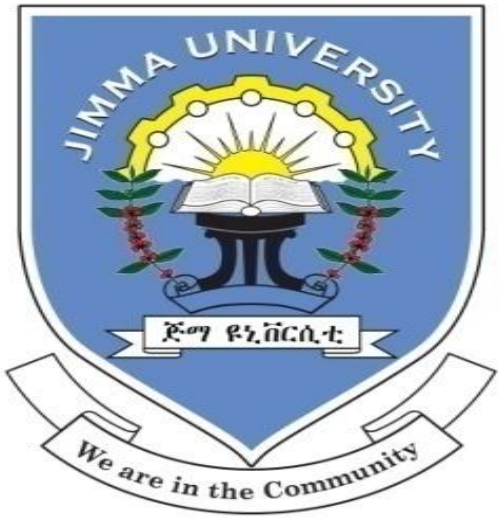

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FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HIGH WAY ENGINEERING STREAM

Challenges on Asphalt Pavement Maintenance Management System (A Case of Jima District Federal Roads)

A Thesis Submitted to the School of Graduate Studies of Jimma University. In Partial Fulfillment of the Requirements for the Degree of Master of Science in Highway Engineering

By: Mohammed Hassen

August, 2020

Jimma, Ethiopia

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By:
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Co – Advisor	Signature	Date

DECLARATION

I declare that this study entitled "Challenges on Asphalt Pavement Maintenance Management System: A Case of Jima District Federal Roads" is my original work. This case study has not been presented for any other university and is not at the same time as submitted in place of any other level, and that all sources of material used for the thesis have been accordingly acknowledged

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Date of submission: August, 2020

This thesis has been submitted for examination with our approval as a university advisor.

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Main advisor	signature	date
Markos Tsegaye (PhD Candidate)	_____	_____
Co- advisor	signature	date

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Firstly, praise and glory to Almighty ALLAH for best outstanding strength with health and power to complete this work.

Secondly, I would like to express my sincere thanks and appreciation to my advisor Dr.-Tamene Adugna, PhD (Ass. Professor) for his advice, patience and guidance throughout the process of completing this thesis and also, he has been devoting his precious time and providing all necessary relevant literatures and information to carry out the research.

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ABSTRACT

Pavement maintenance management system is a set of tools that helps decision-maker to determine optimum strategies for existing pavement condition by evaluation and maintenance of the pavement to reserve acceptable serviceability for the desired period. Jimma district Ethiopian Roads Authority manages the entire district pavement, currently the district road network coverage 2.23% of the whole country. Literature also indicates that most of the district roads severely suffers from lack of proper maintenance and management, there is also an absence of well-compiled inventory, condition survey data, database system, treatment selection, etc. as per the procedure of pavement maintenance management technic.

Quantitative and qualitative research of explanatory type was adopted to assess the existing practice and recommend a solution for the problems. The overall approach to be followed were; having established the basis of the research, necessary data was collected, analyzed, and conclusions and recommendations were made based on the findings. The methods of data collections employed for the research were a desk study, questioner, and interview. The case study was analyzed concerning theoretical suggestions, and the responses obtained from the questioner and interview were also be analyzed. Through interviews and questionnaire surveys of professionals; the present pavement maintenance management practice of Jimma district was assessed and responses were graded by the average index method.

The finding of this study implies that Jimma district ERA doesn't conduct adequate pavement condition evaluation (PCI, IRI, PSI, Etc.), data organization, pavement rating, prioritizing and treatment selection that can be sound input for decision-maker for the determination of optimum strategies to perform maintenance acceptable service for the desired period and maintenance options

It can be concluded that the main challenges in the district are the absence of a well-established pavement management system, well-defined maintenance prioritizing method, and treatment selection techniques. In line with this, the district does not use any data integration system apart from the absence of any economic evaluation analysis method. ERA/Jimma district shall implement giving sufficient attention to the sector, allocate adequate budget, improve the skill of professionals, and adopt a well-organized pavement management system.

Keywords: Asphalt pavement, challenges, pavement maintenance, and pavement management.

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ACRONYMS

AI	Average Index
ADT	Average Daily Traffic
ANAS	Azienda Nazionale Autonoma delle Strade/National Autonomous Roads
ASTM	American Society for Testing and Materials
BOQ	Bill of Quantity
CDs	Compact disc
CEO	Chief Executive Officer
CRS	Condition Rating Scale
DBST	Double Bituminous Surface Treatment
DED	District Engineering Division
DMI	Distance Measuring Instrument
Dtims	Deighton Transportation Infrastructure Management System
DVDs	Digital Optical Disc
E.C	Ethiopian Calendar
ECWC	Ethiopian Construction Work Corporation
ERA	Ethiopia Road Authority
ERCC	Ethiopian Road Construction Corporation
Esri	Environmental Systems Research Institute
FWD	Falling Weight Defloctometer
GIS	Geographical Information System
HDM	Highway Development and Management
IAM	Institute of Asset Management
ICT	Information Communication Technology
IDOT	Iowa Department of Transportation
IHA	Imperial Highway Authority
IPENZ	Institution of Professional Engineers New Zealand
IRI	Index of Relative Importance
ISO	International Standardization Organization
LCCA	Life Cycle Cost Analysis
LTD	Limited

M&R	Maintenance and Repair
MFV	Multi-Function Vehicle
MOFED	Ministry of Finance and Economic Development
NCHR	National Cooperative Highway Research Program
NMT	Non-Motorized Traffic
NPMS	National Pavement Management System
NZ	New Zealand
OECD	Organization for Economic Cooperation and Development
ORA	Oromia Road Authority
PASER	Pavement Surface Evaluation and Rating
PCI	Pavement Condition Index
PMMS	Pavement Maintenance Management System
PMS	Pavement Maintenance System
RAM	Road Asset Management
RAMS	Road Asset Management System
RMS	Road Asset Management System
RNMD	Road Network Management Directorate
RRAs	Regional Roads Authorities
RSDP	Road Sector Development Program
RII	Relative Importance Index
ROW	Right of Way
RSI	Relative Significance Index
RSP	Road Surface Profilometer
RWD	Rolling Weight Deflectometer
SPSS	Statistical Package for Social Sciences
TAM	Transportation Asset Management
UKPMS	United Kingdom Pavement Management System
USA	United States of America
WRO	Woreda Road Offices

CHAPTER ONE
INTRODUCTION

1.1. Back Ground

According to NCHR program report Pavement management, in its broadest sense, encompasses all the activities involved in the planning; design, construction, maintenance, and rehabilitation of the pavement portion of a public works program. A pavement management system (PMS) is a set of tools or methods that assist decision-makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. The function of a PMS is to improve the efficiency of decision-making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization[1].

The purpose of pavement maintenance management system protects government property with an economical and effective expenditure of maintenance funds commensurate with the functional requirements and the planned future use of the facilities. The majority of pavements on country installations were built many years ago, and thus, many have reached their economic design life. Because of limited maintenance funds, timely and rational determination of maintenance and repair (M&R) needs and priorities are very important factors. These factors can be determined by using PMMS. The use of pavement maintenance management system by personnel who have the responsibility for pavement maintenance should assure uniform, economical, and satisfactory surfaced area maintenance and repair[2].

In the context of Ethiopia, road is the most important infrastructure that provides access to rural and urban areas in the country. Road plays a crucial role to reduce transportation cost and support economic growth in the country. However, in the late 1990s; the road network coverage was limited to major urban areas and some rural areas. Most areas in the country were isolated from economic centers, market, and basic social services. The existing road network was largely deteriorated and in poor condition[3].

The pavement maintenance management system is a set of tools that helps decision maker to determine optimum strategies for existing pavement condition by evaluation and maintenance of the pavement to reserve an acceptable serviceability for a desired period of time[4].

Available information indicates that about 64 people die per 10,000 vehicles annually on Ethiopian roads, which is comparatively high by international standards. Furthermore, among these two (2) percent as a result of poor road conditions and the remainder is attributed to various other reasons[5]. The modern road construction era has started during the regime of Emperor Haile Selassie. Public works department was established and their major tasks were to construct roads throughout Ethiopia as well as Jimma district and to other regions. It was since 1949, that road maintenance and rehabilitation duty within ERA Jimma district was made to be the responsibility of the Roads and Building Department of the district[6].

The Ethiopian Construction Works Corporation (ECWC) is a newly established public enterprise with the authorized capital of Birr 20.3 billion; on December 18/2015 based on council of Ministers Regulation No. 366/2015. ECWC is governed by the Public Enterprises Proclamation No.25/1992. Its supervising authority is The Ministry of Public Enterprises and its policy-making body is the Board of the Corporation whose members are appointed by the government selected from different organizations. The headquarters of the corporation is located in the city of Addis Ababa, around Gured Shola. It is head by a Chief Executive Officer (CEO). The corporation is a result of the amalgamation of two formerly independent public enterprises, namely the Ethiopian Road Construction Corporation and the Ethiopian Water Works Construction Enterprise. While it is a recent phenomenon, which is established on December 18/2015, its history part of the history of the above-mentioned former enterprises and hence can be traced back to the late 1940s and early 1950s. At that time the Imperial Government of Ethiopia was convinced to establish a Road Agency solely responsible for rehabilitating/ restoring and expanding the road network throughout the country. Accordingly, in 1951 the Imperial Highway Authority (IHA) was established to plan, design, construct, and maintain roads[7].

1.2. Statement of the Problem

Roads are one of the major financial community assets and provide large benefits to the society. But, due to poor Pavement maintenance management system, many road networks are in danger. Problem of shortfall in investments all over world the maintenance of the road infrastructure and its dramatic consequences: huge deterioration of the network, higher risks of accidents, problems of congestion, increased noise and a reduced service to society. Infrastructure is ageing due to use and time. It requires maintenance, renewal and modernization, which depend on specific needs and life time of each part of the asset. An inventory stating the condition of each asset, values and maintenance needs are the basics for an effective management, for political decision making and for transparency towards the community[8].

The road network of the country is rapidly growing as new asphalt and gravel, rural roads and community roads are built by ERA, RRAS and WRO respectively. Parallel with rapid expansion of roads; maintenance need is also growing rapidly. The Road Fund Office has been collecting revenue mainly from fuel levy and other sources and allocating fund to road agencies for maintenance of roads since 1997. The revenue and allocation of the Road Fund Office has steadily been increasing every year since its establishment but has never been adequate to meet the maintenance need of the rapidly growing road network of the country. The largest problems facing the current Ethiopian road network seem to be overloading and missing maintenance and repair[9].

In Ethiopia, road maintenance is financed by the Government and administered by the Road Fund Office, established in 1997. The financing of road maintenance was stipulated in the Road Sector Development Program (RSDP) that about 26% will be contributed by road users, another 26% will be coming from regular government budget and the remaining 48% coming from the Development Partners (Office of Road Fund Administration, 2001). Nevertheless, ERA's report indicates that ***inadequate fund***, ***absence of integrated maintenance intervention measure and lack of comprehensive approach*** are noticed as the major problems in road maintenance activities in Ethiopia[10].

In fact, the gap between maintenance need of the road network and allocation of fund has been widening from year to year and as a consequence more and more roads left without maintenance every year. Unless the worsening of shortage of fund; maintenance of roads is addressed as early as possible. Otherwise, deterioration of road infrastructure will get even worse and worse[9]. In general, major problems are absence of well compiled inventory and condition survey data, database system, treatment selection techniques etc. as per procedure of pavement maintenance management system requirements in the district.

However, in our country Ethiopia as well as in Jimma district pavement maintenance management does not implemented in full capacity in allocating sufficient fund for maintenance, assisting professionals on pavement maintenance and management to predict future economic, technical, social and environmental outcome of possible investment decisions concerning maintenance management of pavements.

These researches assessed mainly existing challenges of Asphalt road pavement maintenance management system in the district (ERA) and recommended a solution by focusing only on its availability and extent of implementation.

1.3. Research Questions

1. What are the characteristics of existing Asphalt pavement maintenance management system in Jimma district federal road?
2. What are the common problems of Asphalt pavement maintenance management system in the district?
3. What are the main factors that affect Asphalt pavement maintenance management practice in the district?
4. What are the basic approaches for improving Asphalt pavement maintenance management system for the identified problems?

1.4. Objectives of the Study

1.4.1. General Objectives

The general objective of study is to asses challenges of Asphalt pavement maintenance management system in federal road, Jimma district

1.4.2. Specific Objectives

i. To study the characteristics of Asphalt pavement maintenance management system in Jimma district federal road.
ii. To identify the common problems in Asphalt pavement maintenance management system in the district.
iii. To identify the main factors that affect Asphalt pavement maintenance management system in the district.
iv. To suggest remedial measures to improve the existing condition of the Asphalt PMMS of Jimma district federal t road .

1.5. Significance of the Study

The study significantly assists the pavement maintenance management system that could effectively and efficiently be used by financing and budget allocator offices under the district.

Governmental organizations, ERA, decision-makers will be able to utilize the results of the study in which the impact of challenges on PMMS values is used for preliminary budget allocation purposes. It also helps them to prepare a detailed scheme for further PMMS depending on the scope of the anticipated road network.

1.6. Scope of the Study

The scope of the study was limited to the federal Asphalt road network under the Jimma district. The existing practice Pavement Maintenance Management System was assessed using archive data, questionnaire, and interviews.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

Pavement maintenance work is performed from time to time to keep a pavement, under normal conditions of traffic and forces of nature, as nearly as possible in its as-constructed condition. It is the art of keeping pavements in full service, with minimum expenses, and the least inconvenience to the public and the residence. Improper maintenance is usually worse than none at all. No pavement has been constructed that does not need maintenance. Many community associations find out too late that proper maintenance could have prevented costly replacements. The purpose of maintenance is to ensure that the road remains serviceable throughout its design life. Maintenance is important because of it; prolongs the life of the road by reducing the rate of deterioration, there by safe guarding previous investments in construction and rehabilitation, lowers the cost of user on the road by providing a smooth-running surface, keeps the road open for traffic and contributes to more reliable transport services, sustains social and economic benefits of improved road access[6].

Road infrastructure is a major, but not the only, constraint on market access. The national road network increases four-fold in size from 1997 to 2015, but the road density in Ethiopia remains the lowest in Africa. Cross-country regressions predict that the best policy for growth going forward is continued infrastructure investments to address this deficit. Ethiopia's infrastructure deficit remains one of the largest in the world[11]. The developing world, and especially the African continent, has a very poorly developed infrastructure, compared to middle- and high-income countries. On average, Sub-Saharan Africa has a road density of only approximately 200 meters of paved roads per km2 compared to 1400 meters in high-income OECD countries. Ethiopia is a land locked country where the major share of passenger and freight movement is by means of road transport and where the transport network is recognized as a major bottleneck. As the government of Ethiopia cognized the role played by road infrastructure in economic development and poverty reduction, the country has undergone rapid expansion in road infrastructure since 1997 as the result of the Road Sector Development Program (RSDP). Massive amount of capital has been invested by the government with the support of

international donors for the provision of all-weather roads that improve regional connectivity[12].

Road maintenance must be planned, managed, design and executed. Planning and management are done by means of maintenance management systems and procedures. These system and procedures are normally different from a pavement and bridge management systems since it does not focus on long term and strategic repair and upgrading issues. Relevant pavement and bridge can be identified for protective and preventive actions as part of a road maintenance program. On time maintenance is extremely important. From the moment that a road is constructed or upgraded, it will deteriorate due to the effects of weather and traffic. Maintenance is required to be carried out from time to time to restore its condition to be close to its as constructed state. If maintenance is not carried out the road will continue to deteriorate making passage increasingly difficult, uncomfortable and expensive to road users. The road may even become impassable for part or all of the year. It is convenient to view Maintenance as Correcting Defects. In practical terms it is useful to identify and quantify the defects, and then arrange the necessary maintenance to be carried out. [13].

2.2. Asset Management

Asset management enables the realization of values from the physical assets[14]. It is a complex paradigm, requiring stakeholder's consensus on the values, policies, strategies and tactics, which are related to the infrastructure services, performance metrics, and associated management trade-offs[15]. Pointed out that asset management is the profession of balancing cost, performance and risk over the life cycle of an asset. However, the Institute of Asset Management (IAM) defines asset management as "the coordinated activities of an organization to realize values from the controlled assets". This definition is expanded further as a discipline where in an organization can use its principles and concepts to raise the value of the assets by balancing costs, opportunities and risks against the desired performance of the assets. Asset management has been practiced for thousands of years and researched for decades; however, there is no common understanding of what it is. Consequently, asset management is a relatively emergent discipline and there is limited literature, particularly in relation to transport infrastructure[16].

2.2.1. Asset management in infrastructure

Due to the economic crisis in 2008, many agencies and local councils were under huge pressure to satisfy expectations of the public in terms of reliability, safety and availability of the infrastructure networks under reduced financial constraints[17]. Asset management has emerged as an approach which can help to achieve more value with fewer resources[16]. The performance of public infrastructures has a strong influence on the economic viability and social development of nations. To overcome these issues, the agencies are seeking new actions and processes to manage their physical assets more effectively and efficiently.

Road asset management is based on an analysis of road data related to inventory, condition, traffic, unit costs, and road deterioration models. The data is entered into a Road Asset Management System (RAMS) that allows the data to be analyzed, and optimal budget levels and allocations to be determined. However, road asset management is more than just the RAMS, and includes the integration of the RAMS into the wider context of structures and procedures within which it operates, complementing the economic optimization criteria of the RAMS with other policy objectives (connectivity, accessibility, road safety) [18].

A RAMS generally involves a computerized road asset management system, encompassing data collection, data management (database), and data analysis.

•**Data collection**. Involves carrying out surveys and collecting data on the road network Includes data that continuously changes and needs to be updated regularly (road condition, traffic) and data that hardly ever changes (road alignment, topography, surface type).

•**Data management.** Generally, involves a database that brings all the collected data together and makes it readily available for planning and monitoring. May include simple textual or numerical data (road name, road length), and global positioning system (GPS)-related data (alignment, road condition) or multimedia files.

•**Data analysis**. Involves analysis of the collected data to determine the optimal level of required funding and allocation of that funding to different roads and to different types of

interventions often looks only at pavements, but may also include bridges, other structures, road furniture and road service stations.

The term road asset management will, therefore, have a wider focus, including the integration of the RAMS into the institutional framework, road network planning and programming systems, road sector financing and budget allocation procedures, and implementation of road repair and maintenance[18].

2.2.2. Asset management in highway maintenance

Applying asset management principles to highway maintenance is not a new practice. There are a number of research case studies exploring its adoption in Japan, the United States and the Netherlands[18]. It has also been adopted by some highway authorities in the UK but there have been wide ranging approaches to its implementation. Within the existing literature, the use of asset management in a highway maintenance context is often referred to as Transportation Asset Management (TAM) [16]. Figure (2.1) shows a typical Highway Asset Management System in which it includes an Information system, asset data and institutional data where they are all gathered in a common database and formed a decision support system through the analysis process[19].

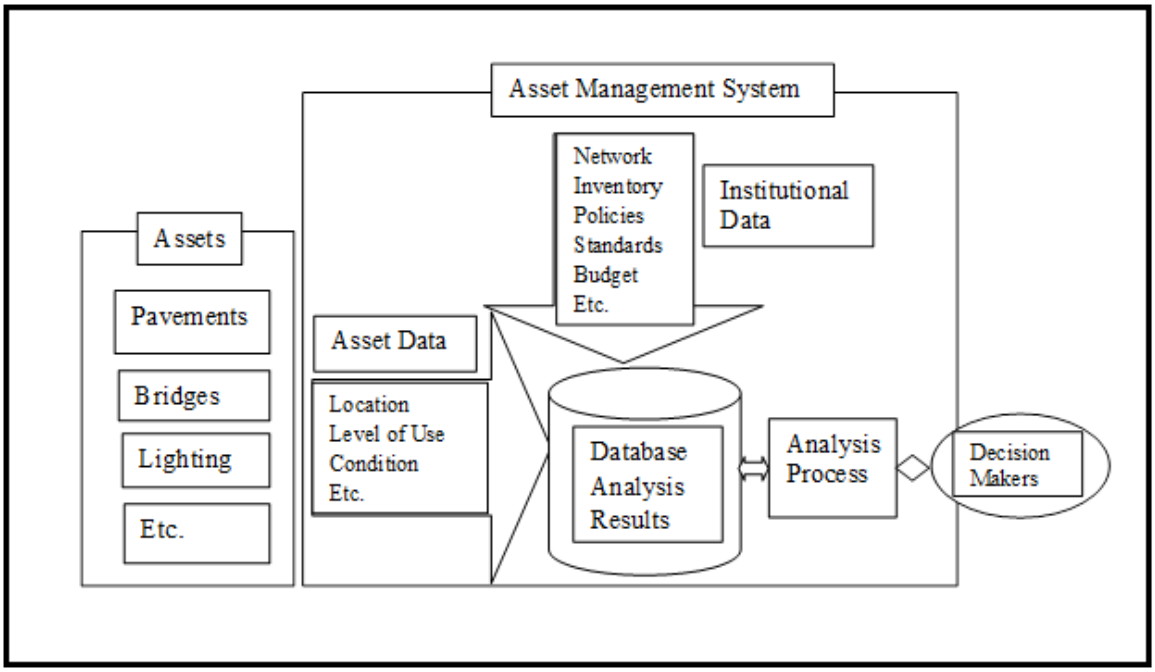

Figure 2.1. A Typical High way Asset Management System [19].

2.3. Pavement Maintenance Management System Definition

Maintenance management and pavement management concepts are two complementary ideas. They reinforce and supplement each other rather than interfere. Pavement maintenance management is, thus, a necessary tool for analyzing and predicting the effects of various maintenance policies.[20] A PMMS can be defined as a systematic methodology to assist in making decisions to provide, evaluate and maintain pavements in an acceptable condition. Its objective is to facilitate the coordination of activities and assess the consequences of decisions in a consistent manner, in order to preserve pavements in the best possible condition with available funds[19].

2.3.1 Pavement management system

The pavement management concept was first conceived of in the mid-1960s to organize and coordinate the activities involved in achieving the best value possible with the available funds. In response to the growing need for highway rehabilitation and maintenance on the one hand and shrinking resources on the other, there has been an increased interest in developing a formal management approach to optimize the utilization of highway construction and maintenance resources. The specific component of this approach related to pavement is termed ‘‘pavement management system’’ [21].

A PMS has been defined as a “set of tools or methods that can assist decision makers in finding cost effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition” [22]. A PMS is a tool that transportation agencies utilize to maintain roadways PMS’S contains specific tools/methods that allow agency decision makers to develop a strategy for maintaining roadway assets. Specifically, a successful PMS must include a dependable pavement inventory along with roadway condition information. This information aids transportation agents by helping to identify, prioritize maintenance needs as well as the necessary rehabilitation needs for a section of roadway. Understanding and utilizing this information allows for agents to have an idea of what the costs for maintenance would be as well as any limits that may be present in a specific location of a roadway. This is extremely important as the information noted above, as it allows for the most cost-effective maintenance method and rehabilitation needs for a roadway. This means that agencies are effectively making decisions and are working efficiently[23].

Pavement management is a systematic approach to forecasting pavement M&R requirements and then optimizing and prioritizing available M&R funding. As shown in Figure 2.2, the primary objective of pavement management is to preserve pavements in good condition rather than wait for them to fail and then reconstruct them[24].

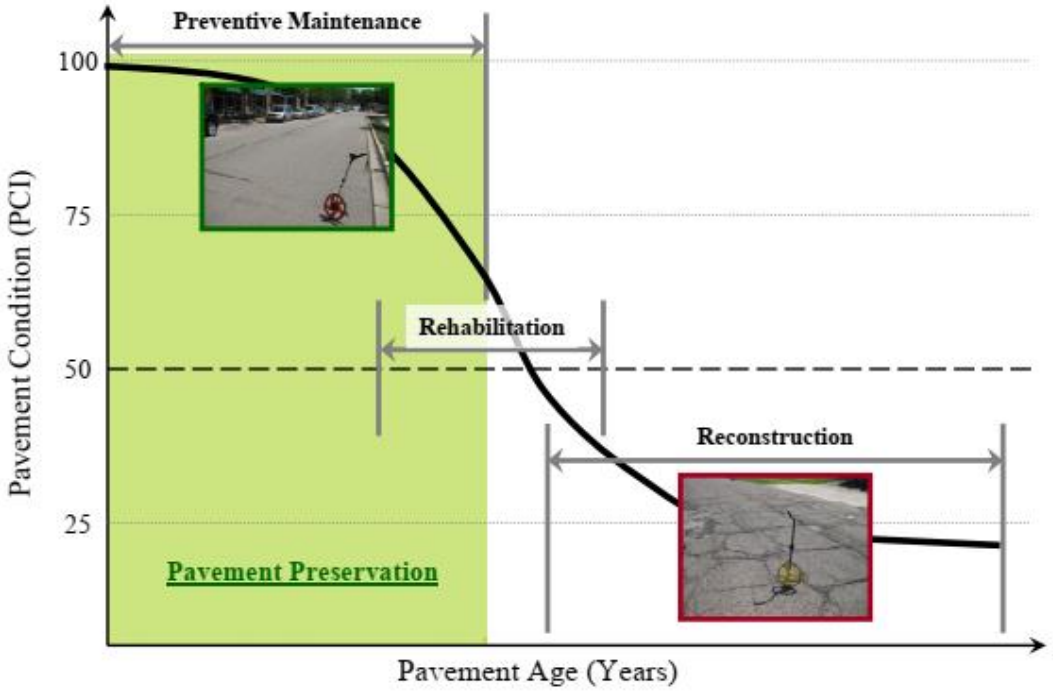

Figure 2.2. Pavement Preservation [24].

When the appropriate preventive M&R treatments (e.g., crack sealing, seal coats, etc.) are applied at the correct times during a pavement's service life, these relatively inexpensive preventive M&R treatments can cost-effectively extend the service life of the pavement[24].

2.3.2. Use of Pavement Management System

With an understanding of the database, an examination of the typical uses of a PMS can be undertaken. The following material briefly describes the main areas where a PMS is applied and the benefits achieved from each[25].

(a) Street Inventory

The most immediate use of the PMS is in having a complete and readily accessible inventory of country's road system including up-to-date conditions. This information is frequently very valuable for day-to-day use in tracking maintenance work and for reference in preparing reports or studies.

(b) Developing Maintenance Budgets

Rather than preparing the typical 1-year maintenance budget, a PMS allows a country to prepare a series of budgets. These budgets can be in the form of a multi-year program, identifying not only short-term (1 year) needs, but outlining needs over the course of many years. Further, alternatives can be prepared and presented to the budget decision makers.

(c) Prioritization

A PMS allows for the prioritization of maintenance projects based on cost and condition ratings and other factors such as traffic. It further can be used for selecting and ranking of projects for the upcoming budget year, as well as for long term financial planning.

2.3.3. Types of Maintenance Management System

There are two types of maintenance management system, the first one is the ***information system***, which collects, organizes and stores data as network information. The second type is the ***decision-support systems***, which comprises applications modules to process the data and provide the information on which decisions can be based, and ultimately implemented[26]. The system has four stages, ***planning; programming; preparation; and operations***. The planning stage of the decision-support system is undertaken to develop long-term and strategic plans for the roadway network as a whole; planning time is typically of five years or more undertaken to determine future budget needs, consequential pavement conditions, and user costs[4].

Pavements Maintenance Management Systems consist mainly of two major components

1. ***An information system*** to collect, store and manage data and information. It could be able to treat inventory data of the pavement segments, condition data, like distress surveys, and traffic data including ADT and heavy traffic axle loading.

2. ***Decision support systems*** to process the data and information for decision making. They include pavement condition, pavement performance, investment and engineering analysis.

The scope and definition of a pavement management varies from one system to another and from one road agency to another. Generally, it includes the following elements for. Project-level management and Network-level management:[19].

a) Location Reference System.

b) Sectioning of Network.

c) Database.

d) Data Acquisition.

e) Pavement Evaluation.

f) Pavement Performance Prediction.

g) Maintenance and Rehabilitation Planning.

h) Prioritization and Optimization.

Elements (a) to (e) constitute the information system and elements (f) to (h) constitute the Project-level management is concerned with selecting the most appropriate and cost-effective alternative for an individual section of the road. The process is similar for both selecting the initial design and the maintenance and rehabilitation treatment for the road without any consideration of other roads in the network. Network-level management involves the assessment of needs and making decisions for funding the entire network[19].

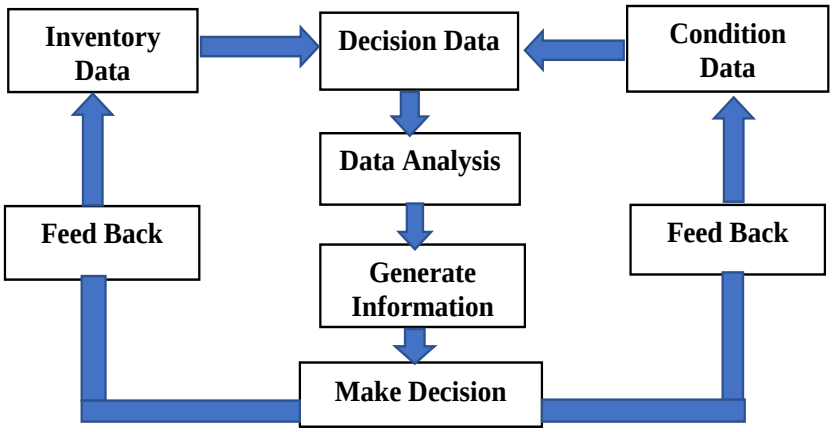

Figure 2.3. Components of PMMS [19]

2.3.4. Levels of Pavement Management System

It is convenient to describe pavement management in terms of two generalized levels: (1) **Network management level**, sometimes called the program level, where key administrative decisions that affect programs for road networks are made, and

(2) **Project management level** where technical management decisions are made for specific projects. Historically, most formal pavement management system development has occurred at the project level. More recently, extensive development in maintenance management and data management methodologies has added to the pressure for development of a total pavement management system; one where all activities are included and explicitly interfaced with each other.

Pavement management systems can provide several benefits for highway agencies at both the network and project levels. Foremost among these is the selection of cost-effective alternatives. Whether new construction, rehabilitation, or maintenance is concerned, a total PMS can help management achieve the best possible value for the public money.

At the network level, the management system provides information pertinent to the development of a statewide or agency wide program of new construction, maintenance, or rehabilitation that will optimize the use of available resources.

Considering the needs of the network as a whole, a total PMS provides a comparison of the benefits 'and costs for several alternative programs, making it possible to identify that program which will have the least total cost, or greatest benefit, over the selected analysis period.

At the project level, detailed consideration is given to alternative design, construction, maintenance, or rehabilitation activities for a particular section or project within the overall program. Here again, by comparing the benefits and costs associated with several alternative activities, an optimum strategy, is identified that will provide the desired benefits or service levels at the least total cost over the analysis period.

At any management level, a cost-benefit comparison may be listed for each strategy considered, providing documentary evidence to support the value of proposed activities[1]. All of the activities at both the project and the network level require data that defines the material properties, loads, environment, behavior, distress, and actual performance. The data must be stored in a central data base and be accessible to the entire pavement management process as illustrated in Figure 2.4 [27].

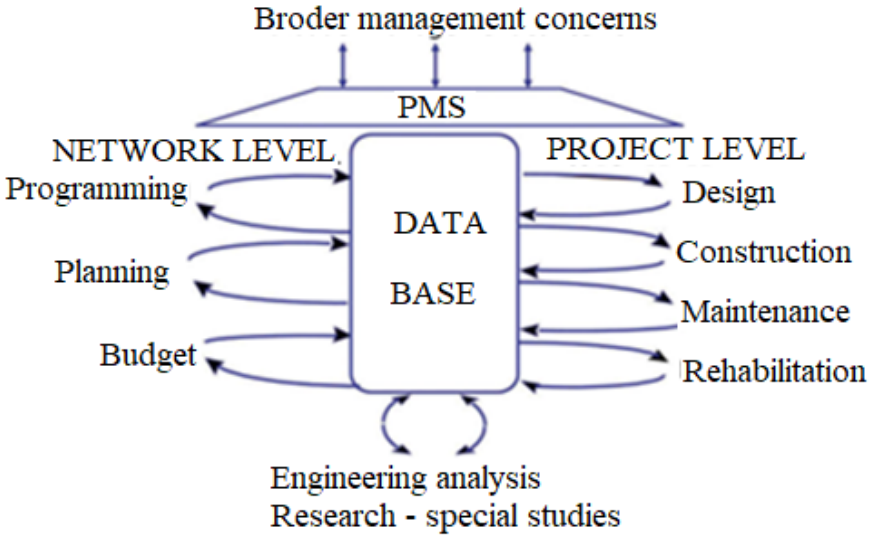

Figure 2.4. Components of a PMS, distinguishing the three level [27].

2.3.5. Pavement Maintenance Management System Requirements

The presentation of Pavement maintenance management System requirements may be conducted through different approaches, the first approach is need analysis, which involves developing maintenance and rehabilitation schedules for pavement being managed. It required that appropriate maintenance activities be selected for each pavement section based on predicted pavement performance. Budget constraints are considered during the development of need analysis so the maintenance activities must be prioritized. The output is a list of annual or semi-annual prioritized maintenance project with cost. The second approach is the impact analysis, which involves comparing different maintenance plans to determine the impact that different decisions will have on the pavement network. By assessing condition trends over time, the road department can quickly determine whether the overall health of the network is improving or deteriorating under certain funding level [4].

2.4. Designing a Pavement Management Process

The development of a systematic and repeatable pavement management process is a key component in the effective planning and management of a pavement network. The steps outlined below serve as a Guide for customizing a pavement management process that fits the needs of each local agency. Prior to starting the implementation process, it is recommended that agencies consider naming a champion and forming a steering committee to work as a group in establishing a process to meet the needs of the agency.

For larger agencies involving a number of staff from all levels and a variety of divisions within the organization helps shape the management process to meet the needs of all potential users in the organization.[28]

Step 1: Define the Roadway Network and Collect Inventory Data

Step 2: Collecting Condition Data

Step 3: Predict Condition

Step 4: Select Treatments

Step 5: Report Results

Step 6: Select Pavement Management Tool

Step 7: Keep the Process Current [28].

2.4.1. Define the Roadway Network and Collect Inventory Data

The first step in designing a pavement management process is to define the roadway network. A roadway network is comprised of an inventory of the physical characteristics of the roadways being managed by the agency. After segments are defined in a manner that best fits the needs of the given agency, the inventory information for each segment is collected by either estimating the data or collecting all needed information. The exact type of inventory information required by an agency depends on what data will be used by the agency to support its decisions.[28]

Factors that may define the boundary between roadway segments include changes in the following attributes:

- Pavement surface type, Pavement structure, Construction history, Roadway geometry, Traffic, Pavement condition and Geographic boundaries

After segments are defined in a manner that best fits the needs of the given agency, the inventory information for each segment is collected. Typical inventory data collected for a pavement management system includes:

- Roadway, Pavement Location, Pavement Dimensions, Pavement Type and Construction History

The data outlined above serves as the minimum amount of data needed to complete the segment inventory. Additional data that may be beneficial to the agency to support the pavement management processes includes, but is not limited to:

- Functional Classifications, Layer Thicknesses, Sub grade Information, Drainage Characteristics, Ownership information, Shoulder Data and Traffic Information

The desired inventory data is summarized for each pavement segment defined in the network. While some inventory data require updates with time, information such as names, location, and dimensions do not normally require modifications unless changes have been made to the network. Compiled inventory information can be stored a variety of ways:

- Paper records, Electronic spreadsheets, Databases and Maps (GIS-based maps)[28].

2.4.2. Collecting Condition Data

Pavement condition data are a major factor in any data-driven, decision-making pavement management process. Within the pavement management process, the condition data can be used to help identify current maintenance and rehabilitation needs, to predict future needs, and to assess the overall impact on the network. Therefore, the type of condition data required and the level of detail depends on the agency and the pavement management process used. Condition data will be collected using either manual or automated data collection methods. With either method, distress data will be estimated or measured[29].

When selecting a condition data collection method, there are two main considerations:

- **Data quantity** – Data quantity refers to what and how much information is collected. Both have time and cost implications since the greater the volume of data collected or the more detailed the collected data, the higher the cost of data collection.

- **Data quality** - Although the associated cost of the data increases, more detailed data for analysis can result in better analysis decisions. For most agencies, the goals for network-level surveys are to develop appropriate budgetary needs and to evaluate the performance of previously implemented strategies.

The main source of information to support pavement management is pavement distress data, such as cracking, potholes, and rutting. For those agencies with expanded resources for condition data collection, additional data related to surface characteristics, subsurface characteristics, and structural conditions might also be collected[29].

Distress Survey Approaches

There are a variety of methods available for determining distress quantities; the methods typically involve surveys that focus on either an estimate of distress or a detailed measurement of distress. Although many variations among these methodologies exist, several examples are presented to illustrate the range of complexities in terms of the survey procedures and methodologies used in PMS.

A - Surveys Based on Estimated Distresses

When distresses are estimated during surveys, the distress severity and quantity information is determined without direct measures. A survey based on estimated distress is the Pavement Surface Evaluation and Rating (PASER) rating procedure, which involves visually rating the surface condition of a pavement on a scale from 1 to 10, with 1 indicating a pavement in failed condition and 10 being a pavement in excellent condition as shown in table 2.1 below[29].

Table 2.1. PASER ratings related to maintenance and repair strategies.[29]

PASER Rating	General Description of Maintenance/Repair Needs
9 & 10	No maintenance required
8	Little or no maintenance
7	Routine maintenance, crack sealing and minor patching
5 & 6	Preservative treatments (seal coating)
3 & 4	Structural improvements and leveling (overlay or recycle)
1 & 2	Reconstruction

A summary of the ratings is provided below (IDOT 2004):

- Poor ($1.0 \leq CRS \leq 4.5$). The pavement is critically deficient and in need of immediate improvement.
- Fair ($4.6 \leq CRS \leq 6.0$). The pavement is approaching a condition that will likely necessitate improvement over the short term.
- Satisfactory ($6.1 \leq CRS \leq 7.5$). The pavement is inacceptable condition (low end) to good condition (high end) and not in need of improvement.
- Excellent ($7.6 \leq CRS \leq 9.0$). The pavement is in excellent condition

B - Surveys Based on Measured Distresses

Pavement condition index

The pavement condition index (PCI) survey is an example of a detailed survey method. It was developed by the U.S. Army Corps of Engineers, adopted by the American Public Works Association and ASTM International (formerly the American Society for Testing and Materials), and documented in ASTM D6433, Standard Test Method for Roads and Parking Lots Pavement Condition Index Surveys. The PCI methodology is a rating system that measures the pavement integrity and surface operational condition based on a 100-point rating scale, as shown in figure 2.5[30].

Present Serviceability Index (PSI)

The Present Serviceability Index Concept was first presented by Carey and Irick. It is based upon the concept of correlating user opinions with measurements of road roughness (as measured by the rough meter or profilometer), cracking, patching and rutting. Pavements were rated on a scale runs from 0 to 5 as shown below in figure 2.5,[6].

Where:

- 0 – 1 indicated a pavement in a very poor condition,
- 1 – 2 was a poor condition,
- 2 – 3 was fair,
- 3 – 4 was good and
- 4 – 5 was very good.

The average of the rating numbers for each section was termed the Present Serviceability Rating (PSR). The original serviceability equation for flexible pavements as developed on the AASHTO Road Test is shown below:

$$\mathbf{PSI = 5.03 - 1.9\ Log\ (1+SV) - 0.01}\left(\sqrt{\mathbf{C + p - 1.3\ RD^2}}\right) \text{..... [Eq.2-1]}$$

Where:

- PSI = Present Serviceability Index (Pt)
- SV = Mean slope variance. (Measured by Slope Profilometer Instrument)
  - Assesses Surface irregularity
- C = Linear feet of major cracking per 1000 ft^2 area
- P = Bituminous patching in ft^2 per 1000 ft^2 area
- RD = Rut Depth in inches (both wheel tracks) measured with a 4 ft straight edge[6].

Figure 2.5. Pavement Condition Categories [29].

2.4.3. Predict Condition

With current pavement condition assessed, agencies are equipped with the information needed to predict the future condition of a segment. In pavement management, conditions are predicted in terms of performance models that estimate the average rate of pavement deterioration each year. In addition to forecasting future conditions, performance models assist with the following activities[26].

- Identifying the appropriate timing for pavement maintenance and rehabilitation for each segment
- Identifying the most cost-effective treatment strategy for pavement segments in the network.
- Estimating pavement needs and associated budgets required addressing agency specified goals, objectives, and constraints.
- Demonstrating the consequences of different pavement investment strategies.

If an agency wants to develop multi-year pavement maintenance and repair program, it needs to project pavement condition into the future. Prediction models are used to determine the future condition of a pavement segment. A performance curve is calculated by evaluating past historical data often in terms of pavement age and condition. The models can be produced for any measure of condition according to agency need[28].

Average Rates of Deterioration

Using the collected condition information, deterioration rates can be estimated for pavement sections using the following equation:

$$\text{Deterioration Rate} = \left(\frac{\text{Past Rating} - \text{CurrentRating}}{\text{Number of Years between Ratings}}\right) \quad \text{..... [Eq.2-2]}$$

An agency can also calculate the deterioration rate for groups of pavement segments using average conditions and pavement ages in the above equation to estimate an average deterioration rate for the pavement family.

Prediction Models using Statistical Analysis

The development of prediction models using statistical analysis is a more complex activity than creating average rates of deterioration. There are a variety of approaches that can be used to develop prediction models. Often agencies accomplish the creation of these models within the pavement management software they utilize. For example, those agencies that use The Micro PAVER software developed by the U.S. Army Corps of Engineers develop performance prediction models using a general procedure called the Family Method. The method consists of the following steps [31].

- Define the pavement family, Filter the data, Conduct data outlier analysis. Develop the family model and Predict the pavement section condition.

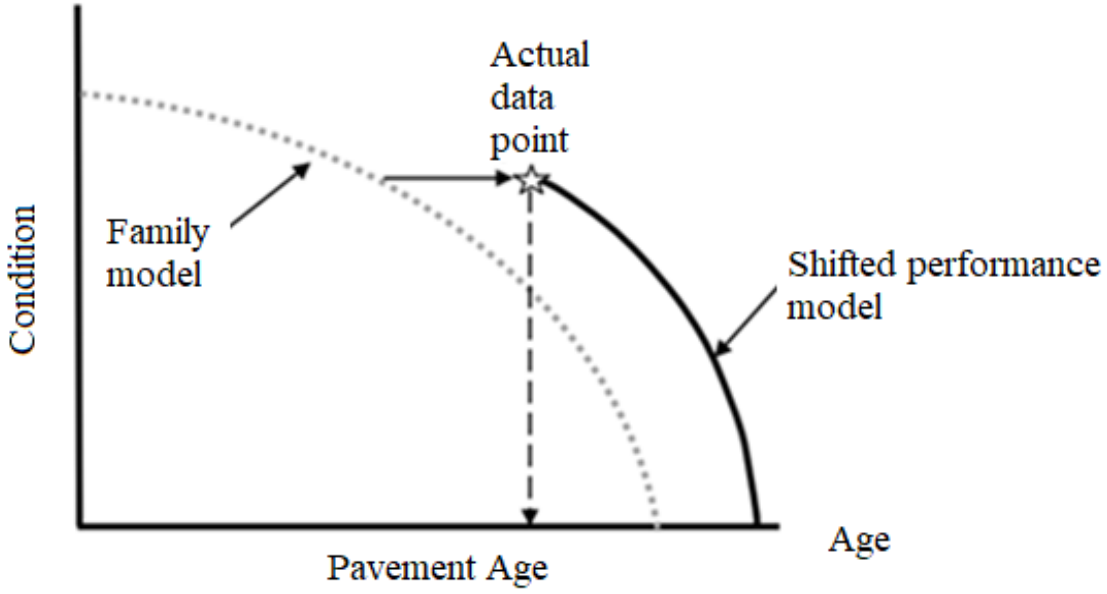

Figure 2.6. Pavement segment prediction in relation to a family model [31]

Example family and segment performance prediction curves are shown in figure 2.6. Various agencies have created statistically developed performance models using other pavement management software and spreadsheet tools[28].

2.4.4. Select Treatments

The fourth step in designing the pavement management process is to select appropriate treatments for the roadway network. Treatments are selected using cyclical schedules or treatment trigger rules. The recommended treatments are then prioritized using ranking or benefit/cost analysis.

Factors that should be considered in the process of selecting an appropriate treatment for the pavement included pavement age, pavement condition, traffic levels, expected future plans, as well as available funding and agency policy. At the network level, a general relationship exists between pavement condition and pavement age. For a properly constructed new pavement, the only treatments that are required are preventive maintenance (maintenance performed to delay the onset of distress). Then, as the pavement ages, it may become a candidate for routine maintenance (crack sealing or chip sealing), rehabilitation and eventually reconstruction. The first step in selecting the

appropriate maintenance treatment is determining, based on the life cycle and pavement condition index of the existing pavement[6].

The selection of treatments is based on the agency's defined maintenance and rehabilitation strategy, which is created by selecting trigger values to identify segments needing repair. Trigger values are thresholds that can be used to signify the need for various treatments to be applied to pavement segments. For example, pavement age, pavement surface condition, or traffic can be used as a factor to determine the eligibility of a pavement for repair. The selection of a treatment can be based on either a cyclical selection or the creation of treatment rules[28].

I - Cyclical Treatment Selection

One method of selecting a treatment for a pavement segment is through a cyclical method of applying a treatment to given pavement sections. Many agencies select maintenance strategies based on pavement age. These treatments are then repeated at specific time intervals. For example, an agency may choose to chip seal all pavements on a 7-year cycle. The agency can then divide the pavement network into seven regions and cycle through the regions every 7 years.

The placement of the treatment increases the pavement life and, if applied at the correct time, can prolong the life of the pavement. However, the timing of such a treatment is critical to its performance and overall cost-effectiveness. Therefore, it is difficult to achieve the most effective treatment timing using cyclical treatment selection as the cyclical placement is regimented and does not allow for flexibility in addressing the placement of the treatment at the right time for each pavement segment independently.

II - Treatment Rules

In addition to the creation of cyclical treatment triggers, another method of treatment selection is the use of treatment rules that are developed into a matrix or a decision tree. To develop treatment rules, an agency needs to define its treatment strategy. That is, select treatments that will be applied at specific condition levels for pavements with specific inventories. Different forms of treatment rules can be developed, including decision trees for selecting treatments for the roadway segments and an example treatment matrix is shown in figure 2.7. This matrix is used by Champaign County to

select an appropriate treatment and determine the overall needs of the pavement network based on collected surface and estimated structural condition information in the form of PCI and Rolling Weight Deflectometer (RWD) deflections, respectively[28].

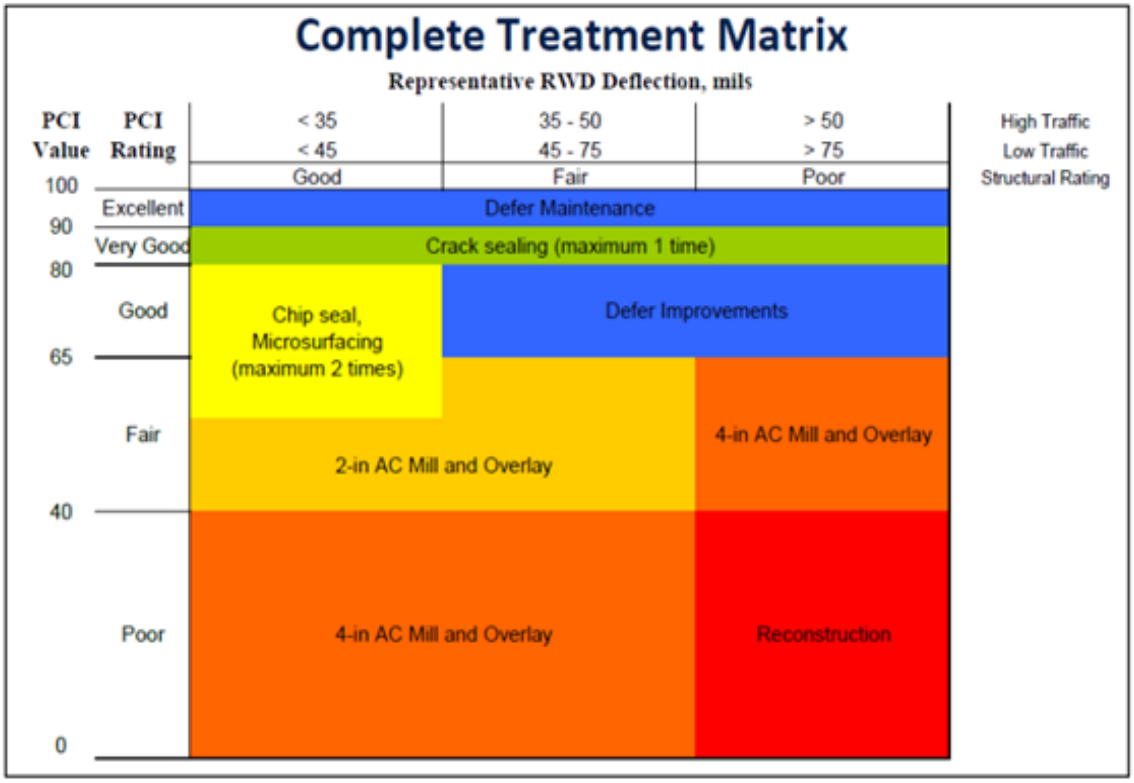

Figure 2.7. Champaign County treatment matrix[28]

Once an appropriate maintenance strategy has been chosen, a specific treatment is selected to address the specific distress mechanism for the pavement.

Remedial measures for different types of distress severity are shown in Table 2.2. As an example, rutting distress requires shallow patching when its severity is medium but deep patching is required when it is high.

Table 2.2. Remedial Measures for Different Types of Distress Severity[6]

ID	Distress Type	Distress Severity Level		
		Low	Medium	High
1	Alligator Cracking	X3	X1	X1
2	Block Cracking	X3	X3	X3
3	Edge Cracking	X3	X3	X1
4	Reflection Cracking	X3	X3	X1
5	Slippage Cracking	X1	X1	X1
6	Longitudinal and Transverse Cracking	X3	X3	X1
7	Corrugation and Shoving		X1	X1
8	Depression		X2	X2
9	Rutting		X1	X2
10	Welling		X2	X2
11	Utility Cut Patching		X1	X1
12	Potholes	X1	X1	X2
13	Raveling		X4	X4
14	Bleeding		X5	X5
X1 = Shallow Patching X2 = Deep Patching X3 = Sealing		X4 = Overlaying X5 = Spreading and rolling fine gravel aggregate		

Table 2.3 shows the suggested pavement maintenance treatment according to the PCI condition evaluation of the network segments. When PCI of a segment ranges between 70 and 100 (condition is excellent or very good), routine maintenance including small patching and crack sealing is required while the reconstruction is needed for segments of failed or very poor condition[6].

Table 2.3. Suggested Pavement Maintenance Treatment versus PCI Ranges[6]

PCI Range	Pavement Condition	Condition Class	Suggested Maintenance
70 – 100	Excellent/Very good	**I**	Routine Maintenance (RM)
55 – 70	Good/without effect of loads	**II**	Routine Maintenance (RM)Very
55 – 70	Good/with effect of loads	**III**	Thin Asphalt Overlay layer (AO1)
25 – 55	Fair /Poor	**IV**	Double Asphalt Overlay layer (AO2)
0 – 25	Very poor/Failed	**V**	Reconstruction (RC)

III - Ranking

Project priorities can be selected using a ranking of projects based on some type of agency priority, such as pavement condition, functional classification, and/or traffic levels as described in this section or by using benefit/cost analysis.

Ranking is the simplest method of selecting projects and normally results in a yearly evaluation of selected projects. One method of using the ranking approach is to fix the pavements in the worst condition first. However, this "worst-first" approach does not help maintain those pavements that are in good condition and can lead an agency into a costly cycle that does not provide any funding for the preservation of pavements. If an agency decides to use a ranking technique, it generally follows the steps listed below.[28]

- Assess needs for a given year by identifying all pavement sections that are not in excellent condition.
- Calculate treatment costs by multiplying the cost of the appropriate treatment for each level of repair times the project area.
- Sort the needs in priority order using the ranking methodology established by the agency. For a worst-first strategy, the road sections in worst condition would be the highest priority.
- Select projects in accordance with the prioritized listing until there is no funding left for that year.
- Consider any remaining unfunded needs in the next year and repeat the process.

As an example, for maintenance prioritization, the following formula was developed by [19]for priority ranking index:

$$PI = \left(\frac{1}{PCI}\right) * TF * FC * MF * SR \ldots\ldots\ldots \textbf{[Eq.2-3]}$$

Where: PI = Priority Index.

TF = Traffic Exposure Factor.

FC = Road Classification Factor.

MF = Maintenance History Factor.

SR = Special Factor to emphasize Priority of Specially Designated Routs.

A larger PCI value indicates better road condition and hence lower priority ranking number for improvement. Thus, the priority ranking system will indicate needs for

maintenance as a function of PCI in a descending order, while the other factors modify the priority ranking index. In South Dakota Department of Transportation in USA, the priority ranking depends on ten factors. These factors are contributed to a percentage to the priority ranking number as follows:

Surface Condition	25%	Surface Thickness	5 %	Current Truck Traffic	3 %
Ride ability	23%	Surface Maintenance	5 %	Friction	3 % [19].
Remaining Surface Life	22%	Roadway Strength	4 %		
Drainage Adequacy	7%	Current Traffic	3 %		

A benefit/cost analysis allows an agency to work at prioritizing, or even optimizing, the choice of treatments on a multi-year period. This approach is preferred over a ranking approach because multiple treatments are considered, consequences of delaying or accelerating a treatment are evaluated, and the cost-effectiveness of a treatment is taken into account in developing the program recommendations[26].

The benefits of the treatment, which are normally represented as the increase in pavement condition, are divided by the construction cost to determine the benefit/cost ratios, as shown in figure 2.8. Therefore, the longer the pavement stays in good condition, the more benefit will be accrued by the user and the higher the benefit/cost ratio. Those projects which provide the greatest benefit for the funds expended are considered the best choices.

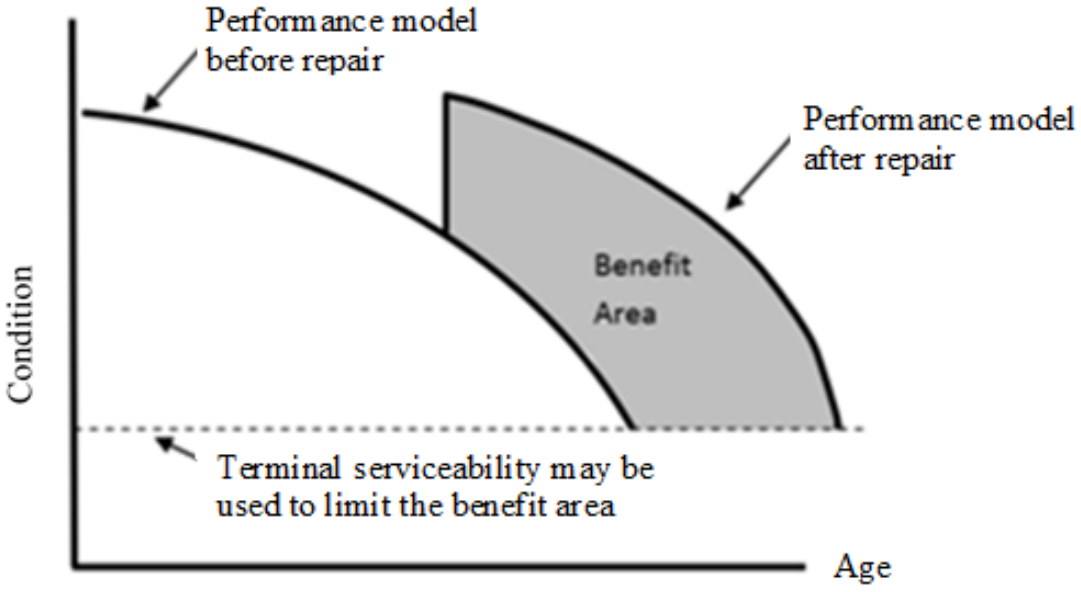

Figure 2.8. Benefit determination using performance curves [26]

IV - Selecting Appropriate Methodology

To help identify the most appropriate treatment for each project, agencies may choose to use either a cyclical schedule or treatment rules. Cyclical timing works well for agencies that utilize a spreadsheet to manage the pavement network, whereas the creation of treatment rules, while possible within a spreadsheet, can be cumbersome. Treatment rules are easily created within public and private pavement management software.

After treatments are determined they then must determine the prioritization of the projects since most agencies have more needs than available funding. Agencies can choose to prioritize projects based on ranking or through benefit/cost analysis. Benefit/cost analysis is best conducted inside a PMS, while ranking can be easily accomplished in a spreadsheet tool. The results of the treatment selection step provide final work plan recommendations for the agency[28].

2.4.5. Report Results

Project results can be reported using different methods to highlight important factors which will assist decision makers with their final decisions. Data reporting is an effective method of communicating not only the recommendations from the pavement management process but also transferring related information to decision makers. The data can be used to generate reports and charts to extract relevant information pertaining to any segments under consideration. The results can be presented either by using ***standard*** charts and reports or ***customized*** summaries. The reporting of project results is the fifth step in the implementation process, in which the results of data analysis are presented. The findings can be reported using different methods to highlight important factors, which will assist decision makers in making various decisions[28].

Standard Reports

Typically, analyzed data can be represented in the form of standard reports and charts that are available from various pavement management software programs or from spreadsheets. The pavement management process tool provides a platform to utilize the results of an analysis and generate different types of reports, such as work history information, section information, and pavement condition information. Standard graphics

are often used to display percent of pavement mileage in various condition categories, example pie and bar graphs. These graphics provide a representation of the overall condition of the roadway network for each entity

Customized Summaries

One advantage to implementing pavement management software is the ability to use the available data to generate user-defined reports that can be modified to suit the requirements of the agency. The customized summaries could also be accomplished with the use of spreadsheets or other customized reporting tools. Some pavement management software also facilitates the generation of reports linked to the GIS component of the database or separately-managed GIS software. The results of the pavement management analysis can also be used to generate summaries for presentations to decision makers. The effect of budget changes on the network condition, often referred to as “what if” scenarios, are often very effective at showing decision makers the need for continued and/or increase levels of funding for the road networks.

Selecting Appropriate Methodology

Most agencies use a combination of standard and customized summaries to display their pavement management information. The visual aids generated depend on the needs of an agency and the type of information to be represented. As shown throughout this section, a variety of forms exist for creating visual aids to report pavement management data. General guidance on the types of visual aids that work best for sharing data with various users of pavement management information and examples of each is summarized in table 2.3[28].

Table 2.4. Visual aids for reporting information to the users of PM data [26]

Visual Aid	When to Use	Examples
Tables	• Incorporate into a report or document for detailed oriented user (engineers, planners, etc.) • Display extensive amount of detailed information • Support detailed analysis and provide technical information	• Inventory listing (e.g., segment location and name, surface type, age, traffic) • Condition listing (e.g., segment name, condition indices) • Maintenance listing (e.g., segment name, year of maintenance activity, maintenance type and cost) • Budget listing (e.g., money proposed for repairs for each segment or for various functional classifications)
Charts	• Present information to nontechnical audiences, such as elected officials and the public • Emphasize points to be made (easy method to convey simple summaries)	• Pie chart (shows size of each part as a percentage of the whole) • Column chart (show how items change with time or compare to one another) • Line chart (shows how items change over time and can compare "what if" budget scenarios)
Maps	• Display single type of information on a geographical basis • Present information to nontechnical audiences, such as elected officials and the public	• Segment surface type • Color-coded current condition • Color-coded projects by year • Future condition for a funding scenario • Deferred projects

2.4.6. Select Pavement Management Tool

The selection of a pavement management tool is influenced by the requirements of the agency and user's needs. The tool provides a platform to store the pavement management information and to perform different types of analysis depending on whether a spreadsheet, GIS tool, and/or a pavement management system (public or private) are selected. Depending on the needs of the agency, a local agency can also opt

to use a combination of pavement management software and customized spreadsheets and/or GIS software to suit their requirements.[28]

In some cases, the agencies use a combination of all three tools to complete their pavement management process. For example, they may use their pavement management system to produce customized summaries of pavement information and also determine benefit/cost ratios for various treatment scenarios for pavement segments in their network. Then they might use the spreadsheet tools to finalize work plan recommendations and create further tables of pavement information. Finally, the summarized information may be linked to a GIS map and shared graphically. If an agency decides that pavement management software is the ideal tool for them, there are a number of pavement management software programs to consider. Some of the available public domain and proprietary pavement management software programs commonly used in Illinois and highlighted:[28].

Public Domain Software

- Micro PAVER by the U.S. Army Corps of Engineers.
- Road Soft GIS by Center for Technology and Training at Michigan Technological University.
- Street Saver by the Metropolitan Transportation Commission in the San Francisco Bay Area, California

Proprietary Software

- PAVEMENT view by Cartograph.
- Pave Pro Manager by Infrastructure Management Services (IMS).
- Pub Works by Tracker Software Corporation.
- Road Care by Applied Research Associates, Inc.

The general capabilities of the pavement management tool most commonly used are outlined in figure 2.9.

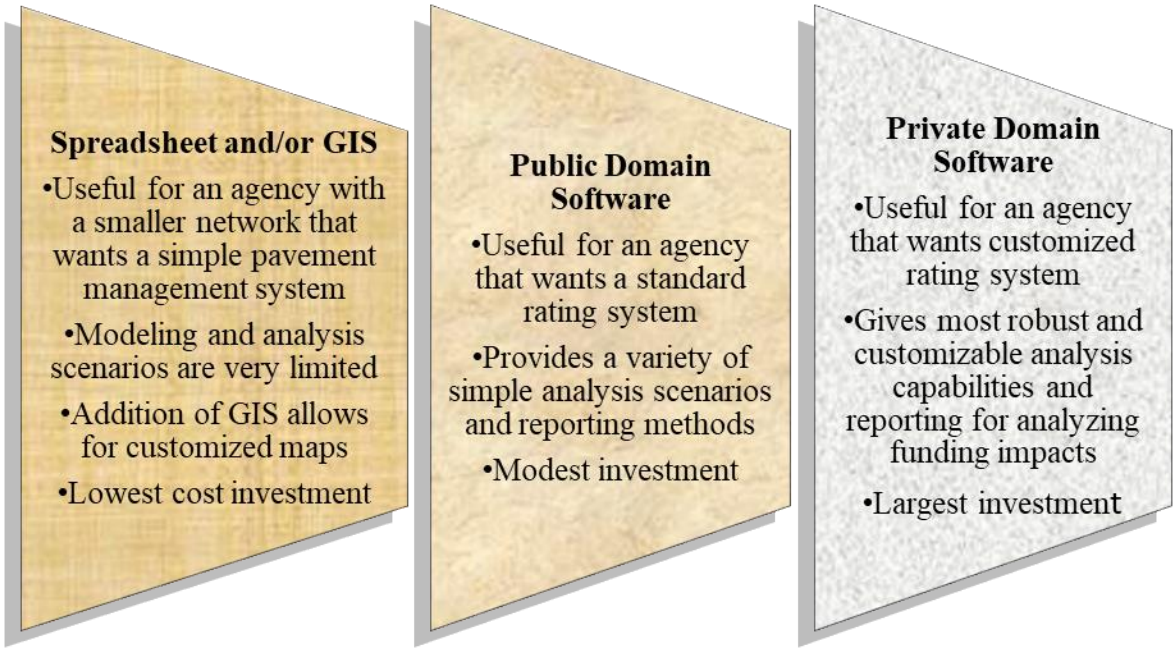

Figure 2.9. Comparison of pavement management tools[28].

Selecting Appropriate Methodology

Additional guidance on the selection of a pavement management tool is provided in figure 2.10. The selection of a software tool is based on the decisions made by the agency in steps 1 through 5 of the outlined pavement management process to meet the needs of the agency and its customers. In general, if an agency made process decisions that fall primarily on the left side of figure 2.9, then they are an agency that may be best suited with a spreadsheet tool. Those agencies that are interested in robust, customizable survey procedures and models, along with a variety of analysis scenarios, are best suited to implement proprietary pavement management software. Those agencies that fall between these two examples may be best suited with public domain software as it bridges the gap between the other tools. Of course, these choices must be balanced against the cost of the tools. When implementing the selected tool, agencies should look internally for expertise and, when needed, work with universities, vendors, or consultants for assistance in the implementation of the selected pavement management tool.[28]

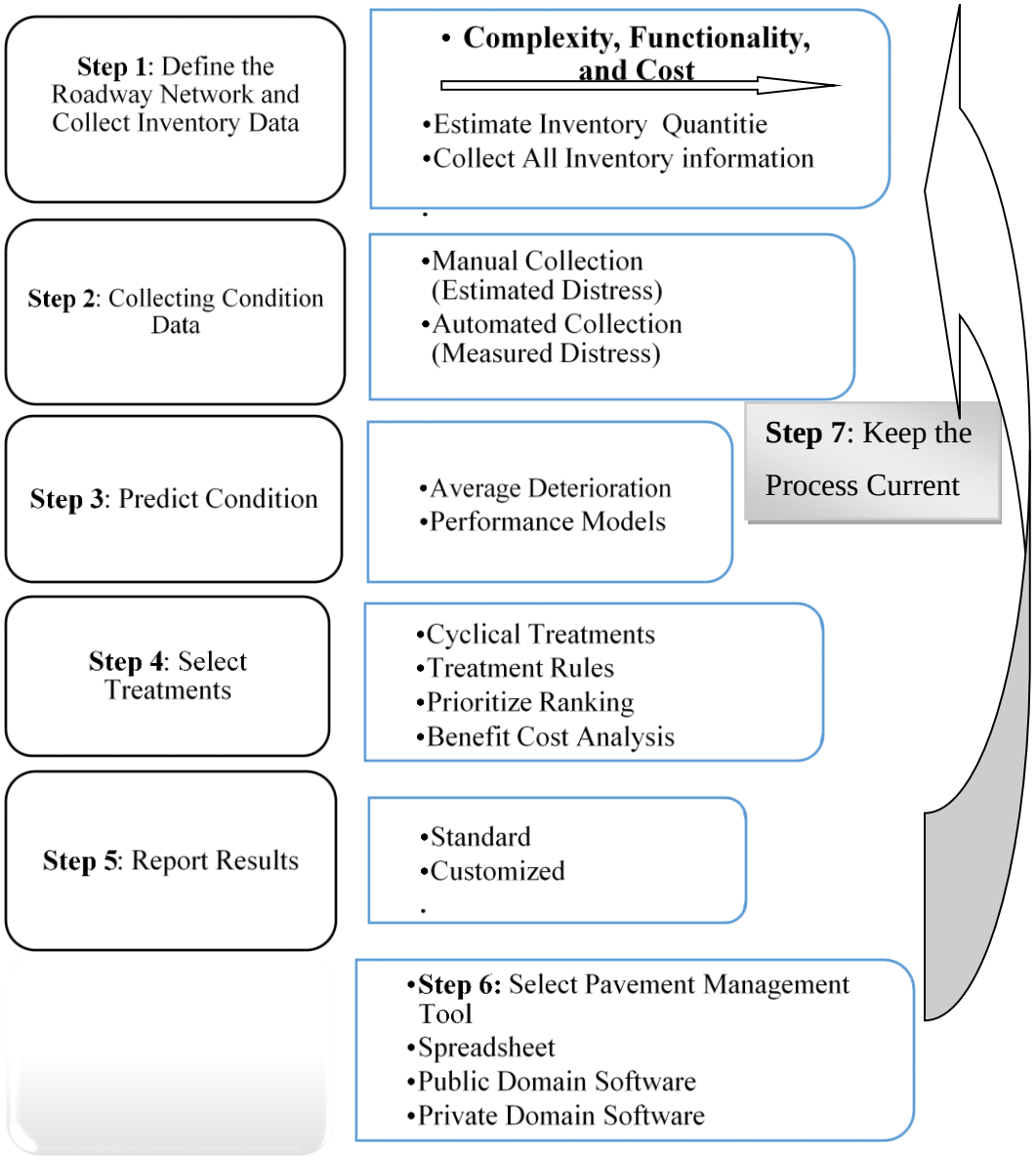

Figure 2.10. Pavement management Options[28]

2.4.7. Keep the Process Current

Pavement management is a dynamic process that requires regular updates. Pavement management is not a one-time activity, so agencies must make an effort to update the information incorporated in the pavement management process. Data management is a key component to maintaining the database and keeping the information current[28].

The required updates needed to keep the overall pavement management process current are outlined for the first five pavement management process steps:

1. Define Network and Collect Data – Inventory information related to pavement segments are relatively constant components of a database. These elements need to be updated only in the case of major changes to the pavement network. Work history details, however, should be updated on an annual basis to keep proper track of maintenance and rehabilitation activities on the pavement sections.

2. Collect Condition Data – General pavement management practices recommend that condition information is collected on a minimum 3-year cycle on pavement segments. Therefore, this data should be collected and updated in the pavement management spreadsheet or software on the same cycle.

3. Predict Condition – Average deterioration rates can be updated with each data collection cycle. If prediction models are utilized, consider updating them every 3 years when initially developed and then on a 5-year cycle after they are established.

4. Select Treatments – As agencies use the results of recommended treatments based on treatment selection processes, the rules and priorities should be updated to ensure that the process continues to improve in the future.

5. Report Results – Report results will be used by an agency with each new pavement management plan, which ideally should be conducted each year or on a maximum 3-year cycle to correspond with the 3-year data collection cycle

2.5. Maintenance Types

The third approach is prioritization guidelines, which will act as a sort of ranking system for the pavement projects identified during the analysis as a needing maintenance action when available funds are limited. Such guidelines are based on the practice of the road department and pavement condition[6].

Three types of pavement maintenance operations generally recognized are the following.

A. Preventive Maintenance: Performed to improve or extend the functional life of the pavement. It is a strategy of surface treatments and operations intended to retard progressive failures and reduce the need for routine maintenance and service activities.

B. **Corrective Maintenance**: Performed after a deficiency occurs in the pavement, such as loss of friction, moderate to severe rutting, or extensive cracking. May also be referred to as "reactive" maintenance.

C. **Emergency Maintenance**: Performed during an emergency situation, such as a blowout or severe pothole that needs repair immediately. This also describes temporary treatments designed to hold the surface together until more permanent repairs can be performed.

Based on their required frequency, forms of maintenance can also be categorized to "routine", "recurrent", "periodic" and "urgent",

a) **Routine maintenance**: required continually, whatever its engineering characteristics or traffic volume. Example - grass cutting; drain clearing; re-cutting ditches; culvert maintenance; road signs maintenance.

b) **Recurrent maintenance**: required at intervals during the year with a frequency that depends on the volume of traffic using the road. Example - repairing pot-holes; patching; repairing edges; sealing cracks.

c) **Periodic maintenance**: are repairs that carried out less frequent are considered periodic maintenance. Periodic maintenance includes all sorts of repairs including resurfacing, overlays, and reconstruction of pavement, base, and even sub base course. Periodic maintenance intervals vary according to the needs and may be irregular. The intervals depend to a large extend on the quality of the construction. Example – resealing (surface dressing, slurry sealing, fog spray, etc.); gravelling shoulders and road surface marking.

d) **Urgent maintenance**: maintenance activities that have to carried out immediately to save lives or prevent disastrous consequences of damaged infrastructure. Needed to deal with emergencies and problems calling for immediate action when a road is blocked Example - removal of debris and other obstacles; placement of warning signs and diversion works[6].

2.6. Pavement Distresses

Distress is the precursor (leading indicator) for serviceability (smoothness) and performance. It is also a key indicator of the type, extent, and timing of maintenance and/or rehabilitation intervention needed. In other words, distress is the "what and when and where" for annual and long-term budgeting and programming decisions[27].

2.6.1. Asphalt Pavement Surface Distress

Pavement distresses are visual defects on the pavement surface. It is generally agreed that the ability of a pavement to safely and smoothly sustain traffic loads is adversely affected by the occurrence of observable distress. Many agencies use pavement distress as the main pavement condition measure[27].

Distresses can be divided into two groups: structural distress and functional distress.

Structural distress is associated with the ability of the pavement to carry the design load. ***Functional distress*** is mainly associated with ride quality and safety of pavement surface. The distress is generally described in terms of severity and extent or density. However, the distress identification and measurement procedures may slightly vary from agency to agency.[27]

Pavement structural evaluation can be broadly classified as ***nondestructive or destructive.*** The data acquired is essential to assessing the structural capacity of pavement sections and networks. In the former case, it is commonly used in the design of rehabilitation treatments such as overlays, and for networks it can involve the allocation of funds.

Nondestructive pavement evaluation technologies have improved during the last 20 years, but there are still situations when it is beneficial to take core samples or to examine the layers by cutting a trench across the pavement. However, due to the expense and inconvenience to the motoring public, destructive evaluation is not a regular PMS function and is primarily used for research projects and forensic evaluations. Deflection measurements remain the primary method of nondestructive structural evaluation Effective use of deflection data requires knowledge of pavement layer thicknesses. Ground Penetrating Radar (GPR) for determining pavement thickness, as is as-built

construction records and Falling Weight Deflectometer (FWD) etc. are the most widely used device for measuring pavement deflection is a nondestructive option. [27]

Road deterioration is caused by the effects of the physical environment, traffic, material properties, and quality of road construction, design standards and the age of the pavement. The deterioration of pavement is apparent by various external signs and indicators called distresses. Pavement distress is often a result of a combination of factors, rather than just one root factor discussed in the above paragraphs. Before the appropriate repair strategy to be applied to a distressed asphalt pavement, the type and extent of the deterioration must be understood, and the cause of the distress must be identified. Generally, pavement distresses are fall into one of the following categories[27].

The four major categories of common asphalt pavement surface distresses are:[6]

A. Cracking

B. Surface deformation

C. Disintegration (potholes, etc.)

D. Surface defects (bleeding, etc.)

A. Cracking

Cracks in flexible pavements are caused by deflection of the surface over an unstable foundation, shrinkage of the surface, thermal expansion and contraction of the surface, poorly constructed lane joints or reflection cracking. The following are examples of cracks that may occur in flexible pavements;

- Fatigue cracking (Alligator cracking), Longitudinal cracking, Transverse cracks, Block cracking, Slippage cracking, Reflective cracking, Edge cracking etc.

B. Surface deformation

Pavement deformation is the result of weakness in one or more layers of the pavement that has experienced movement after construction. The deformation may be accompanied by cracking. Surface distortions can be a traffic hazard. The basic types are:

- Rutting, Corrugation, Shoving, Depressions, Swell etc.

C. Disintegration

The progressive breaking up of the pavement into small, loose pieces is called disintegration. If the disintegration is not repaired in its early stages, complete reconstruction of the pavement may be needed. The two most common types of disintegration are:

- Potholes, Patches etc.

D. Surface defects

Whereas the previous types of distress are mostly related to the supporting layers beneath the surface, surface defects are related to problems in the surface layer. The most common types of surface distress are:

- Raveling, Bleeding, Polishing, Delimitation etc.[6]

2.6.2. Distress Survey Collection Methods

After determining the survey approach for collecting the distress data, an agency must choose between the two primary methods of collecting pavement condition data: manual and automated[32].

I. Manual Distress Survey Collection Method

Manual surveys are generally considered to be visual assessments of field conditions conducted by one or more individuals who view the pavement through the windshield of a vehicle or as they walk the pavement. Data from a manual survey may be recorded on a sheet of paper, into a handheld tool or in a computer.

Rut depth survey (BCMoTI 2012). Class I roughness survey (BCMoTI 2012).

Figure 2.11. Manual Condition Survey [32].

II- Automated Distress Survey Collection Method

Automated surveys are conducted using vehicles equipped with specialized cameras and sensing devices that record images and data related to the pavement being evaluated. An example data collection vehicle is shown in figure 2.12.

Figure 2.12. a) Automatic Condition Survey and Falling Weight Deflectometer
b) Dynatest Multifunction Vehicle [24].

The Dynatest Road Surface Profilometer (RSP) mounted on the MFV is designed to provide accurate and repeatable pavement profile data[24].

I- Selecting Appropriate Methodology

With a range of levels of sophistication and required resources (time and money) to complete condition data collection, a significant amount of consideration must be given to this choice of survey procedures.

The choice between using manual or automated surveys can be determined by evaluating the advantages and disadvantages associated with each procedure listed in table 2.4.[28].

Table 2.5. Advantages and disadvantages of manual and automated surveys [33].

Survey Methodology	Advantages	Disadvantages
Manual	• Detailed distress information can be collected • Simple to conduct • No capital expenditures required	• Resource intensive • High safety risk • Potential for high variability in the data without strong training programs and quality control checks
Automated	• Lends itself to capturing large quantities of data • Multiple types of data can be collected at the same time • Data can be collected at traffic speeds • Images are stored and available for other uses	• May require a large capital investment or contracting fees • Data must be viewable from the pavement lanes • Some distress characteristics are difficult to capture (e.g. weathering and raveling of the pavement surface)

2.7. Road Maintenance Process

The approach involves defining activities, planning, allocating resources, overseeing implementation, monitoring and evaluation of works[34]. It normally contains the following components:

a) ***Inventory***: This is used as the basic reference for planning and carrying out maintenance and inspections. Inspection of road condition is the process of taking physical measurements of defects on the road network in the field.

b) ***Maintenance needs***: These are determined by comparing the measurements of road condition with predetermined maintenance intervention levels that are based upon economic criteria.

c) ***Costing***: Unit costs are applied to the identified maintenance tasks to determine the budget required.

d) ***Priority setting***: If the budget is insufficient for all of the identified work to be carried out, it is then necessary to determine priorities to decide which work should be undertaken and which should be deferred.

e) ***Execution of works***: The work identified is carried out through with the assistance of several systems of scheduling and cost-accounting.

f) ***Monitoring***: Monitoring serves two purposes. That is, it ensures that work identified has, in fact, been carried out and it also provides data to enable unit cost and intervention levels to be checked and adjusted if necessary.

2.8. Highway Management Software

2.8.1. Highway Data Management in ArcGIS

Introduction Esri is in the software development phase of creating a new highway data management solution. This document presents a vision of how that solution will help highway departments more easily exchange information between users and systems, overcoming the challenges of maintaining and integrating both spatial and non-spatial data that is broadly distributed throughout an agency[35].

Highway departments manage and maintain a broad spectrum of information about their highways. This information is generally distributed throughout the agency, and each dataset is often maintained in its own separate system. Furthermore, these datasets might each relate to the highway in a different way. The public safety group, for example, might maintain crash data based on mileposts located along the highway. The pavement group, on the other hand, may locate pavement sections based on measurements taken from the point where the highway intersects a maintenance district and measured using a distance measuring instrument (DMI)[35].

Any given highway department might have dozens of these datasets, each maintained in a separate system, many with their own methods for referencing locations along the highway. This can create significant problems when different groups within the agency need to access data maintained by other groups. Esri's highway data management solution is a multitier approach that attacks the problem at three levels:

- Workflow, Applications and Maps and reports

The implementation of an integrated information and systems framework based on industry best practices and standards is an effective way to support the exchange and integration of information across business units within a transportation organization. This approach can facilitate interoperability between component systems and across business units by leveraging existing data and establishing improved processes to gather, maintain, and analyze that data. Utilizing this approach will also allow agencies with limited budgets to achieve the maximum potential from existing systems and initiatives while leaving the basic purpose and structure of each component system intact[35].

Workflows support a wide variety of users from data collection crews to GIS analysts to maintenance crews in the field.

Applications support multiple clients through desktop, Web, and mobile implementations.

Maps and reports can be generated that leverage data from disparate datasets across multiple systems.

Prerequisites

This is an entry-level white paper targeted at highway department field supervisors, highway engineers, and geographic information system (GIS) analysts who manage and interact with highway data. The reader should have a cursory understanding of GIS and a high-level understanding of highway information[35].

2.8.2. Highway Development and Management (HDM-4)

In managing the road network under the jurisdiction of a given authority, it is important that actions taken at different management levels are justified from all relevant perspectives to ensure that sustainable road network will result which minimizes long-term transportation costs (given budget constraints) and which creates conducive

environment to economic growth and development. This has implications for analyses at the strategy level, the program level and the project level.

2.8.2.1. Purpose of the HDM-4

The Highway Development and Management (HDM-4) tool is aimed at facilitating the analysis of alternatives in respect of road maintenance and investment activities. It focuses on the technical and economic appraisal of road projects, the preparation of road investment Programs as well as the analysis of road network strategies[10].

- **Strategy Analysis**

Typical examples of strategy analysis by road agencies would include the following:

- Medium to long term forecasts of funding requirements for specified target road maintenance standards;
- Forecasts of long-term road network performance under varying levels of funding;
- Optimal allocation of funds according to defined budget heads; for example, routine maintenance, periodic maintenance and development (capital) budgets;
- Optimal allocations of funds to sub-networks; for example, by functional road class (main feeder and urban roads, etc.) or by administrative region; and
- Policy studies such as impact of changes to the axle load limit, pavement maintenance standards, energy balance analysis, provision of non-motorized traffic (NMT) facilities, sustainable road network size, evaluation of pavement design standards, etc.

- **Program Analysis**

Program analysis "... deals primarily with the prioritization of a defined long list of candidate road projects into a one-year or multi-year work program under defined budget constraints".

- **Project Analysis**

Project analysis deals with the "...evaluation of one or more road projects or investment options; application analyses a road link or section with user-selected treatments, with associated costs and benefits; projected annually over the analysis period. Economic

indicators are determined for the different investment options". Projects may typically include "... the maintenance and rehabilitation of existing roads, widening or geometric improvement schemes, pavement upgrading and new construction.

HDM-4 is a tool for economic optimization of maintenance of road networks and has been adopted or applied in many different countries for economic analysis and prioritization. It utilizes road network inventory and condition, traffic and economic data to feed a series of road deterioration and cost models, and to formulate candidate work programs for road networks[10].

2.8.3. dTIMS™ Software

dTIMS™ is a software product developed by Deighton Associates Limited which offers a set of tools for implementing a custom database and a custom analysis model. The software allows the user to create and maintain an inventory integrating any and all types of data (roads, bridges, signs, etc.…) in one place and relate them together using location referencing. In addition, the software enables the user to perform life cycle cost analysis (LCCA) on those assets, meaning it will forecast condition into the future and determine the best maintenance or rehabilitation action subject to budget constraints[36].

2.9. Road Management in Ethiopia (Ethiopian Roads Authority)

In 1951, when the Ethiopian Roads Authority was established, the total road network amounted to 6,400 km. This network was built mainly during Italian invasion. Past failure to undertake adequately funded, planned and managed maintenance programs have led to the situation where the massive capital investments of the Road Sector Development Program (RSDP), have become necessary. However, the lessons of the past have been well learned by the Government and the Ethiopian Roads Authority (ERA), and much attention is now being focused on maintenance tasks[37]. ERA has been carrying out the maintenance of roads by the district maintenance contractors, which is recently established as a separate enterprise that is ECWC.

2.9.1. Road network in Ethiopia (Ethiopian Roads Authority)

The cumulative impact of implementation of the RSDP on Ethiopia' road network over the 19 years of implementation of RSDP (from 1997 when RSDP1 started to 2016 to the

first year of implementation of RSDP5) is shown in table 2.6. It includes the following: the Ethiopia' road network increased from 26,550 km in 1997 to 113,066 km in 2016, a 326 percent increment. Thus, the road density per 1,000 km2 increased from 24.1 km in 1997 to 102.8 km in 2016. Furthermore, the condition of the country's road network has improved with the proportion of road network in good condition increased from 22 percent in 1997 to 72 percent in 2016. Overall total investment is ETB 266.2 billion (US$ 9.66 billion[3]. According to the ministry, the country's road network coverage has currently reached 121,171km, including URRAP and municipality roads [38].

Growth of the Classified Road ERA Network comparison between 1997 & 2016, surface type, Change in Road Density proportion of types of roads, pavement condition and Average distance to all-weather road mentioned in the table 2.6 and Figure 2.13 below shown. As well as the Road Condition Improvement in Ethiopia (1997/98 - 2015/16) illustrated the table 2.7 and Figure 2.14 below.

Table 2.6. Change in Some Performance during 19 years of RSDP Implementation [3]

Indicators	**(RSDP Start) 1997**	**(First Year of RSDP V) 2016**
Proportion of asphalt roads in good condition	**17%**	**73%**
Proportion of gravel roads in good condition	**25%**	**59%**
Proportion of rural roads in good condition	**21%**	**55%**
Proportion of *woreda* roads in good condition	—	**83%**
Proportion of total road network in good condition	**22%**	**72%**
Road density per 1,000 km2	**24.1 km**	**102.8 km**
Road density per 1,000 population	**0.46 km**	**1.23 km**
Proportion of area more than 5 km from all-weather road	**79%**	**35.80%**
Average distance to all-weather road	**21km**	**4.9 km**
Road network length (in km) including URRAP and municipality roads	**26,550**	**113,066**

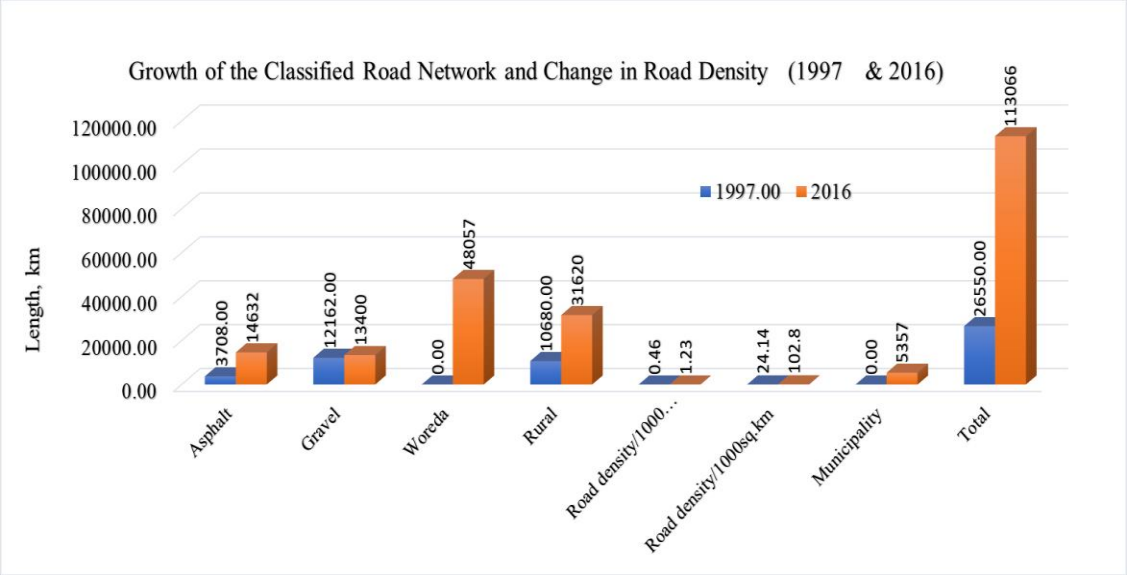

Figure 2.13. Surface type and Change in Road Density (1997 & 2016) [3]

Table 2.7. Road Condition Improvement in Ethiopia (1997/98 - 2015/16)) [3]

Year	1997	2000	2003	2006	2009	2012	2015	2016
Good(%)	22	28	32	47	54	64	70	72
Fair(%)	26	32	30	22	24	22	21	20
Poor(%)	52	41	38	31	22	14	9	8

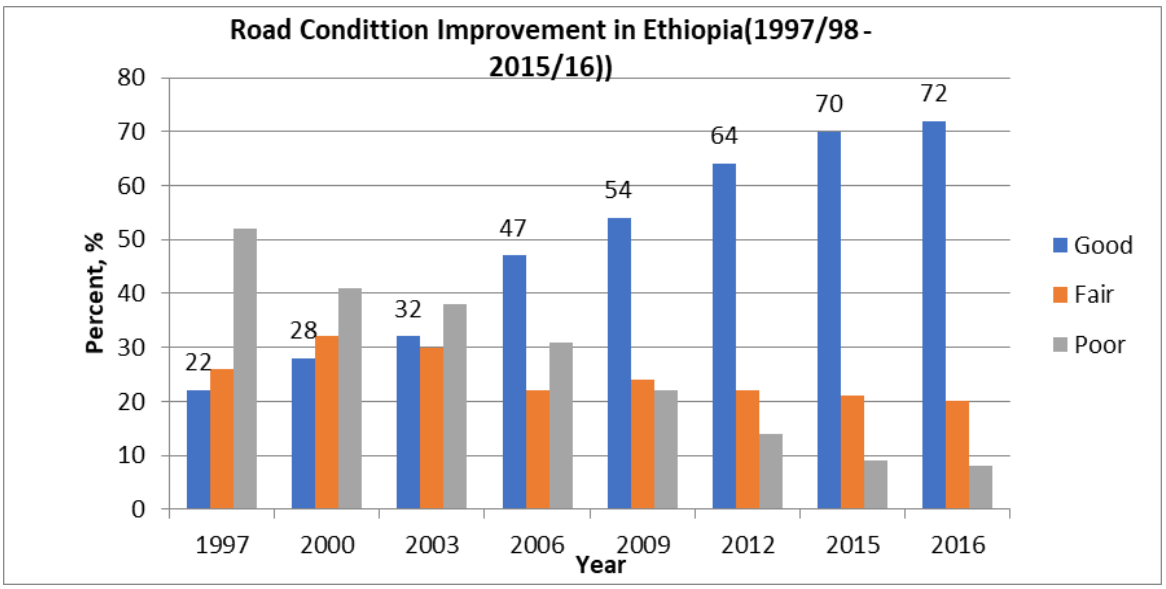

Figure 2.14. Road Condition Improvement in Ethiopia (1997/98 - 2015/16) [3]

2.10. Pavement Maintenance Management System in Jimma District

As all districts in the country the Jimma district ERA also responsible principally concerned with planning, scheduling, and performance, reporting and evaluating maintenance work at district level. Figure 2.15 chart shows the general organizational structure of ERA Jimma district but ECWC stands by itself. Source: Jimma District Office.

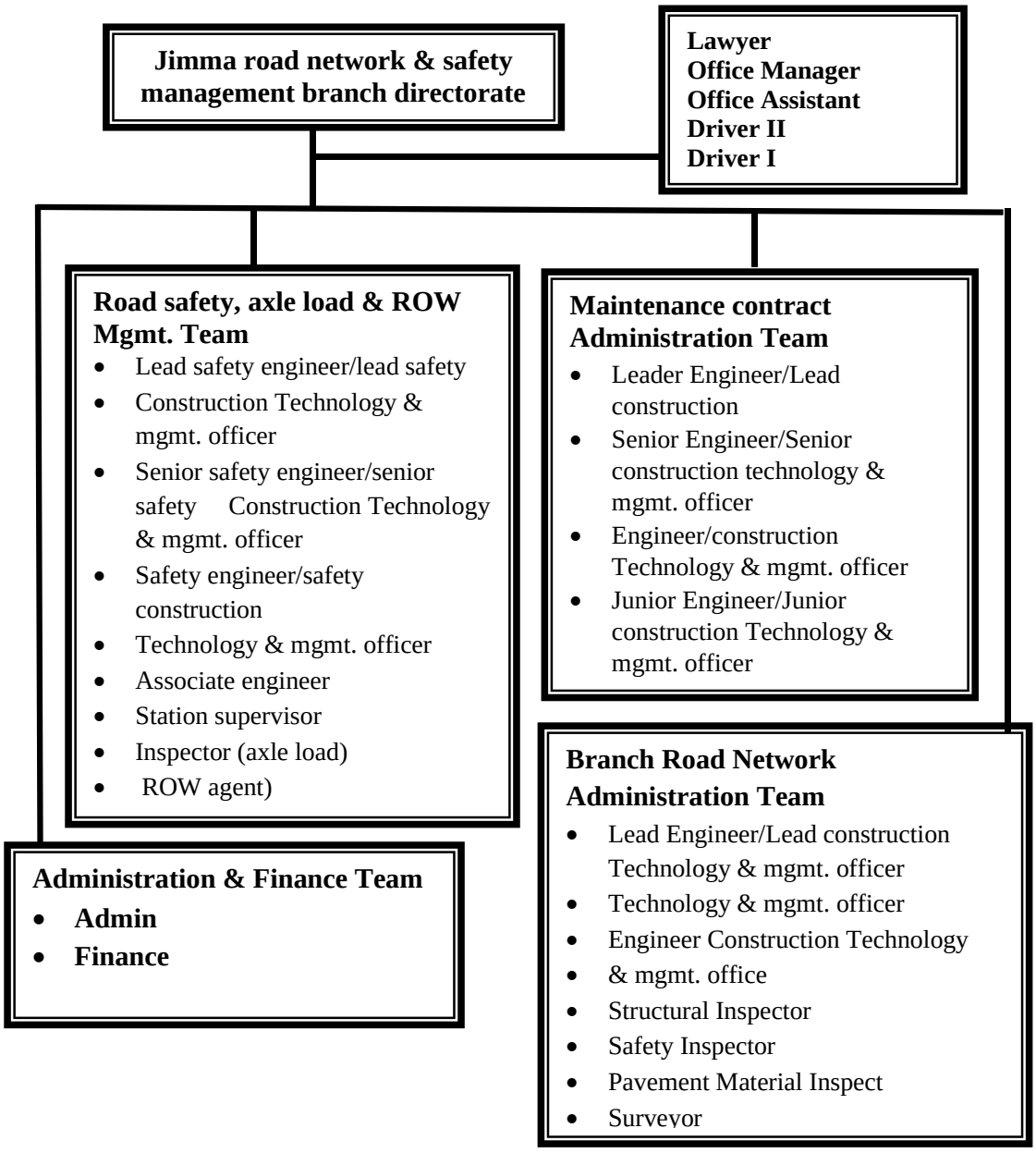

Figure 2.15. Organizational structure of Jimma district, (ERA)

The District Engineering Division Manager will have the following responsibilities:

- Carry out surveys – Inventory, Condition, Traffic etc.
- Estimate Total Maintenance requirements
- Produce annual maintenance plan and budget
- Prioritize maintenance work program
- Prepare contract packages
- Quality control of maintenance works (Certification of work done according to specification)
- Train DED staff and assist with the training of contractors [39]

Jimma Road Network Management Branch Directorate named previously, as District Engineering Division (DED) is one of the Directorate Office under ERA, Road Asset Management, and DDG whose main office is located in Jimma town of Oromia Regional state at km 356 from Addis Ababa.

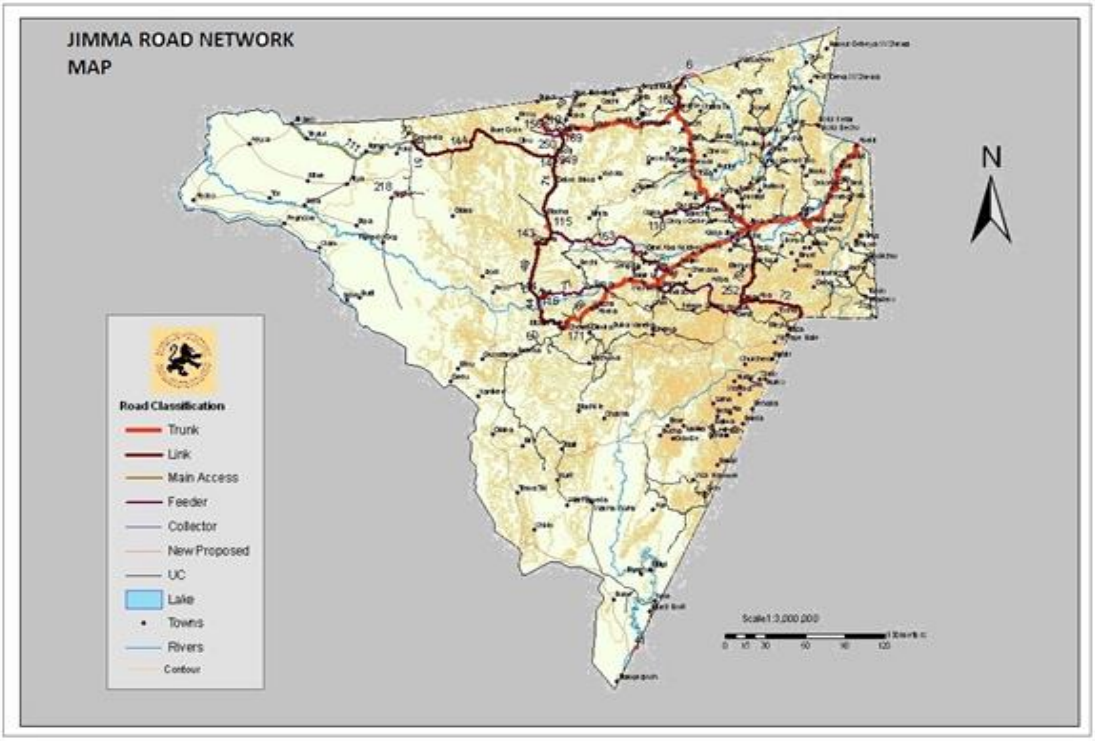

Figure 2.16. Road Network Map of the district [40].

Jimma Road Network Management Branch Directorate is currently responsible for administering 54 road segments having a total length of 2,699 Km, which are found in Oromia, SNNP and Gambella regional states. Out of the total road networks 996.1Km (36.9%) are Paved road (Hot mix Asphalt, Cold mix Asphalt and DBST) and 1,702.9Km are unpaved (Both Crushed stone and Natural gravel). The functional

classifications of the road networks under administration of Jimma RNMD, which are 24.58% Trunk, 26.56% Link, 14.08% Main Access, and 15.96% Collector and 18.81% Feeder Roads. [40]

Table 2.8. Jimma RNMD Road asset in 2019[40]

Types or Road	**Road length/ KM**	
	Paved	**Un paved**
Trunk Roads	656	
Link	210	495
Main Access	130.9	255
Collector		426
Feeder		526.9
Total Length	**996.9**	**1702.9**

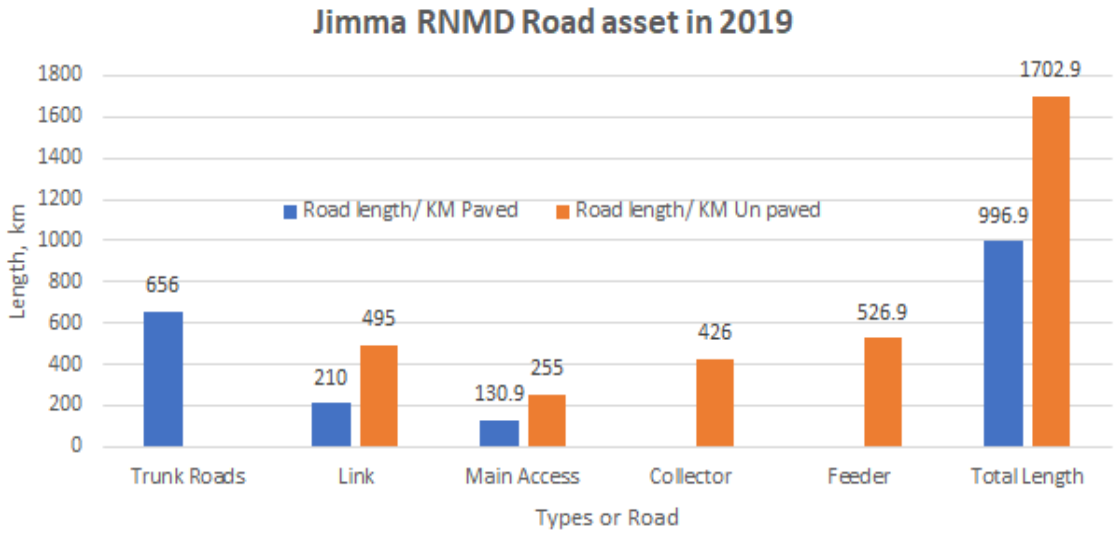

Figure 2.17. Jimma RNMD Road asset in 2018 [40]

Road Segments whose Construction/Upgrading/Rehabilitation works are under progress are the following:

1. Bedele – Metu (Lot 2) Road upgrading project by China international Water and Electric corporation;
2. Bedele – Metu (Lot 1) Road upgrading project by Hawk International Finance and Construction.
3. Bonga – Ameya – Chida (Lot-1) Road upgrading project by CGC Overseas Construction Group Co.ltd.
4. FelegeSelam – Ameya – Chida (Lot-2) Road upgrading project by Zhongmei Engineering Group LTD
5. Mizan – Dimma Road Upgrading Project /China MCC 17 Group co. Ltd
6. Dimma – Rad by Ethiopian Construction Works Corporation, Transport Infrastructure Construction
7. Adura – Akobo – Burbe Road Construction by SATCON Construction [40]

2.11. Pavement Management Systems in Different Countries

a) PMS in Australia, like in other countries across the world, is managed at the district and state level, only. It was developed as in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. Other states use commercially available software for this purpose. All states use pavement data collection systems. Data gathered includes, but is not limited to roughness, rutting, strength, texture, cracking, skid resistance and seal coat age[25].

b) By 2005, 1,900,000 km roads had been constructed in China, among them 40,000 km roads were expressways, another 15,000 expressways would have been constructed by 2010. By 2020, a national highway network would be completed with 85,000 expressways. Clearly, China needed a pavement management plan to address past and future pavements. In 1984, China initialized and developed a PMS and since its introduction significant progress, in terms of pavement management, has been made. The implementation of this PMS has not gone so well, due to less focus and acceptance. Most transportation departments in China are more focused on road construction and not maintenance[25].

c) Australia uses long-term (10-year) maintenance contracts to turn over total control and responsibility for roadway system maintenance, rehabilitation, and capital improvements to private contractors. In 1992 the managing authority of the French National Roads Network decided to modernize the means of evaluating the condition of its roads, i.e. develop a PMS. The tool set up to do this was based primarily on a systematic survey of pavement surface damage, completed by skidding resistance measurements. For the evaluation tool to have the expected qualities there had to be a special effort to make the damage survey a means of investigation as reliable as a measurement. The laboratories used a highly formalized method that precisely fixed the conditions in which the survey had to be performed, the type of information recorded, and its codification. Asset management programs for pavements have been used as effective methods for determining maintenance needs and increasing funding[25].

d) In Germany the design of a new, complete pavement management system is under way. Major components are already operational. Meanwhile, data on road conditions

have been collected with high-speed monitoring systems over the national road network, including the Autobahn. The data is assembled according to evenness, skid resistance, and surface damage and subsequently classified via a special grading system. By applying special algorithms, a service value, a structural value, and an overall condition value are being developed. The results of the survey are then presented in lists, route section graphs, and network graphs with different colors indicating where specific target, warning, and threshold values are exceeded. By means of continuous feedback, the information collected is used to improve and adjust the system's components and the plausibility of the output. There is an agreement that for an effective PMS application, repeated automated network monitoring is necessary. To minimize necessary monitoring and evaluation efforts, the use of multifunctional automated monitoring systems is used to collect all necessary data during a single pass[25].

e) The first experience of PMS in Italy was through the Province of Milano. Following the adoption of a new law in 2001, major portions of the interurban state road network had been transferred from the national road agency (ANAS) to the jurisdiction of the provincial governance. This transferable of competences brought up a number of consequences in the field of maintenance and management and in particular the need for the Provinces to optimize budget funds dedicated to the new additions to their road network. The latter situation led the Province of Milano to the adoption of a new approach for the task of pavement maintenance aiming at a more rational solution based on objective criteria for intervention planning[25].

f) In December 1998, New Zealand (NZ) embarked on an ambitious project to implement a National Pavement Management System (NPMS). Software called Deighton Transportation Infrastructure Management System (dTIMS) was chosen as the software application for multi-year programming road works. A pragmatic approach was selected and followed in the implementation of the NZ NPMS. The main aim or benefit of this approach was that it manifested an evolutionary progression for everyone rather than perfection of a system for a few and at much later date. In adopting this approach, a preliminary NZ dTIMS system was developed within a relatively short time-frame during the first seven months of the project using available information and systems (Phase I).

This system was then further refined from feedback from the system users and the refined system was released in October 2000, marking the end of Phase II of the project. Phase II included further research and development. Phase III of the project was also developed and has brought about further refinements, operational research and enhancements, continued training and support for users. A year after the beginning of the NZ Dtims project, more than 84 systems were being used by about 47 different RCAs throughout NZ. To date, the system is being used by all RCA's in NZ, with success. NZ has reported that its NPMS has been successful since its implementation. NZPMS has even awards at home and internationally and is recognized all engineering institutions in NZ, including the Institution of Professional Engineers New Zealand (IPENZ)[25].

g) The United Kingdom Pavement Management System (UKPMS) is a computer system that was designed for the economic management of the structural maintenance budget of a road network and dates back to the early 1980's. It incorporates a new system of visual data collection, data analysis, and budget allocation for all roads and has combined data from different types of condition surveys. Other significant features include the ability to project condition data into the future; this enables the user to take account of the economics of alternative maintenance treatments when deciding where and what treatments should occur. The core philosophy of UKPMS is to defer treatments where it is cost-effective and safe to do so and to give priority instead to preventive maintenance. The UKPMS provides standards for the assessment and recording of network condition and for the planning of investment and maintenance on roads, kerbs, footways and cycle-tracks within the UK. UKPMS provides a framework for combining the systematic collection of data with the decision-making processes necessary to optimize resources for the maintenance and renewal of pavements, including the generation of programs of works and corresponding budgets. It is used by local authorities in the UK for the management of roads, and for the production of performance indicators that are used nationally[25].

CHAPTER-THREE
RESEARCH MATERIALS AND METHODOLOGY

3.1. Study Area

Jimma district federal Asphalt road is located south west region of Ethiopia road network. The road networks of the Directorate office are currently grouped in to five sections for ease of maintenance management. These are; Jimma Section, Chida Section, Metu Section, Tepi Section and Gambella Section. Figure 3.1 shows location of the road network in the country.

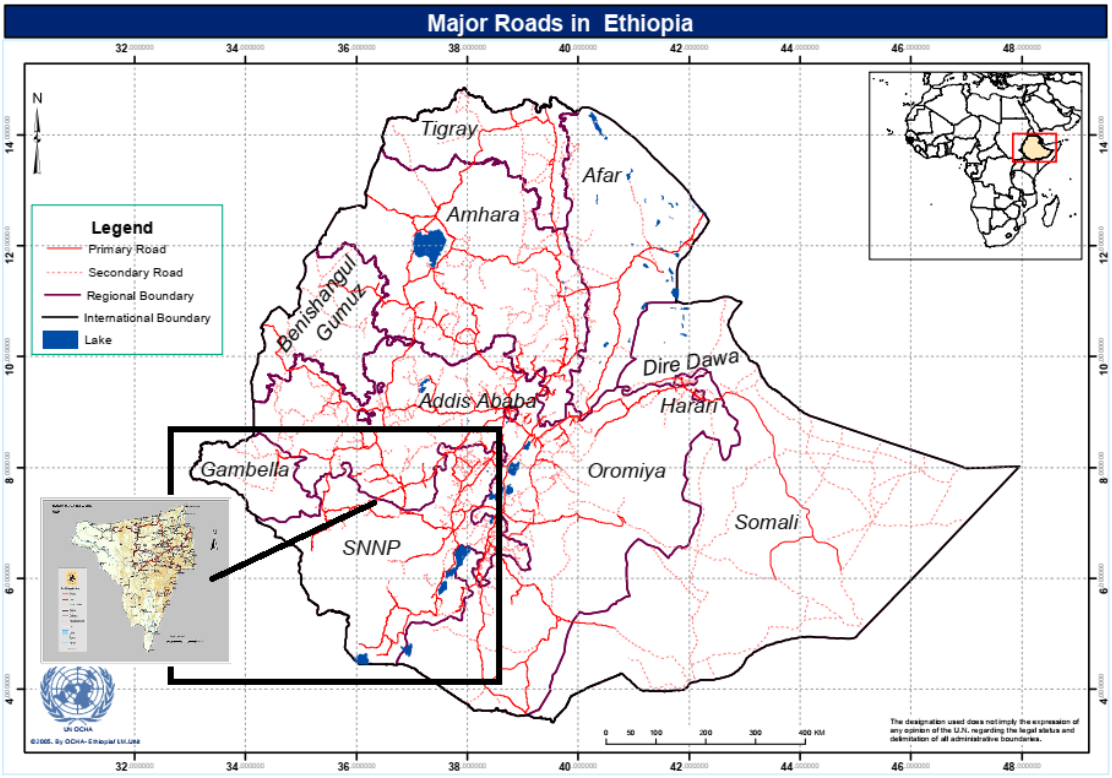

Figure 3.1. Location of the study area. [41]

3.2. Study Period

This research was conducted using two phases; the first phase concerns the relevant collection of data that were necessary for conducting the research work. The phase had a duration of 12 weeks, basically for collecting, organizing, and sorting data that started from July 15/2019. The second phase is concerned on data analysis and document preparation, and it covered 12 weeks duration started from October 15/2019

3.3. Study Design

Quantitative and qualitative research of explanatory type was adopted to assess the existing practice and recommend a solution for the problems. The overall approach to be followed were; having established the basis of the research, necessary data was collected, analyzed, and conclusions and recommendations were made based on the findings. The methods of data collections employed for the research were a case study, desk study questioner & interview. The case study was analyzed concerning theoretical suggestions, and the responses obtained from the questioner and interview were also be analyzed. The next sections discuss the tools used for data collection and the method of analysis.

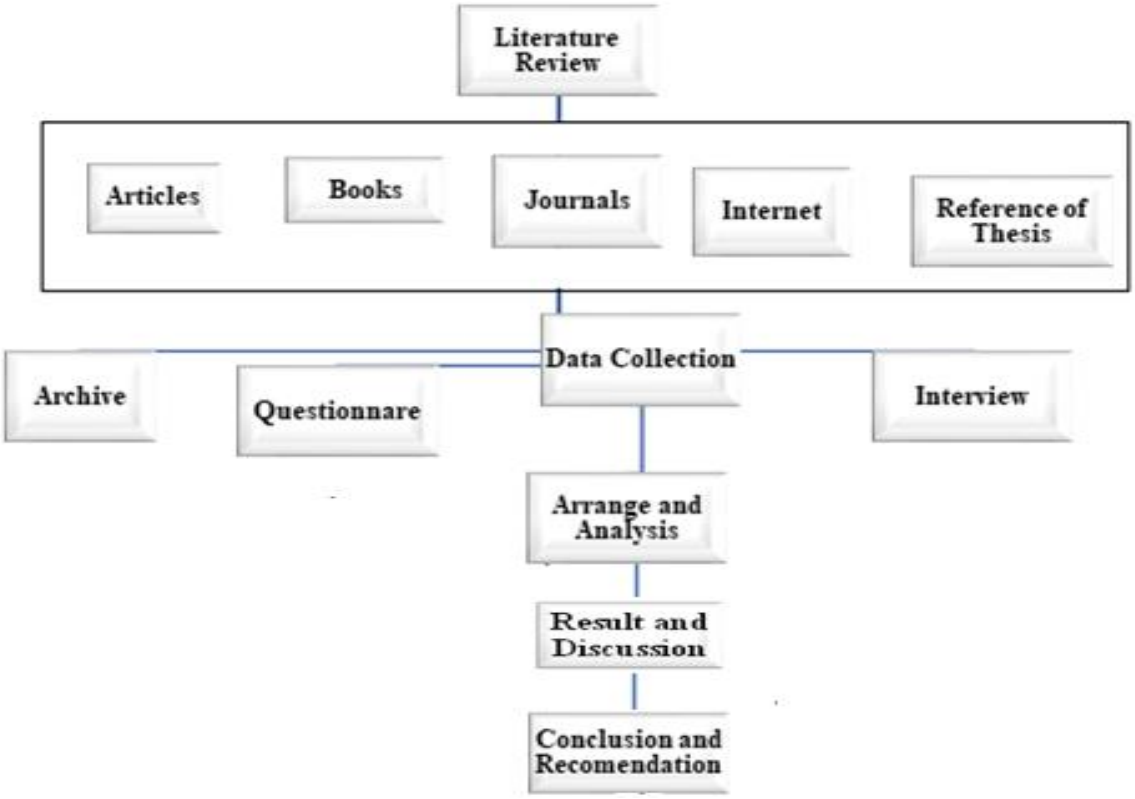

Figure 3.2 Flow Chart of Research Methodology

3.4. Research Population

The research population was drawn from agencies involved in district federal Asphalt road maintenance management systems. ERA, ECWC, and Consultant who are involved in pavement maintenance management system.

3.5. Sample Size

The research size was drawn from agencies involved in district federal Asphalt road maintenance management projects professionals or experts were involved in it in the near past. As much as possible attempts have been made so that the samples drawn from the population were representatives, were present the entire population size. The table 3.1 below shows the total professionals in the district. Among the total professionals in the district two third of the professionals are selected purpose full to participate in the study.

Table 3.1. Total professionals in the district

Division of Organization in the district	Professionals		Sub Total
	Top and middle managements , Group -I	PMMS experts, Roads maintenance Engineers, Group -II	
Client	5	11	**16**
Contractor	2	10	**12**
Consultant	1	3	**4**
Total			**32**

3.6. Materials required

The following materials used to fulfill the objectives of this project. Computer, Printer, Stationeries (e.g. ream paper), flash disk, questionnaire and interview.

3.7. Sampling Techniques

The study employed the stratified sampling Technique, Stratified Sampling is the probability sampling technique where the researcher divides the entire population into different subgroups or strata and then randomly selects the final subject's proportionality from the different strata. Among the total population two third was addressed due to the professional's inactiveness on their job, the study population is categorized into two main groups:

I. Whom involved in pavement maintenance works PMMS experts, Roads maintenance Engineers for questionnaire.
   a) Client b) Contractor c) Consultant

II. Roads Director or top managements (Technicians and Programmer) for interview.

a) Client b) Contractor c) Consultant

The number of sample size from each group mathematically computed using equation (3.1)

$$Sr = Pc \times (St/Pt) \quad \text{[3.1]}$$

Where:

Sr – Sample respondent.

Pc – Total Population

St – Total sample respondent

Pt – Total population estimated for the study [42].

Among the thirty-two professionals in the district questionnaire from seventeen and five from interview was collected. The interview was taken from top and middle management chair holders three from client side, one from consultant and one from contractor detail sampling included in appendix C.

3.8. The study variables

The study variables both dependent and independent were assessed.

3.8.1. Independent variables

- Defined Roadway Network and Collected Inventory Data
- Condition and performance
- Prediction tools
- Selected Treatments
- Reported Results
- Selected Pavement Management Tool
- Kept Current Process

3.8.2. Dependent variables

The dependent variables were the Challenges on Asphalt pavement maintenance management system in Jimma district federal road.

3.9. Data collection process

3.9.1. Case Study

In this study, the challenges on pavement maintenance management system in the district federal roads were chosen as one of the tools to find out the answer for the 1st research question. Almost the questionnaire distributed to all the professionals due to the population size is small. The study population was categorized into two main groups (I- Experienced workers, PMMS experts, Roads maintenance Engineers whom involved in pavement maintenance works, II- Roads Director and top managements)

3.9.1.1. Desk Study

Desk study was chosen as one of the instruments to assess and obtain actual data about the practices pavement maintenance management system from relevant studies, reports and documents.

3.9.1.2. Questionnaire

The questionnaire was developed to assess the existing challenges on pavement maintenance management practice in jima district and how to minimize and avoid those challenges for effective and efficient pavement maintenance management work.

The schedule consists of four sections with a total of 22 questions. Section one contains general questions about the informants. Section two assesses the current practices of pavement maintenance management system at district level. Section three examines Inventory, performance, prioritizing and selecting treatments etc. based maintenance management for Ethiopian federal roads in the district. Section four investigates the implementation of PMMS.

The questionnaire schedule shown in the Appendix A; assesses the current practices of pavement maintenance management system (Inventory, performance, prioritizing and selecting treatments etc.), maintenance management and investigates the implementing the PMMS at district level used.

3.9.1.3. Interview

Information for research questions was searched from key informants in order to expand the findings of the case study and desk study. Purpose of the interview was to assess the

practices and insights of key informants on pavement maintenance management system practices in general.

The interview schedule shown in the Appendix B; data acquiring and storage media, an application of suitable asset management software which will integrate all individual pavement management systems, data used for prioritize and select between two projects, how decisions were made in the organization to finance a project maintenance, which economic evaluation analysis method used, problems occur during the process of pavement management system and propose to improve the road pavement management system.

3.10. Data processing and Analysis

The case study and desk study were analyzed in relation to the theoretical propositions. The method used to analyze the questionnaire and interview data are descriptive statistics method. This method of analysis helps to analyze the responses in actual numbers. All the data collected were organized and relevant answers were summarized in order to reach at meaningful conclusion. Secondary data were used as supplementary source of information.

Questionnaire and interview were made with the Engineers of district Pavement Management Department who are working on district PMS at district level (i.e. they are responsible to coordinate data collecting process and overall PMS operations). Among the professionals involved in Pavement Management Department questionnaire and interviews including the Team Leader directly/indirectly involved in PMS at district office. Based on this information questionnaire and interview were made to all twenty-two professionals (appendix A and B).

To reinforce the study, the district archival, PMS user manuals, reports, data collected (inventory survey and conditional) concerning the Pavement management system in the district, and other documents were reviewed and analyzed.

The next logical step, after collecting the information was to analyze available data. The analysis also was based on the qualitative measurement or ranking system. The relative weight method was used to identify the most critical factor for assessing the pavement

maintenance management system in Jimma district. One must recall that Likert-type data is ordinal data, i.e. we can only say that one score is higher than another. [43] described in detail about the average index method based on the following formula.

$$\textbf{Average Index} = \frac{\sum aixi}{\sum xi} \text{..... [3.2]}$$

Where: ai = constant that represent the weight of i,

xi = variables that represent the respondent frequency for i

i = 1, 2,3,4,5.

To determine the satisfaction level of related personnel on maintenance management system, average index method with five different scales is used. The scales are shown below:

1 = 'Very satisfied' 1.00 < Average Index < 1.50

2 = 'Satisfied' 1.50 < Average Index < 2.50

3 = 'Average satisfied' 2.50 < Average Index < 3.50

4 = 'Not satisfied' 3.50 < Average Index < 4.50

5 = 'Least satisfied' 4.50 < Average Index < 5.00

The result and the average index for each part was shown in the same table. Using Likert scale score approach of 1 to 5, the factors are assigned rating in scale of 1 to 5 to the factors affecting prioritization, with 5= Very High, 4=High, 3= Moderate, 2=Low and 1=Very Low[42].

CHAPTER-FOUR
RESULTS AND DISCUSSION

4.1. Introduction

This chapter discuss on results and discussion obtained from professionals who are working with district professionals who have experience on pavement maintenance management, in construction and consulting activities. The analysis of the data has been made using Likert scale. The analysis illustrates the finding results of survey frequency and importance indices. Besides, the results of each assumed questions raised in each section have been dealt with.

4.2. Analysis of Hypothesized Questions

The respondents were asked to express their opinion by agreement /disagreement on twenty-four hypothesized questions and also they were asked to specify reasons. Moreover, they were asked four to five questions in each section to rank based on the degree of importance for the listed problems or constraints so that to understand and mitigate the encountered problems.

Though the respondents (questionnaire) were asked to respond their agreement /disagreement in five scales and interview also collected. The summaries of questionnaire and interview have been included in appendix A and B.

4.3. General Back Ground Questionnaire and Interview

This part mainly designed to provide general information about the respondents in terms of the organization type, Position, Level of Education and Experience.

4.3.1. Type of Respondent's Organization

The distributed questioners were to 24 professionals; i.e. among the distributed the returned was 17; 8 each working for the client (ERA), 7 contractors and 2 consultants. The expected interview was to 8 professionals; i.e. among the expected the interviewed was 5; 3 each working for the client (ERA), 1 contractor and 1 consultant. It was possible to distribute 17 questioners and 5 interviews to the desired professionals as much as

possible and attempts have been made. The following tables 4.1 and 4.2 illustrate the sample and their distribution as well as the response rate.

Table 4.1. Professionals with their respective response rate, questioner

Division of Organization in the district	Total Professional (Total questionnaire distributed)	**Questionnaire Returned**	**Returned, %**
Client	11	8	72.72
Contractor	10	7	70.00
Consultant	3	2	66.67
Average			**69.80**

Table 4.2. Professionals with their respective response rate, interview

Division of Organization in the district	Total Professional (Interview Estimated)	**Interviewed**	**Interviewed, %**
Client	5	3	60.00
Consultant	2	1	50.00
Contractor	1	1	100.00
Average			**70.00**

4.3.2. Position, Level of Education and Experience of Respondents

Assessment of position of individual respondents shows that 22.73%, 31.82% and 45.45% find individuals have Top Level Mgmt., Mid-Level Mgmt.(PMMS experts) and Bottom-Level(Roads maintenance Engineers) Mgmt. position respectively shown in figure 4.1 and table appendix D.

Assessment of Level of Education of individual respondents shows that 9.10%, 77.27% and 13.63% find individuals have Master's Degree, B.Sc. Degree and Diploma or Technical Certificate respectively as shown in figure 4.2 and table appendix D.

Assessment of experience of individual respondents shows that 40.92%, 36.37% and 22.72% find individuals have less than five years, between five to ten years and greater than ten years of experience respectively as shown in figure 4.2 and table appendix D

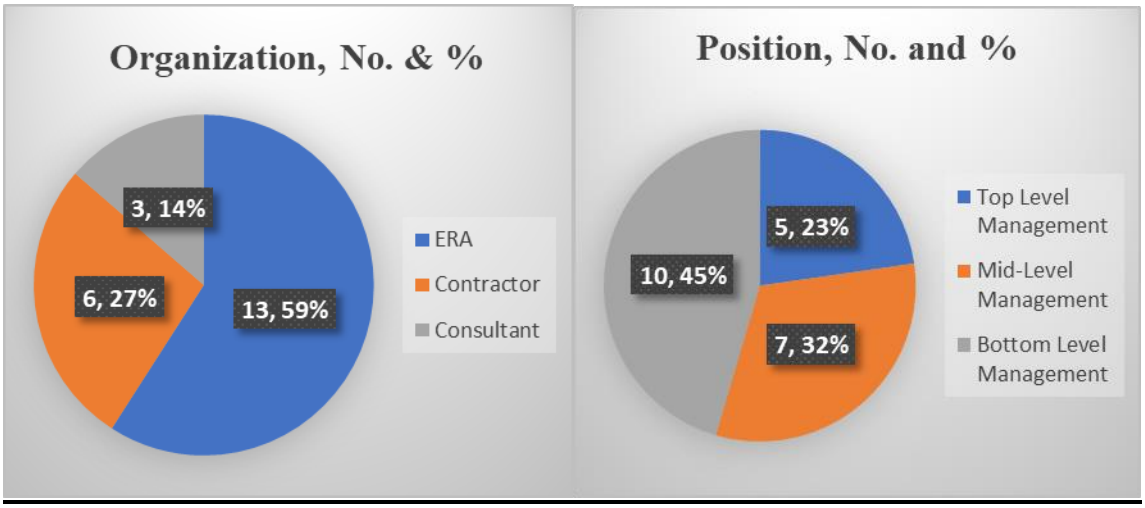

Figure 4.1. Respondent organization and position

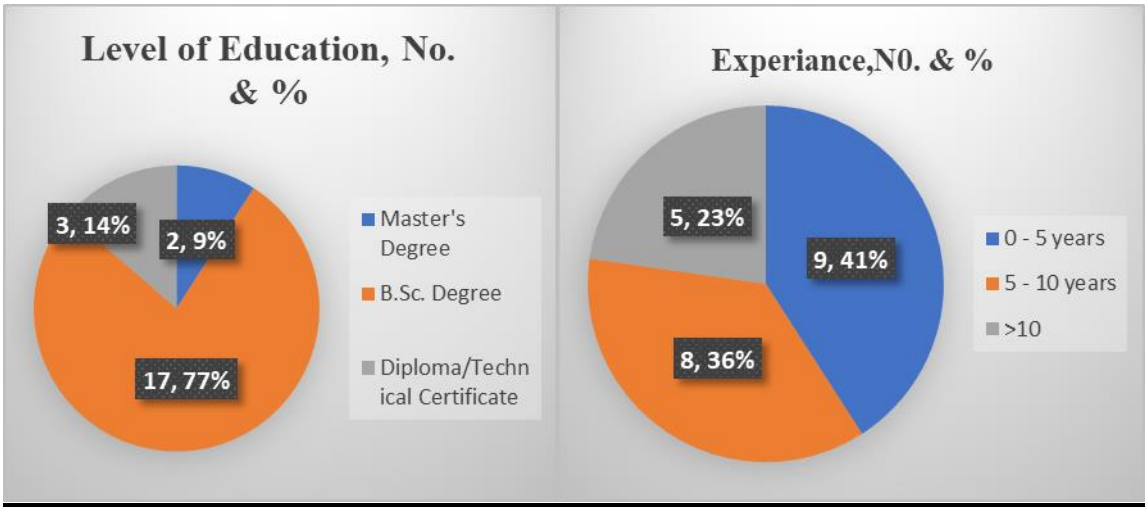

Figure 4.2. Respondent level of education and experience

4.4. Questionnaire

4.4.1. Current MMS evaluations

2.1. In your opinion in Jimma district asphalt federal road condition status is good?

- The result indicates (**Slightly disagree)** but from the given reason Jimma district federal asphalt road condition status is ***not good.***
- Design problem, construction quality, climatic condition of the region, poor under layer soil condition.
- Lack or absence of on time preventive maintenances and not handled properly.
  - ✓ Even the road conditions are not good currently the maintenance condition showing an improvement and some of the roads are under maintenance.

2.2. Did ERA/District currently carry out destructive and non-destructive tests other than visual pavement condition evaluation method?

- The result indicates **Slightly agree** but the actual is the reverse ***there is no*** destructive and non-destructive tests as obtained from the condition survey crew and interview of top managements.

2.3. Does the present pavement evaluation method used by ERA/ District is adequate for evaluating the pavement for structural, functional and safety of road condition periodical?

- Even if the result indicates **Slightly agree** the given reason inverse that ***Not adequate due to***
  - Costly of condition survey equipment visual inspection is carried out for a time being.
  - In adequate budget, skilled man power and other reasons.

2.4. What are the main problems for practicing different evaluation method in ERA/District; those are mandatory for recommending the best maintenance option?

- The main problems for practicing different evaluation method in ERA/ District that is in the ***first rank*** budget constraint and the ***next*** Absence of appropriate machinery, Lack of appropriate pavement management system and skilled manpower all have the same ***second rank***.

Table 4.3. Current Maintenance Management System Evaluation Summary

➢ **Questions**	**Response Scale**					**Result in AI**
	Strongly agree	**Slightly agree**	**Neutral**	**Slightly disagree**	**Strongly disagree**	
	Percentage					
District asphalt federal road condition status is good?	0.00	35.29	5.88	58.82	0.00	**3.24**
Are there destructive and non-destructive tests	17.65	35.29	17.65	11.76	17.65	**2.76**
Is pavement evaluation adequate for structural, functional and safety of road condition periodical?	0.00	58.82	5.88	29.41	5.88	**2.82**
➢ Problems for practicing different evaluation method for recommending the best maintenance option?	**Very Important**	**Important**	**Average**	**Least Important**	**Not Important**	**Result in AI**
	Percentage					
Budget constraint	47.06	35.29	11.76	5.88	0.00	**1.76**
Absence of appropriate machinery	35.29	47.06	5.88	0.00	11.76	**2.06**
Lack of appropriate pavement management system	29.41	47.06	11.76	5.88	5.88	**2.12**
Limited skilled manpower	29.41	35.29	5.88	17.65	11.76	**2.47**

4.4.2. Pavement Rehabilitation and Maintenance

3.1. Did ERA/ District apply alternative pavement treatment types different from overlay patching? If your answer is “YES”, how well does the service provided?

- The result indicates ERA/ District applies alternative pavement treatment types different from overlay patching (***Somewhat well)***.

3.2. ERA/District uses overlay and patching as preventive and rehabilitation maintenance strategy. Are those strategies adequate for preserving pavement in good condition and reducing expensive maintenance work? If your answer is “ADEQUATE”, how would you rate the value?

- The result indicates ERA/ District overlay and patching as preventive and rehabilitation maintenance strategies are adequate for preserving pavement in good condition and reducing expensive maintenance work (***Somewhat well)***.

3.3. In your opinion did ERA/District apply different types of maintenance treatment selection techniques that are mandatory for recommending specific and cost-effective remedial maintenance measures to be taken? If your answer is "YES", How do you evaluate the treatment selection techniques?

- The result indicates ***very well*** but the given reason concludes not well and as follow:
  - There is lack on budget constrain and absence of appropriate machinery.
  - The treatment techniques are best because for each maintenance type there is remedial treatment procedures and manuals.
  - We select maintenance in derivation as per the defect extents.
  - Evaluation of the treatment is taken after condition survey is collected by estimation during that the evaluation may be in correct.

3.4. Do you consider the quality of maintenance and rehabilitation work in ERA/District is sufficient? If your answer is "SUFFICENT", How well does the service provided?

- The result indicates ***somewhat well*** but the given reason concludes not sufficient and as follow:
  - Due to cost and financial problem, poor management and poor machinery work quality of maintenance may be not sufficient.
  - Not sufficient because the country road year to year increase and wide so it needs modern technology with efficient and sufficient man power must be full filled.
  - It is sufficient because each activity of maintenance work carried out with lab. Test.
  - Because of the limitation (problem 2.4) provided above, it is very difficult to say sufficient quality have insured.

3.5. What are the main constraints for implementation of effective road maintenance and rehabilitation work in ERA/District?

- The main constraints for implementation of effective road maintenance and rehabilitation work in ERA/District are in the ***first rank*** Budget constraint and absence of appropriate machinery, in the second rank Lack of monitory and quality control, in the third rank Lack of appropriate pavement management system, and Limited skilled manpower.

Table 4.4. Pavement Rehabilitation and Maintenance Practice Summary

➢ **Questions**	**Response Scale**					**Result in AI**
	Extremely well	**Very well**	**Somewhat well**	**Not so well**	**Not well at all disagree**	
	Percentage					
How well does District apply alternative pavement treatment types different from overlay patching?	11.76	23.53	23.53	23.53	17.65	**3.12**
How would you rate the value of using overlay and patching as preventive and rehabilitation maintenance strategy	0.00	41.18	47.06	11.76	0.00	**2.71**
How do you evaluate the treatment selection techniques for recommending specific and cost-effective?	17.65	35.29	23.53	23.53	0.00	**2.53**
Do you consider the quality of maintenance and rehabilitation work in ERA/District is sufficient?	0.00	5.88	58.82	35.29	0.00	**3.29**
➢ What are the main constraints for implementation of effective road maintenance and rehabilitation work in ERA/District?	**Very Important**	**Important**	**Average**	**Least Important**	**Not Important**	**Result in AI**
	Percentage					
Budget constraint	64.71	23.53	5.88	5.88	0.00	**1.53**
Absence of appropriate machinery	52.94	29.41	11.76	0.00	5.88	**1.76**
Lack of monitory and quality control	29.41	23.53	41.18	0.00	5.88	**2.29**
Lack of appropriate pavement management system	23.53	23.53	35.29	5.88	11.76	**2.59**
Limited skilled manpower	17.65	29.41	35.29	11.76	5.88	**2.59**

4.4.3. Pavement maintenance management.

4.1. Is there well-established road maintenance management system in ERA/District for effective planning and management of pavement network?

- According to the given responds there is no well-established road maintenance management system in ERA/District for effective planning and management of pavement network. (***slightly disagree)***

4.2. There are different alternate maintenance prioritizing methods to insure the limited available resource to be utilized in most effective manner. Did ERA/ District have well defined organizational maintenance prioritizing method?

- According to the given responds ERA/ District has not well-defined organizational maintenance prioritizing method implemented. (***slightly disagree)***

4.3. ERA/District outsources rehabilitation and maintenance works to other private contracting companies?

- According to the given responds the result indicates satisfactory but the given reason indicates ERA/District outsources rehabilitation and maintenance works to other private contracting companies are not satisfactory .(S***lightly agree)***
  - Private company mainly a cost benefit analysis rather than give a treatment
  - Behavior of intensity of maintenance is not measurable and it is difficult to put fixed quantity in the contract. This leads to loot a budget easily in wrong manner
  - ERA head office outsources any contract works with bid, but not with district level. In addition, any contract signs the agreement is completed in head office level

4.4. What are the main constraints to establish pavement maintenance management system (PMMS) in ERA/District?

- The main constraints to establish pavement maintenance management system (PMMS) in ERA/District. The result indicates in the first rank budget constraint and absence of appropriate machinery in the second rank and Limited skilled manpower, Political influence or involvement and Lack of awareness for its benefits and costs of PMMS in the third rank.

Table 4.5. Pavement maintenance management

➢ **Questionnaire. No.**	**Response Scale**					**Result in AI**
	Strongly agree	**Slightly agree**	**Neutral**	**Slightly disagree**	**Strongly disagree**	
	Percentage					
Is there well-established road maintenance management system in ERA/District for effective planning and management of pavement network?	5.26	15.79	15.79	42.11	21.05	**4.00**
Did ERA/ District have well defined organizational maintenance prioritizing method?	17.65	11.76	11.76	58.82	0.00	**3.12**
ERA/District outsources rehabilitation and maintenance works to other private contracting companies?	17.65	35.29	29.41	11.76	5.88	**2.53**
➢ What are the main constraints to establish pavement maintenance management system (PMMS) in ERA/District?	**Very Important**	**Important**	**Average**	**Least Important**	**Not Important**	**AI**
	Percentage					
Budget constraint	35.29	47.06	5.88	5.88	5.88	**2.00**
Absence of appropriate machinery	23.53	47.06	11.76	5.88	11.76	**2.35**
Limited skilled manpower	23.53	17.65	41.18	11.76	5.88	**2.59**
Political influence or involvement	29.41	23.53	11.76	17.65	17.65	**2.71**
Lack of awareness for it benefits & costs of PMMS	17.65	23.53	35.29	5.88	17.65	**2.82**

4.5. Interviews

4.5.1. Database, economic evaluation, maintenance prioritize, problems etc.

1. What is the mechanism you follow to manage the data collected in your organization? (Paper format, electronic databases, and geo-referenced database (GIS, hard disks, magnetic tapes, CDs, DVDs))

   - Once the data have been acquired by one or more methods and technologies they are stored in paper format/EXCELL storage media.

2. What data integration system you use in your organization? (a fused database and many interoperable databases.)

   - The district does not use any data integration system.

3. What data are used to prioritize and select between two projects for example between two pavement maintenance projects and how much important is it?

   - To prioritize and select projects between two pavement maintenance projects much important things taken in the first rank Structural condition (i.e., how adequate it is for its purpose), in the second rank Location, Attributes/characteristics (i.e., materials, service life, geometry, etc.), Customer/user feedback and/or complaints, Functional condition (i.e., how well it can serve the public), in the third and Initial agency cost construction/provision), Life-cycle costs (including M&R and user costs), Usage (i.e., how many users utilize it on a specific time basis, e.g., a day) in the fourth rank.

Table 4.6. Data prior given to prioritize and select between two projects

➢ What data are used to prioritize and select between two projects ,maintenance projects (how much important is it?)	**Response Scale**							**AI**
	Very low	**Low**	**Medium**	**High**	**Very High**	**Not important**	**Don`t know**	
	Percentage							
Initial agency cost construction/provision)	0.00	20.00	**80.00**	0.00	0.00	0.00	0.00	**2.00**
Usage (i.e., how many users utilize it on a specific time basis, e.g., a day)	20.00	20.00	**40.00**	0.00	20.00	0.00	0.00	**2.00**
Life-cycle costs (including M&R and user costs)	0.00	20.00	**40.00**	20.00	20.00	0.00	0.00	**2.43**
Customer/user feedback and/or complaints	0.00	20.00	20.00	**60.00**	0.00	0.00	0.00	**2.43**
Location	0.00	20.00	20.00	40.00	20.00	0.00	0.00	**2.57**
Functional condition (i.e., how well it can serve the public)	0.00	0.00	40.00	**60.00**	0.00	0.00	0.00	**2.57**
Attributes/characteristics (i.e., materials, service life, geometry, etc.)	0.00	0.00	20.00	**80.00**	0.00	0.00	0.00	**2.71**
Structural condition (i.e., how adequate it is for its purpose)	0.00	0.00	0.00	40.00	**60.00**	0.00	0.00	**3.29**

4. How decisions are made in your organization to finance a project maintenance or rehabilitation needs?

❖ Finance decided by higher officials (federal)

- Depend upon the required activity and road fund capacity or capital budget allocated for maintenance, reconstruction and upgrading
- Severity level, traffic, previous maintenance history, maintenance type, haul distance, service year and Road safety etc...

5. Which economic evaluation analysis method you use in your organization to evaluate the pavement economic viability?

➢ There is no at all (pass ability) economic evaluation analysis method used to evaluate the pavement economic viability.

6. When did ERA PMS launched?

➢ ERA PMS launched both the respondents said in 1942Et. C. (Both the team work as one) i.e. Client, Consultant and Contractor and by 2003(divided or dismantled in to different team)

7. Explain the current procedure for ERA Pavement Management System which applied at District.

➢ Procedure used for pavement management system which applied in the district:

- Define NW- Condition survey- rating -treatment selection-BOQ (Recommending maintenance type
- Define NW-Inventory- Condition (visual- over or under estimate)-Rate-Prioritize-Treatment selection -BOQ
- Define NW – condition (visual)- Rate (1-3)-BOQ- treatment selection
- Define NW – condition (visual)- Rate (1-3)- treatment selection- Budget (road fund and capital) – BOQ

8. At what level do you conduct Pavement Management? (i.e. project level and network level) why?

➢ Project level Pavement Management conducted in the district and the given reason as follow:

- ❖ Network level :
  - Difficult to manage (Not mandate of the district).
  - Requires detail specification
    - ✓ Requires huge budget
    - ✓ Well-organized machinery, equipment and skilled man power

9. Problems occur during the process of Pavement management system (PMS).

- ➢ Giving deficient attention for the PMS sector by the government.
- ➢ Budget allocation restriction and most of the time from road fund instead of capital budget.
- ➢ Existing machinery and equipment are worn out and old .
- ➢ Absence of modern Equipment (condition survey), machinery and adequate skilled man power(professionals)
- ➢ Lack of latest and modern management system, data organization (database system or ICT) and vehicles(inspection) and Drones
- ➢ Absence of Handling of professionals (occurrence of works beyond the scope that is difficult to manage)
- ➢ Existing condition of the road is above routine maintenance and also the manual prepared for routine maintenance.
- ➢ Over estimate of public needs (interest) during (ROW overhand & Quarry site) and Security (on site)

10. Propose to improve the road Pavement management system (PMS) at ERA/District.

- ➢ Provision of well-organized
  - o Management system, Database system, Modern equipment and machinery
- ➢ Allocation of adequate skilled professional man power or upgrade the educational status of staff (short- and long-term training)
- ➢ The budget should allocate from capital and adequate
- ➢ Update the manual including upgrading
- ➢ Handling of professionals
- ➢ Improve or peter the Security on site and resolve the bureaucracy problem

11. What your expectations for Pavement management system (PMS) in the future?

- In the near future we can achieve significant improvement and all the PMS process will be improved in the district.
- Strategic plan reform in all side corridor and revision of organizational structure in the authority can bring:
  - Modernize equipment and machineries usage
    - ✓ Condition survey, traffic count, maintenance, laboratory equipment etc.
    - ✓ Additional equipment ordered(laser)
    - ✓ Provision/ introducing CCTV camera (Closed Circuit TV)
  - Staff capacity improvement and system protection.
  - Database network (ICT) installation.

4.6. Archive

4.6.1. Inventory and Condition Survey of Pavement in Jimma district (ERA)

After road network definition, an inventory of the physical characteristics of the roadways being managed by the agency the existing pavement condition must be evaluated. Such an evaluation usually involves the assessment of the existing pavement structural, functional and surface condition survey using visual evaluation. Automated equipment currently used in the district if only data required by the federal road authority.

Pavement condition survey techniques differ between different countries and highway agencies; they are more focused one establishing the type, severity and extent of existing distress in order to determine the best maintenance management strategies. In this study period, PMS team is responsible for pavement evaluation. It is done on yearly bases using visual condition survey method in spread sheet which comprises. Street number, street name, total length, road type, defect type, defected area detail (specific area, length Width, area and condition) even if not depend up on PMMS procedure[40].

They perform condition survey for paved road with a team composed of data collectors (technicians) and engineers and carries out road condition survey once a year. This condition survey team collects by visual estimate for budget allocation until 2017 but for the rest two years the survey out sourced for private sector and collected at each network

segment as per ERA condition survey manual. After visual condition survey the pavement condition become summarized and reported as very good, good, fair, poor, very poor and also by types of distress. ***The maintenance type, unit rate and maintenance priority will be defined and reported to the maintenance department traditionally***. There are no destructive and none destructive test procedures for structural, functional and safety evaluation other than visual surface condition evaluation method which plays significant role in identifying major structural and functional condition of pavements for recommending the best option for maintenance and rehabilitation decisions.

During the interview it is found that districts road network directorate quantifies the defects based on the condition survey output, estimated maintenance type, estimated amount of work sent to the ERA head office so that the head office allocates maintenance budget. In district ERA most of maintenance activities are done by own construction firm called Ethiopian Road construction Corporation (ECWC) and few labor-based works are contracted to private firms. They undergo periodic and routine maintenance but they did not practice advanced pavement maintenance delivery systems as an alternative road maintenance system [40].

4.6.2. Pavement Construction and Maintenance in Jimma district (ERA)

The responsibility for maintaining the road network of Jimma district is assigned to the Roads Department of Construction and Maintenance of the Ethiopian Construction Works Corporation (ECWC) and private contractors. The Department of Roads Construction and Maintenance in Jimma ECWC is responsible for maintaining road network, consisting of trunk and link and main access paved roads. The district-maintained pavements for the last two years financial expenditure in Birr and physical in kilometer shows the allocated budget is only up to 50% from the required and decreased by 36.34% and shown in table 4.11 and figure 4.3 below[40].

Table 4.7. Pavement maintenance in Jimma district (in Birr and Kilo Meter) [40]

Financial, Birr	**Year**	**2010**	**2011**
	Initial Annual Budget	569,961,476	389,811,000.00
	Planed	564,382,643	382,320,834.44
	Actual	***284,033,401***	***180,808,088.59***
Physical, km	Planed	1,788	1,644.80
	Actual	1,056	1,627.81
Percentage	Financial, Birr		
	Planed	99.02	98.08
	Actual	**49.83**	**46.38**
	Physical, km	**59.06**	**98.97**

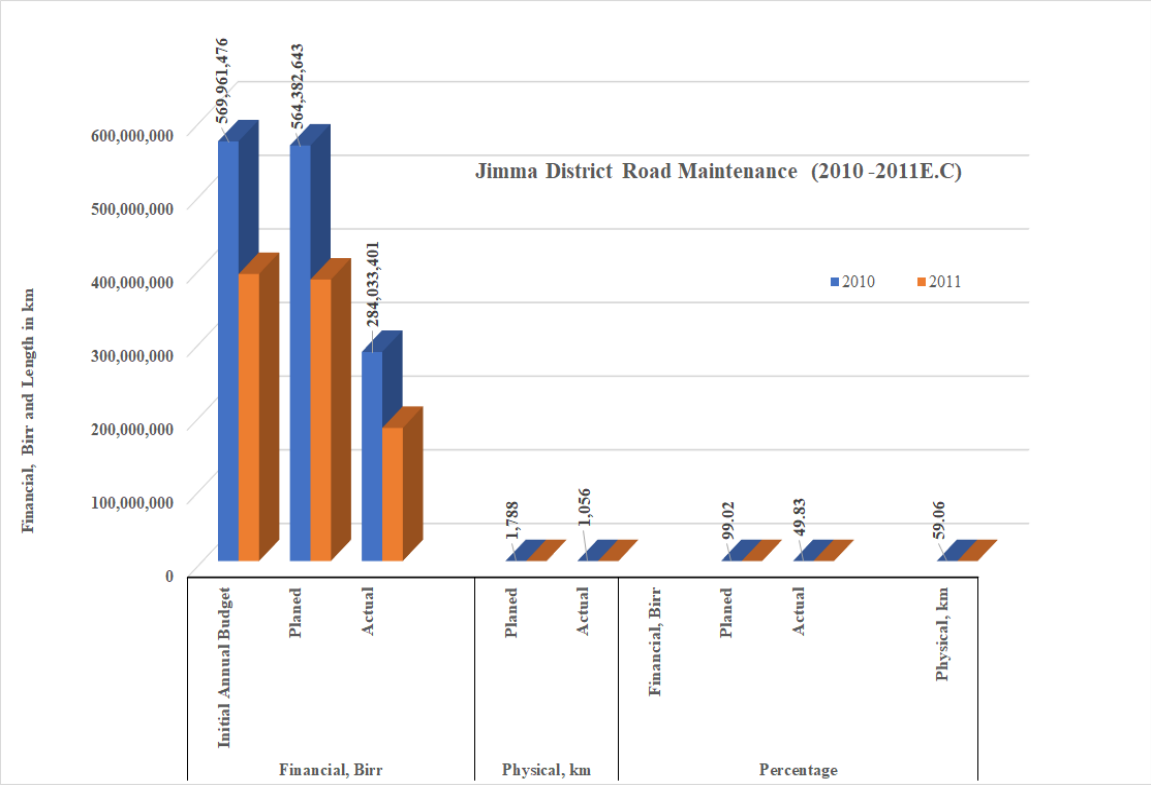

Figure 4.3. Pavement maintenance in Jimma district (in Birr and Kilo Meter)

The Department of Road Maintenance at district is responsible for performing routine and periodic maintenance works for the federal asphalt road. The department develop schedule for the maintenance activities to be done either patching, overlay and rehabilitation (surface treatment) which is already specified by road asset management department. The maintenance activates are usually done throughout the year as the condition is suitable. The available resources at the department in terms of technical

skills, human resources, and the quantity and condition of equipment are the backbone for its capability to carry out the road maintenance and rehabilitation programs. As it was informed by case team head during the field survey. Equipment Required for Maintenance work and agreed with ECWC for their Deployment, mobilized and the gap are illustrated in table included in appendix F. From the obtained or gathered information from the archives dump truck, logistics and machineries in the district construction division were not adequate [40].

Currently the whole maintenance and rehabilitation work under construction are seven but only two paved road. Every evaluation and maintenance activate not outsourced rather they work by own force.

- Jimma -Gibe Heavy Maintenance Road Project
- Saja- Fofa - Gilgel Gibe II Heavy Maintenance Road Project
- Meteso- Chida- Waka Periodic Maintenance Road Project
- Limu Jun - Kosa Routine Maintenance Road Project
- Gera Paving Town Section Project
- Slide Protection work of Yembero- Bedele Road Segment
- Shebel -Gambela- Abobo Routine Maintenance Road Project [40]

4.6.3. Road Maintenance and Rehabilitation Procedure

The Jimma district Road Asset Management Department is responsible for registering all road assets and defining the necessary maintenance activity with the respective maintenance cost to be done for district roads based on the condition survey data. The condition survey data is summarized in this office based on ERA manual severity and extent standards estimation. Since the budget allocated by the Authority for the maintenance and rehabilitation is limited for maintenance and rehabilitation works, they prioritize based on severity grade to the road which is affected worst for maintenance and rehabilitation prioritization. Moreover, they will focus on emergency works and other woks ordered by political pressure.

After defining the specific are types of maintenance and rehabilitation to be done, volume of work and the unit cost. They will provide to the construction and maintenance department to be repair. After receiving the works to be done the road construction and

maintenance department will make schedule, inform their schedule to the private consultant who signed contract for supervision and repair the defects[40].

4.6.4. Rehabilitation and Maintenance Strategies and Technique

Different rehabilitation and maintenance alternatives can be employed after determining the current pavement condition, the minimum acceptable level, and the prediction for pavement performance deterioration. As we discussed in the literature review maintenance treatment strategies are categorized as preventive maintenance and corrective maintenance. There are three maintenance strategies that are usually done in Jimma district these are pavement patching, overlay and surface treatment as preventive maintenance and rehabilitation.

Different road authorities have different maintenance technique for maintenance of asphalt pavement which helps in enhancing the life of asphalt pavement. For example, they use distress severity (density) to decide shallow or deep patching, sealing, overlaying and also, they use PCI values for suggesting either maintenance or rehabilitation works to be done. In Jimma district based on the distress types they categorize either patching, overlay and surface treatment will be done by experience. The thickness of overlay and the depth of patching are decided by the maintenance crew on site. There are no other specific maintenance treatment selection techniques practiced by the authority. Most of the major rehabilitation and upgrading of the district road maintenances out sourced for the private local and international contractors by maintenance contract administration team at federal level[40].

4.6.5. District Report on Paved Roads

Encountered Problems in respect of Projects with Slow Progress and/or Projects which were not commenced until the end of the fiscal year taken from report of Sept. to August 2019/20.

1. Jimma Section Routine Maintenance Road Project (HOT MIX ASPHALT ROAD)

- Shortage of resources such as; Dump Truck, Steel Roller, Motor Grader, Mini-Mixer (Hot-Mix Asphalt) and Asphalt Cutter
- Frequent Breakdown of Equipment owing to ageing. Example; Steel Drum Rollers, Pedestrian Roller (2.5 ton) and Dump Trucks

- Delay by the Contractor, ECWC in supplying Equipment spare parts owing to lack of adequate cash flow
- Right of way problem at quarry site. Example; Babu crusher stopped its operation for more than a year and in effect, routine maintenance work of Limmu junction to Kosa road and Atnago town section paving are significantly hampered.

2. Gore - Diri junction - Tepi Routine Maintenance Road Project.
   - Poor management and lack of proper organization of resources
   - Shortage of Fuel
3. Metu Section Routine Maintenance Road Project (HOT MIX ASPHALT & GRAVEL ROAD).
   - Shortage of Dump Trucks
   - Lack of resources (material, tools and equipment) in respect of asphalt concrete road maintenance
   - Lack of Gravel wearing course materials with good quality
   - Poor management and lack of proper organization of resources
   - Shortage of Fuel
4. Bure - Gambella - Jikawo Routine Maintenance Road Project (HOT MIX ASPHALT ROAD)
   - This Project was planned to be executed by ECWC following signature of a contract agreement. However, due to delay in contract signature, commencement of the planned maintenance works was also delayed. On the other hand, even if the contract was ready for implementation; the contractor had no resource at hand to execute maintenance works of the project.

5. Didessa River I - Dembi - Bedelle Heavy Maintenance Road Project (HOT MIX ASPHALT ROAD)
   - The Project was planned to be executed by private Contractor and in effect its workload was sent to engineering procurement six months ago. Nevertheless, owing to delay in procurement of a contractor, the planned maintenance work was not started until end of the fiscal year[40].

4.7. Summary

In this section, the findings of the research were compared, summarized, and discussed from the perspectives of the literature review and objectives of the study regarding pavement maintenance management system practice.

From the analysis of the study, there is no pavement maintenance management system components implementation practice in its fullest sense in the district like strategies and policies which guides how to practice pavement maintenance management system. Condition survey of the road in the network should be clearly defined and categorized, most common pavement management performance measures relate functional and structural capacity of the pavement. These categories of performance features could provide the basis for cross pavement maintenance treatment selection, prioritization, and optimization.

Data collections and selections in the district are manual are predominantly based on past practices and personnel experience. Data management methods used in the district and storing the collected data manually on paper-based then converted into an Excel sheet and stored in computers. Mostly they do not collect data with data collection standards and input needs of management systems behind the rationalization of data collection.

Pavement management training has been an important aspect of management strategy. It is noted that a good pavement management system requires well-informed staff capable of understanding the data-collection process, data management, interpretation, and what the data mean but the district lacks it.

Pavement management administrators should identify and need to change the principles of the organization to think of pavement management as an important occupational area as an important task. The organization had a management position responsible for pavement management should work on creating organizational principles. As the experience of other countries found, pavement management practices have been used successfully to obtain funding, if the pavement management system used fully and operational it will help to minimize financial challenges. And also, competent professionals in the area have to be produced, sharing experience from other countries' professionals on how to develop competency.

CHAPTER-FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the results obtained from this research, the following conclusions of the research are drawn:

- There is a lack of Pavement Maintenance Management System implementation practice in its comprehensive sense in the district Roads Authority. The execution stage of a Pavement Management system is still at the scheduling stage. Most of the management systems have not been utilized well.

- The study finds that the challenge/characteristics of PMMS for effective planning and management of the pavement network are:

  - ✓ The present pavement evaluation method used by the district is not adequate for evaluating the pavement for structural and functional road conditions periodical.

  - ✓ There is no well-defined maintenance prioritizing method and also outsourcing maintenance and rehabilitation works to other private contracting companies are not established well.

  - ✓ The district does not apply different types of maintenance treatment selection techniques that are mandatory for recommended specific and cost-effective remedial maintenance measures.

  - ✓ Data stored in paper format/EXCELL storage media and does not use any data integration system.

  - ✓ There is no economic evaluation analysis method used to evaluate the pavement economic viability, this has resulted in the maintenance operation not to be efficient and effective.

- The main problems for practicing different pavement evaluation method, implementation of effective asphalt road pavement maintenance and rehabilitation work and to establish pavement maintenance management system (PMMS) in the district are:

  - ✓ A budget constraint, absence of appropriate machinery, lack of monitory and quality control, lack of appropriate PMS, shortage of skilled manpower, political influence or involvement and lack of awareness for its benefits and costs of PMMS.

  - ✓ Lack of vehicles for inspection, handling of professionals, delay in contract signature and payments, and most of the existing condition of the road is above routine maintenance and the manual prepared for routine maintenance.

  - ✓ Overestimate of public interest during ROW overhand & Quarry site, and Security (on-site).

- The main factors that affect implementing the PMMS are:

  - ✓ The government giving deficient attention to the pavement maintenance management sector, using the sector for political reasons and limitation of the country's economy.

  - ✓ Limitation of professional competency, awareness, initiation, and responsibility for benefits of procedural implementation of PMMS components.

  - ✓ Absence of awareness and willingness to cooperate during the land acquisition by the owner of the land on ROW and quarry site.

5.2. Recommendations

Based on the finding of this research, the following recommendations have been forwarded for use by relevant policymakers at Road Authority as well at the government level.

- For a well-organized Pavement Maintenance Management System, a very important components like Location Reference System, Sectioning of Network, Database, Data Acquisition, Pavement Evaluation, Pavement Performance Prediction, Maintenance, and Rehabilitation Planning, and Prioritization and Optimization should execute.
  - ✓ Quality Management has to be integrated at all stages in pavement maintenance: data collection, storage and analysis to ensure accurate information that has to be given to the management decision-makers.
  - ✓ To ensure effective and efficient use of resources, ERA/District shall assess alternative PMMS tools like a spreadsheet, GIS tool, and/or a pavement management software and apply the methods or in a combination of methods.
  - ✓ PMMS has to be designed and managed: for maintenance and rehabilitation activities optimization, pavement deterioration reduction with proper implementation of pavement conditions evaluation with available funds, considers current and future pavement conditions, database system, rating, priorities, funding, and execution of works and monitoring.
  - ✓ ERA/District administration and authority must emphasize road maintenance works and seek for various funding options to fill the gap on maintenance and repair postponement.
  - ✓ It is recommended that ERA/District has to organize the pavement maintenance management department with adequate skilled manpower, equipment and, machinery also has to establish pavement maintenance management systems.
  - ✓ The Pavement maintenance management systems has to be manageable at the district level, responsible for the implementation at every step of management and free from political influence.
  - ✓ Giving an awareness benefits and costs of Pavement Maintenance Management System for the stakeholders and ensure security (on-site).

5.3. Future Research Needs

- Pavement was not addressed for unpaved road maintenance management interventions in this study. Thus, future studies are needed by collecting data on both paved and gravel road maintenance options for proper decision-making.
- Since the data of pavement maintenance management depends on such factors like Inventory, condition and others, future research is needed on pavement maintenance in Ethiopia by taking representative sample roads from all ERA's road maintenance regional areas and ten maintenance districts.
- Given the limited amount of budget for Pavement maintenance in Ethiopia, determining the possible project of different pavement maintenance interventions using the PMMS and HDM-4 was left to future studies in the area

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APPENDIX

A - Questioner Schedule

Introduction

This interview schedule is prepared to obtain information from key informants with semi structured questions. The information will require for the academic research entitled "**Challenges on pavement maintenance management system (Case Study in Jimma district federal asphalt road)**" which is being conducted as partial fulfillment of MSc in highway engineering. The main objective of the research will to asses current management system in relation to the status of the pavement maintenance and make recommendations based on the findings.

The schedule consists of four sections with a total of 22 questions. Section one contains general questions about the informants. Section two, assesses the current practices of pavement maintenance management system at district level. Section three examines Inventory, performance, prioritizing and selecting treatments etc. based maintenance management for Ethiopian federal roads in the district. Section four investigates the implementing the PMMS.

- **Your response, in this regard, is highly valuable and contributory to the outcome of the research.**
- **All feedback will be kept strictly confidential, and utilized for this academic research only.**
- **Thank you in advance for your willingness to fill the questionnaires and returning it back on time.**

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Jimma, Ethiopia

Section -1: The questions below are related to your organization and yourself. Please indicate your response by ticking (x or √) the appropriate box (es), and also finding the blank spaces provided as appropriate.

1.1 Respondents name _____

1.2 Name of organization _____

1.3 Type of organization: Employer ☐ Contractor ☐ Consultant ☐

1.4 Address(optional) _____

1.5 Designation _____

1.6 Experience in:

- Experienced workers ☐
- Pavement maintenance works ☐
- Accounts ☐
- PMMS experts ☐
- Roads maintenance Engineers ☐
- Roads Director ☐

<5years ☐ 5-10 years ☐ >10 years ☐

1.7 Level of Academic: Diploma ☐ First Degree ☐ Second Degree ☐

Other specify _____

Section: 2 Current MMS evaluations

2.1 In your opinion in Jimma district asphalt federal road condition status is good?

Strongly agree ☐ slightly agree ☐ Neutral ☐ slightly disagree ☐ strongly disagree ☐

Please specify reason _____

2.2 Did ERA/District currently carry out destructive and non-destructive tests other than visual pavement condition evaluation method?

Strongly agree ☐ slightly agree ☐ Neutral ☐ slightly disagree ☐ strongly disagree ☐

2.3 Does the present pavement evaluation method used by ERA/ District is adequate for evaluating the pavement for structural, functional and safety of road condition periodical?

Strongly agree ☐ slightly agree ☐ Neutral ☐ slightly disagree ☐ strongly disagree ☐

Why_____

2.4 What are the main problems for practicing different evaluation method in ERA/ District, that are mandatory for recommending the best maintenance option?

1. Very important 2. Important 3. Average 4. Least important 5. Not important

A. Limited skilled manpower	1	2	3	4	5
B. Lack of appropriate pavement management system	1	2	3	4	5
C. Budget constraint	1	2	3	4	5
D. Absence of appropriate machinery	1	2	3	4	5

E. Other specify _____

Section: 3 Pavement Rehabilitation and Maintenance

3.1 Did ERA/ District apply alternative pavement treatment types different from overlay patching? If your answer is "YES", How well does the service provided?

Extremely well ☐ Very well ☐ Somewhat well ☐ Not so well ☐ Not well at all ☐

3.2 ERA/District uses overlay and patching as preventive and rehabilitation maintenance strategy. Are those strategies adequate for preserving pavement in good condition and reducing expensive maintenance work? If your answer is "ADEQUATE", How would you rate the value?

Extremely well ☐ Very well ☐ Somewhat well ☐ Not so well ☐ Not well at all ☐

3.3 In your opinion did ERA/District apply different types of maintenance treatment selection techniques that are mandatory for recommending specific and cost-effective remedial maintenance measures to be taken? If your answer is "YES", How do you evaluate the treatment selection techniques?

Extremely well ☐ Very well ☐ Somewhat well ☐ Not so well ☐ Not well at all ☐

Why_____

3.4 Do you consider the quality of maintenance and rehabilitation work in ERA/District is sufficient? If your answer is "SUFFICENT", How well does the service provided?

Extremely well ☐ Very well ☐ Somewhat well ☐ Not so well ☐ Not well at all ☐

Please specify reason _____

3.5 What are the main constraints for implementation of effective road maintenance and rehabilitation work in ERA/District?

1. Very important 2. Important 3. Average 4. Least important 5. Not important

A. Limited skilled manpower	1	2	3	4	5
B. Lack of appropriate pavement management system	1	2	3	4	5
C. Budget constraint	1	2	3	4	5
D. Absence of appropriate machinery	1	2	3	4	5
E. Lack of monitory and quality control	1	2	3	4	5

F. Other specify _____

<u>Section 4</u>: Pavement maintenance management

4.1 Is there well-established road maintenance management system in ERA/District for effective planning and management of pavement network?

Strongly agree ☐ slightly agree ☐ Neutral ☐ slightly disagree ☐ strongly disagree ☐

4.2 There is different alternate maintenance prioritizing methods to insure the limited available resource to be utilized in most effective manner. Did ERA/ District have well defined organizational maintenance prioritizing method?

Strongly agree ☐ slightly agree ☐ Neutral ☐ slightly disagree ☐ strongly disagree ☐

4.3 ERA/District outsources rehabilitation and maintenance works to other private contracting companies?

Strongly agree ☐ slightly agree ☐ Neutral ☐ slightly disagree ☐ strongly disagree ☐

Please specify reason _____

4.4 What are the main constraints to establish pavement maintenance management system (PMMS) in ERA/District?

1. Very important 2. Important 3. Average 4. Least important 5. Not important

A. Limited skilled manpower	1	2	3	4	5
B. Lack of awareness for its benefits and costs of PMMS	1	2	3	4	5
C. Budget constraint	1	2	3	4	5
D. Absence of appropriate machinery	1	2	3	4	5
E. Political influence or involvement	1	2	3	4	5

F. Other please specify _____

THANK YOU!

B - Interview Schedule

I wish to thank you for your participation in this research. The interview you are about to answer to questions is regarding a research for a degree of Master of Science in Highway Engineering. This research is being done on "**Challenges on pavement maintenance management system (Case Study in Jimma district federal asphalt road)**"

ORIENTATION AND INTRODUCTION FOR PARTICIPANTS IN RELATION TOTHEINTERVIEW QUESTIONS:

1. First of all, I would like say thank you for your valuable time and cooperation to answer the following interview questions.

2. Please note that your response is anonymous and will be treated in absolute confidentiality.

3. The interview comprises some questions and may take approximately up to 30 minutes to complete.

4. Should your company or organization wish to receive a copy of the final research report, you are welcome to contact Mr. Mohammed Hassen; phone +251 913301958; Email: moha.1958@yahoomail.com.

Organization and Respondent's position

- Branch Road Network Administration Team ☐
- Road Safety, Axle Load & ROW Management Team ☐
- Maintenance Contract Administration Team ☐
- Administration & Finance Team ☐

1. Once the data have been acquired by one or more methods and technologies they are stored in various formats and storage media. Data formats include: paper format, electronic databases, and geo-referenced database systems (such as Geographic Information Systems, GIS). The storage media employed can be paper forms (still in use in many agencies), hard disks, magnetic tapes, CDs, DVDs and combinations of there after what is the mechanism you follow to manage the data collected in your organization?_____

2.Integration of road asset management system is an application of suitable asset management software which will integrate all individual road management systems. Data integration alternatives include two main approaches: a fused database and many interoperable databases. In the first case the integration strategy leads to the creation of one database that contains all integrated data; in the second case existing or newly created databases are linked together and the integration of the data is achieved with the use of queries that provide a view of the linked data. Or GIS software and related functionalities can alternatively be incorporated in the databases as external software that enhances the analytical and reporting capabilities of the system. What data integration system you use in your organization? _____

3.What data are used to prioritize and select between two projects for example between two pavement maintenance projects and how much important is it?

Road way asset data	Level of importance						
	Very low	Low	Medium	High	Very high	Not important	Don't know
Location							
Attributes/characteristics (i.e., materials, service life, geometry, etc.)							
Structural condition (i.e., how adequate it is for its purpose)							
Functional condition (i.e., how well it can serve the public)							
Initial agency cost construction/provision)							
Life-cycle costs (including M&R and user costs)							
Usage (i.e., how many users utilize it on a specific time basis, e.g., a day)							
Customer/user feedback and/or complaints							

4.How decisions are made in your organization to finance a project maintenance or rehabilitation needs?_____

5.Which economic evaluation analysis method you use in your organization to evaluate the pavement economic viability?_____

6.When did ERA PMS launched?_____

7.Explain the current procedure for ERA Pavement Management System which applied at District. _____

8.At what level do you conduct Pavement Management? (i.e. project level and network level) why? _____

9.Problems occur during the process of Pavement management system (PMS). _____

10.Propose to improve the road Pavement management system (PMS) at ERA/District.

_____

11.What your expectations for Pavement management system (PMS) in the future?_____

C - Sample size computation per group per organization

Roads Director or top managements (Group –I) who involved;

a) Client
   Sr = Pc x (St/Pt) = 22*(5/32) = 3
b) Contractor
   Sr = Pc x (St/Pt) = 22*(2/32) = 1
c) Consultant
   Sr = Pc x (St/Pt) = 22*(1/32) = 1

PMMS experts, Roads maintenance Engineers, Group –II

a) Client
   Sr = Pc x (St/Pt) = 22*(11/32) = 8
b) Contractor
   Sr = Pc x (St/Pt) = 22*(10/32) = 7
c) Consultant
   Sr = Pc x (St/Pt) = 22*(3/32) = 2

Sample size of study area

S. No.	Category of study population	Total population estimated for the study				Total respondent			
		Client	**Contractor**	**Consultant**	**Total**	**Client**	**Contractor**	**Consultant**	**Total**
1	Roads Director or top managements, Group -I	5	2	1	**8**	3	1	1	**5**
2	PMMS experts, Roads maintenance Engineers, Group -II	11	10	3	**24**	8	7	2	**17**
Total					**32**				**22**

Out of the total thirty-two professional questionnaires seventeen and five interview a total of 22(68.75%) returned and was taken.

D - Respondents' distribution respective position, Level of Education & Experience

Respondents' distribution respective position

Division of Organization in the district	Position			Percentage (%)		
	Top-Level Mgmt.	Mid-Level (Maintenance experts)	Bottom-level (Maintenance Engineers)	Top Level Mgmt.	Mid-Level	Bottom-Level
ERA	5/22	7/22	10/22	**22.73**	**31.82**	**45.45**
Contractor						
Consultant						

Respondents' distribution respective Level of Education

Division of Organization in the district	Level of Education			Percentage (%)		
	Master's Degree	B.Sc. Degree	Diploma/Technical Certificate	Master's Degree	B.Sc. Degree	Diploma/Technical Certificate
ERA	2/22	17/22	3/22	9.10	77.27	13.63
Contractor						
Consultant						

Respondents' distribution respective Experience

Division of Organization in the district	Experience in years			Percentage (%)		
	0 – 5	5– 10	>10	0 – 5	5– 10	>10
ERA	9/22	8/22	5/22	40.91	36.37	22.72
Contractor						
Consultant						

E - Summary of Response

Average Index Value (Questionnaire)

Value	Strongly agree			Slightly agree			Neutral			Slightly disagree			Strongly disagree			Total Response			AI
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	AI
2.1	0	0	0	4	1	1	0	0	1	5	2	3	0	0	0	9	3	5	**3.24**
2.2	3	0	0	3	1	2	3	0	0	0	2	0	0	0	3	9	3	5	**2.76**
2.3	0	0	0	6	0	4	1	0	0	2	2	1	0	1	0	9	3	5	**2.82**

2.4 Value	Very Important			Important			Average			Least Important			Not Important			Total Response			AI
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	AI
Limited skilled manpower	2	0	3	3	2	1	0	1	0	2	0	1	2	0	0	9	3	5	**2.47**
Lack of appropriate pavement management	2	1	2	4	2	2	1	0	1	1	0	0	1	0	0	9	3	5	**2.12**
Budget constraint	3	3	2	3	0	3	2	0	0	1	0	0	0	0	0	9	3	5	**1.76**
Absence of appropriate machinery	3	0	3	4	2	2	1	0	0	0	0	0	1	1	0	9	3	5	**2.06**

Value	Extremely well			Very well			Somewhat well			Not so well			Not well at all			Total Response			AI
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	AI
3.1	2	0	0	4	0	0	1	2	1	0	1	3	2	0	1	9	3	5	**3.12**
3.2	0	0	0	2	2	3	7	0	1	0	1	1	0	0	0	9	3	5	**2.71**
3.3	2		1	4	1	1	3	0	1		2	2	0	0	0	9	3	5	**2.53**
3.4	0	0	0	0	0	1	7	1	2	2	2	2	0	0	0	9	3	5	**3.29**

3.5 Value	Very Important			Important			Average			Least Important			Not Important			Total Response			AI
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	AI
Limited skilled manpower	1	0	2	4	0	1	1	3	2	2	0	0	1	0	0	9	3	5	**2.59**
Lack of appropriate pavement management system	1	1	2	2	1	1	4	0	2	1	0	0	1	1	0	9	3	5	**2.59**
Budget constraint	7	1	3	0	2	2	1	0	0	1	0	0	0	0	0	9	3	5	**1.53**
Absence of appropriate	4	2	3	3	0	2	1	1	0	0	0	0	1	0	0	9	3	5	**1.76**
Lack of monitory and quality control	2	1	2	1	1	2	6	0	1	0	0	0	0	1	0	9	3	5	**2.29**

Value	Strongly agree			Slightly agree			Neutral			Slightly disagree			Strongly disagree			Total Response			AI
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	AI
4.1	1	0	0	0	1	2	1	1	1	5	3	0	2	0	2	9	5	5	4.00
4.2	3	0	0	0	1	1	1	0	1	5	2	3		0	0	9	3	5	3.12
4.3	3	0	0	3	1	2	2	2	1	1	0	1	0	0	1	9	3	5	2.53

4.4 Value	Very Important			Important			Average			Least Important			Not Important			Total Response			AI
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	AI
Limited skilled manpower	1	1	2	0	2	1	5	0	2	2	0	0	1	0	0	9	3	5	**2.59**
Lack of awareness for it benefits & costs of PMMS	1	0	2	2	0	2	4	1	1	0	1	0	2	1	0	9	3	5	**2.82**
Budget constraint	2	2	2	4	1	3	1			1			1			9	3	5	**2.00**
Absence of appropriate machinery	1	1	2	5	0	3	1	1	0	1	0	0	1	1	0	9	3	5	**2.35**
Political influence or	4	0	1	0	2	2	1	0	1	3		0	1	1	1	9	3	5	**2.71**

Average Index Value (Interview)

What data are used to prioritize and select between two projects for example between two pavement maintenance projects and how much important is it?	AI
Location	**2.57**
Attributes/characteristics (i.e., materials, service life, geometry, etc.)	**2.71**
Structural condition (i.e., how adequate it is for its purpose)	**3.29**
Functional condition (i.e., how well it can serve the public)	**2.57**
Initial agency cost construction/provision)	**2.00**
Life-cycle costs (including M&R and user costs)	**2.43**
Usage (i.e., how many users utilize it on a specific time basis, e.g., a day)	**2.00**
Customer/user feedback and/or complaints	**2.43**

Percentage (Questionnaire)

Value	Strongly agree			Slightly agree			Neutral			Slightly disagree			Strongly disagree			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
2.1	0.00	0.00	0.00	23.53	5.88	5.88	0.00	0.00	5.88	29.41	11.76	17.65	0.00	0.00	0.00	52.94	17.65	29.41
2.2	17.65	0.00	0.00	17.65	5.88	11.76	17.65	0.00	0.00	0.00	11.76	0.00	0.00	0.00	17.65	52.94	17.65	29.41
2.3	0.00	0.00	0.00	35.29	0.00	23.53	5.88	0.00	0.00	11.76	11.76	5.88	0.00	5.88	0.00	52.94	17.65	29.41

Value	Strongly agree			Slightly agree			Neutral			Slightly disagree			Strongly disagree			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
2.1	0.00			35.29			5.88			58.82			0.00			100.00		
2.2	17.65			35.29			17.65			11.76			17.65			100.00		
2.3	0.00			58.82			5.88			29.41			5.88			100.00		

2.4 Value	Very Important			Important			Average			Least Important			Not Important			Total Percentage(%)		
Sector	Client	Consu	Contra	Client	Consu	Contra	Client	Consu	Contra	Client	Consu	Contra	Client	Consu	Contra	Client	Consu	Contra
Limited skilled manpower	11.76	0.00	17.65	17.65	11.76	5.88	0.00	5.88	0.00	11.76	0.00	5.88	11.76	0.00	0.00	52.94	17.65	29.41
Lack of appropriate pavement management system	11.76	5.88	11.76	23.53	11.76	11.76	5.88	0.00	5.88	5.88	0.00	0.00	5.88	0.00	0.00	52.94	17.65	29.41
Budget constraint	17.65	17.65	11.76	17.65	0.00	17.65	11.76	0.00	0.00	5.88	0.00	0.00	0.00	0.00	0.00	52.94	17.65	29.41
Absence of appropriate machinery	17.65	0.00	17.65	23.53	11.76	11.76	5.88	0.00	0.00	0.00	0.00	0.00	5.88	5.88	0.00	52.94	17.65	29.41

2.4 Value	Very Important			Important			Average			Least Important			Not Important			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
Limited skilled manpower	29.41			35.29			5.88			17.65			11.76			100.00		
Lack of appropriate pavement management	29.41			47.06			11.76			5.88			5.88			100.00		
Budget constraint	47.06			35.29			11.76			5.88			0.00			100.00		
Absence of appropriate machinery	35.29			47.06			5.88			0.00			11.76			100.00		

Value	Extremely well			Very well			Somewhat well			Not so well			Not well at all			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
3.1	11.76	0.00	0.00	23.53	0.00	0.00	5.88	11.76	5.88	0.00	5.88	17.65	11.76	0.00	5.88	52.94	17.65	29.41
3.2	0.00	0.00	0.00	11.76	11.76	17.65	41.18	0.00	5.88	0.00	5.88	5.88	0.00	0.00	0.00	52.94	17.65	29.41
3.3	11.76	0.00	5.88	23.53	5.88	5.88	17.65	0.00	5.88	0.00	11.76	11.76	0.00	0.00	0.00	52.94	17.65	29.41
3.4	0.00	0.00	0.00	0.00	0.00	5.88	41.18	5.88	11.76	11.76	11.76	11.76	0.00	0.00	0.00	52.94	17.65	29.41

Value	Extremely well			Very well			Somewhat well			Not so well			Not well at all			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
3.1	11.76			23.53			23.53			23.53			17.65			100.00		
3.2	0.00			41.18			47.06			11.76			0.00			100.00		
3.3	17.65			35.29			23.53			23.53			0.00			100.00		
3.4	0.00			5.88			58.82			35.29			0.00			100.00		

3.5 Value	Very Important			Important			Average			Least Important			Not Important			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
Limited skilled manpower	5.88	0.00	11.76	23.53	0.00	5.88	5.88	17.65	11.76	11.76	0.00	0.00	5.88	0.00	0.00	52.94	17.65	29.41
Lack of appropriate pavement management system	5.88	5.88	11.76	11.76	5.88	5.88	23.53	0.00	11.76	5.88	0.00	0.00	5.88	5.88	0.00	52.94	17.65	29.41
Budget constraint	41.18	5.88	17.65	0.00	11.76	11.76	5.88	0.00	0.00	5.88	0.00	0.00	0.00	0.00	0.00	52.94	17.65	29.41
Absence of appropriate machinery	23.53	11.76	17.65	17.65	0.00	11.76	5.88	5.88	0.00	0.00	0.00	0.00	5.88	0.00	0.00	52.94	17.65	29.41
Lack of monitory and quality	11.76	5.88	11.76	5.88	5.88	11.76	35.29	0.00	5.88	0.00	0.00	0.00	0.00	5.88	0.00	52.94	17.65	29.41

3.5 Value	Very Important			Important			Average			Least Important			Not Important			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
Limited skilled manpower			17.65			29.41			35.29			11.76			5.88			100.00
Lack of appropriate pavement management system			23.53			23.53			35.29			5.88			11.76			100.00
Budget constraint			64.71			23.53			5.88			5.88			0.00			100.00
Absence of appropriate machinery			52.94			29.41			11.76			0.00			5.88			100.00
Lack of monitory and quality			29.41			23.53			41.18			0.00			5.88			100.00

Value	Strongly agree			Slightly agree			Neutral			Slightly disagree			Strongly disagree			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
4.1	5.88	0.00	0.00	0.00	5.88	11.76	5.88	5.88	5.88	29.41	17.65	0.00	11.76	0.00	11.76	52.94	29.41	29.41
4.2	17.65	0.00	0.00	0.00	5.88	5.88	5.88	0.00	5.88	29.41	11.76	17.65	0.00	0.00	0.00	52.94	17.65	29.41
4.3	17.65	0.00	0.00	17.65	5.88	11.76	11.76	11.76	5.88	5.88	0.00	5.88	0.00	0.00	5.88	52.94	17.65	29.41

Value	Strongly agree			Slightly agree			Neutral			Slightly disagree			Strongly disagree			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
4.1		5.26			15.79			15.79			42.11			21.05			100.00	
4.2		17.65			11.76			11.76			58.82			0.00			100.00	
4.3		17.65			35.29			29.41			11.76			5.88			100.00	

4.4 Value	Very Important			Important			Average			Least Important			Not Important			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
Limited skilled manpower	5.88	5.88	11.76	0.00	11.76	5.88	29.41	0.00	11.76	11.76	0.00	0.00	5.88	0.00	0.00	52.94	17.65	29.41
Lack of awareness for it benefits & costs of PMMS	5.88	0.00	11.76	11.76	0.00	11.76	23.53	5.88	5.88	0.00	5.88	0.00	11.76	5.88	0.00	52.94	17.65	29.41
Budget constraint	11.76	11.76	11.76	23.53	5.88	17.65	5.88	0.00	0.00	5.88	0.00	0.00	5.88	0.00	0.00	52.94	17.65	29.41
Absence of appropriate machinery	5.88	5.88	11.76	29.41	0.00	17.65	5.88	5.88	0.00	5.88	0.00	0.00	5.88	5.88	0.00	52.94	17.65	29.41
Political influence or	23.53	0.00	5.88	0.00	11.76	11.76	5.88	0.00	5.88	17.65	0.00	0.00	5.88	5.88	5.88	52.94	17.65	29.41

4.4 Value	Very Important			Important			Average			Least Important			Not Important			Total Percentage(%)		
Sector	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor	Client	Consultant	Contractor
Limited skilled manpower			23.53			17.65			41.18			11.76			5.88			100.00
Lack of awareness for it benefits & costs of PMMS			17.65			23.53			35.29			5.88			17.65			100.00
Budget constraint			35.29			47.06			5.88			5.88			5.88			100.00
Absence of appropriate machinery			23.53			47.06			11.76			5.88			11.76			100.00
Political influence or			29.41			23.53			11.76			17.65			17.65			100.00

F- Equipment Required, agreed, mobilized and the gap with ECWC[40].

S. No.	Type	Required	Mobilized to the Site	Gap	Rental	Under Repair
1	Dump Truck	47	29	30	18	
2	Roller (> 8 tone)	9	5	4		
3	Pneumatic Tire Rollers 8-10 Tone	5	3	2		2
4	W/Truck	12	7	5		2
5	Grader	9	5	4		
6	Asphalt hot Mini Mix	0	0	0		
7	Dozer	2	2	0		
8	Asphalt Cutter	0	0	0		
9	Loader	11	9	4	1	1
10	Excavator	5	4	5	2	
11	Crusher	7	5	4		
12	Light Plant	2	3	0		
13	Back loaded	0	1	1		
14	Asphalt distributor 6000Ltrs	5	2	3		2
15	Bitumen kettle	3	1	2		
16	Chipping spreader	1	0	1		
17	Paver	2	1	1		
18	Asphalt Plant	2	1	1		