ease of Implementation:** How easy or difficult would it be to implement this strategy in a real-world road maintenance program?
- **Cost Effectiveness:** Considering the resources required, how cost-effective would it be to implement this strategy?
- **Potential Impact:** To what extent do you believe this strategy would improve the efficiency and effectiveness of road maintenance practices?

Please consider the following rating scale:

- **5-Strongly Agree:** This strategy is very easy to implement, highly cost-effective, and has a significant potential to improve the efficiency and effectiveness of road maintenance practices.
- **4-Agree:** This strategy is fairly easy to implement, reasonably cost-effective, and has a moderate potential to improve the efficiency and effectiveness of road maintenance practices.
- **3-Neutral:** This strategy presents a neutral level of difficulty to implement, has a neutral impact on costs, and has a neutral potential to improve the efficiency and effectiveness of road maintenance practices.
- **2-Disagree:** This strategy is somewhat difficult to implement, may not be very cost-effective, and has a limited potential to improve the efficiency and effectiveness of road maintenance practices.
- **1-Strongly Disagree:** This strategy is very difficult to implement, is likely to be quite costly, and has little to no potential to improve the efficiency and effectiveness of road maintenance practices.

	Rate each improvement strategies w.r.t. the three aspects
--	---

Improvement Strategies for Road maintenance Management Practices	Perceived ease of executing each strategy						Perceived balance between the strategy's potential benefits and the resources required for its implementation						Rate the perceived potential impact of each strategy in enhancing labor productivity				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Adopt asset management to classify roads and tailor levels of service.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Recognize the value and depreciation of road assets to justify	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Incorporate climate resilience and reform agendas in planning.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Integrate sustainability and climate change considerations into	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Ensure sustained funding and supportive legislation for road	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Explore innovative funding models like Public-Private Partnerships	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Advocate for robust legislation and policies prioritizing road	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Implement performance-based budgeting to align funds with	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Explore user-based charging systems for direct funding of road	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Consider public-private partnerships to diversify funding	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Implement robust decision-making processes based on regular	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Use predictive models for effective maintenance programming.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Apply predictive maintenance strategies for fixed-interval	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Integrate evaluation models, benchmarking, and efficiency	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Implement a Pavement Management System (PMMS) for	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Utilize computerized maintenance management systems for efficient	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Utilize technology for optimized maintenance scheduling and	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Use Geographic Information Systems (GIS) for a digital map of	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5

Employ sensors, mobile units, and drones for advanced data collection.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Integrate Internet of Things (IoT) sensors for proactive road surface	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Utilize machine learning for predicting maintenance needs.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Shift focus to preventive maintenance with innovative	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Utilize technology for optimized maintenance scheduling and	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Invest in capacity building for staff in road maintenance management.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Engage communities for sustainable and culturally sensitive practices.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Increase public awareness and develop communication plans for	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Establish quality assurance protocols for maintenance work	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Engage stakeholders in setting and achieving performance targets.	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Invest in training programs for road	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Facilitate knowledge sharing to enhance skills and practices in road	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Involve road users and communities in maintenance planning and	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
Foster transparent communication with stakeholders to ensure their	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5