# EVALUATION OF THE FLEXIBLE ROAD PAVEMENT CONDITION WITHIN UNIVERSITY OF BENIN, UGBOWO CAMPUS USING GEOGRAPHICAL INFORMATION SYSTEMS (GIS) TECHNIQUES

**BY**

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# PLAGIARISM

This work **EVALUATION OF THE FLEXIBLE ROAD PAVEMENT CONDITION WITHIN UNIBEN ENVIRONMENT GEOAGRAPHICAL INFORMATION SYSTEMS (GIS) TECHNIQUES** by ALONGE, Imuzeze Onome with Number ENG2006165 of the Department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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# CERTIFICATION

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# DEDICATION

This study is dedicated to God Almighty, whose grace and guidance have been instrumental in the successful completion of this academic work.

It is also dedicated to my parents and family members, whose unwavering support, encouragement, and sacrifices have been invaluable throughout the course of my undergraduate education.

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# ABSTRACT

In Nigeria, road construction is often followed by neglect, with little or no provision for maintenance. This accelerates pavement deterioration due to factors such as rainfall, traffic loads, poor drainage, and harsh environmental conditions. This study aims to evaluate the condition of a 0.25 km road connecting Ethiope River Road and the University of Benin Back Gate (Ugbowo Campus).

The study involved a field survey to document visible deterioration, followed by an assessment using the Pavement Condition Index (PCI) and Pavement Condition Rating (PCR) methods. The procedure adhered to ASTM D6433-07 standards, with the roadway divided into 5 sample units. Each unit was inspected for distress type, severity, and extent, and PCI values were calculated and categorized from "Failed" to "Excellent." The results were analyzed and mapped using ArcGIS software for spatial visualization.

The calculated PCI values for the five sample units, S1, S2, S3, S4 and S5 were 75, 49, 62, 55, and 32 respectively. These values correspond to pavement condition ratings (PCR) spanning from Satisfactory to Very Poor. The overall PCI for the road section was determined by computing the average of the individual unit PCI values, yielding an overall PCI of 54.6 for the Ekosodin Road, which classifies the pavement as being in a poor condition according to ASTM D6433-07 standards. The GIS-based spatial analysis revealed a concentration of severe pavement distresses toward the mid and lower portions of the road, suggesting localized structural and drainage-related problems. The results (Overall PCI of 54.6 and the digitized road section) indicates that while the pavement remains marginally serviceable, it requires urgent maintenance and partial rehabilitation to restore its functionality and prevent further deterioration. The combined use of PCI, PCR, and GIS tools proved to be a reliable and effective approach for comprehensive pavement condition assessment and should be adopted for routine pavement management within the University of Benin and similar environments.

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# ACRONYMS

AADT – Annual Average Daily Traffic

AASHTO – American Association of State Highway and Transportation Officials

ASTM – American Society for Testing and Materials

B.Eng – Bachelor of Engineering

CAD – Computer-Aided Design

CGIS – Canadian Geographic Information System

DMS – Degrees, Minutes and Seconds

DR – Distress Rating

DSM – Digital Surface Model

ESALs – Equivalent Single Axle Loads

ESRI – Environmental Systems Research Institute

FWD – Falling Weight Deflectometer

GIS – Geographic Information System

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

H – High Severity

IRI – International Roughness Index

L – Low Severity

LiDAR – Light Detection and Ranging

M – Medium Severity

M&R – Maintenance and Rehabilitation

PASER – Pavement Surface Evaluation and Rating

PCC – Portland Cement Concrete

PCI – Pavement Condition Index

PCR – Pavement Condition Rating

PMMS – Pavement Maintenance Management System

PMS – Pavement Management System

PSI – Present Serviceability Index

PSR – Present Serviceability Rating

QGIS – Quantum GIS

QPCI – Quantum Pavement Condition Index

RAP – Reclaimed Asphalt Pavement

ROMDAS – Road Measurement & Data Acquisition System

SfM – Structure-from-Motion

UAV – Unmanned Aerial Vehicle

UNIBEN – University of Benin

UPMS – Urban Pavement Management System

UTM – Universal Transverse Mercator

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background of The Study

Flexible road pavement remains the most commonly used pavement type for highway construction in Nigeria, primarily due to its relatively low construction cost (Adeke et al., 2019). A nation’s transportation infrastructure is closely tied to its development and economic growth, making the maintenance and management of road pavements essential, especially amid rapid roadway expansion (Adanikin et al., 2022). Regardless of construction quality, all pavements deteriorate over time; thus, timely repairs are crucial. Allowing pavement to degrade to a hazardous condition can compromise safety and the integrity of road use (Adanikin et al., 2022). Pavement performance naturally declines with prolonged usage and increasing traffic load (Yang et al., 2016). Inadequate maintenance further contributes to road accidents, property damage, and social disconnection (Oyedepo et al., 2019). Deterioration can stem from several sources, including excessive traffic loads, climatic variations, poorly constructed shoulders, weak clayey subgrades, and inadequate drainage systems (El Nthaga et al., 2025). The quality of a pavement's performance depends heavily on proper assessment and timely implementation of maintenance measures (Adanikin et al., 2022). Assessing pavement conditions enables engineers to detect distresses (failures) effectively and economically by identifying their type, severity, and extent. This is typically conducted through visual inspection and with the aid of digital tools such as Google Earth, Micro PAVER software—used to compute Pavement Condition Index (PCI) values—and ArcGIS software for developing a Pavement Management System (PMS) database to guide Maintenance and

Rehabilitation (M&R) planning. There are two primary types of failures: structural distresses, which involve breakdowns in one or more pavement layers, and functional distresses, which may or may not involve structural failure but cause driver discomfort (Almuhanna et al., 2018). To determine the necessary maintenance actions and to ensure the pavement remains at a satisfactory service level, PCI serves as a critical indicator (Abdulmajeed & Alaswadko, 2023). PCI reflects current pavement condition based on the combined assessment of distress type, density, and severity, with standard PCI scales ranging from "good" to "failed." Some versions simplify the rating to "good," "fair," and "poor," often displayed using color-coded maps generated in Micro PAVER 6.5.7 (Almuhanna et al., 2018). Notably, PCI focuses on visual surface conditions rather than structural soundness (Adeke et al., 2019). GIS simplifies what would otherwise be time-intensive tasks, and while initial setup may be costly, it offers long-term efficiency gains (Ahmad & Firincioglu, 2019). Its spatial analysis tools are especially useful in enhancing pavement management through features like graphical representations of pavement status (Al-Neami et al., 2018). By conducting thorough inventories and condition assessments, GIS-based PMS models can identify the most cost-effective M&R interventions (Khodary & Naggar, 2023). These platforms are not only flexible and efficient but also produce detailed maps that aid decision-making by illustrating the location, extent, and severity of pavement distresses far better than manual methods (Beto, 2021). GIS is instrumental in providing quick visual data through charts and map graphics (Hashim et al., 2021), and by linking spatial and geometric information, it offers more effective ways of storing and analyzing transportation data compared to traditional paper-based approaches. Recent research supports the integration of GIS and remote sensing for more accurate pavement assessments (El Nthaga et al., 2025). The U.S. Army Corps of

Engineers established the PAVER system—a Pavement Maintenance Management System (PMMS)—to objectively and consistently evaluate pavement quality and optimize rehabilitation funding (Abdulmajeed & Alaswadko, 2023). Micro PAVER is now used for managing roads, parking areas, and airfield pavements (Al-Neami et al., 2018), and it bases its assessments on the PCI survey method (Norlela et al., 2009). PCI for flexible pavements can be calculated using the PAVER system with GIS-acquired data. For example, Al-Amarah Street in Al-Kut city recorded a PCI of 64 (a "Fair" rating) using Micro PAVER 5.2 software (Al-Neami et al., 2018). Similarly, Hadidi et al. (2014) reported PCI values between 5 and 96 in Amman, averaging 56.95, which represented fair conditions and highlighted severe degradation in the city's eastern zones. These PCI values enabled the development of GIS models that prioritized maintenance actions and estimated associated costs. In Pinatt et al. (2020), ArcGIS 10.2 mapping showed that 92.21% of pavements ranged from very good to fair, while 7.94% were classified as poor to very poor. Beto (2020) demonstrated how GPS-integrated GIS and PCI analysis revealed that all sub-sections of a 53 km road were in very poor condition, requiring urgent intervention. The use of Micro PAVER 5.2 software also helped eliminate errors common in manual PCI calculation. The resulting PCI score of 64 confirmed a "Fair" condition with critical deterioration (Al-Neami et al., 2018). This project will involve conducting a visual inspection of road segments within the study area to identify distresses, their types, severity, and spread. GPS and GIS tools will be employed to map the location and length of the road segment, and the data collected will serve as the basis for determining its pavement condition.

## 1.2 Statement of the Problem

The sustainability of road infrastructure is constantly challenged by various deteriorating factors, including traffic loads, material properties, environmental conditions, pavement age, structural design, construction quality, road geometry, and maintenance policies (Adeke et al., 2019). In civil engineering, road networks are fundamental to the transportation sector, underscoring the responsibility of transportation engineers to ensure that roads are adequately maintained to prevent structural failures. This is crucial, as the development status of any country is often gauged by the extent and quality of its road network (Patil and Patil, 2018). Environmental conditions, vehicle loads, material deficiencies, substandard construction practices, and aging infrastructure are primary contributors to pavement degradation (Fakhri and Desfoulani, 2017). In Nigeria, many road pavement projects are either abandoned or constructed without any provision for proper monitoring, maintenance, or management, resulting in widespread deterioration and compromising public safety and property. Furthermore, the use of inferior materials, poor supervision, and incomplete drainage infrastructure—often a result of high construction costs—further accelerate pavement failure. One of the most frequent and severe forms of failure is the development of potholes, caused by water accumulation and heavy traffic loads. This deterioration is typically due to inefficient drainage systems that allow water to pool on pavement surfaces, weakening the structure over time. Surface drainage performance is measured by the pavement's ability to effectively shed water and prevent ponding, whether on the road surface or adjacent shoulders (Adebanjo, 2013). Failures in constructed pavements can also result from dynamic vehicle loads, poor subgrade preparation, inadequate mixing techniques, climate impacts, and several other variables. However, if maintenance and restoration efforts are implemented early, more than 50% of repair costs can be avoided (Arabani et al., 2017).

Given the numerous challenges leading to pavement deterioration in developing countries such as Nigeria—where Pavement Maintenance Management Systems (PMMS) are rarely implemented—Geographic Information Systems (GIS) present a powerful solution. GIS tools play a vital role in monitoring, analyzing, and generating the data necessary to support informed maintenance and rehabilitation planning. For instance, Beto (2021) evaluated road pavement conditions using the Pavement Condition Index (PCI) alongside GIS to create a digital database of pavement distresses. This facilitated the prioritization of pavement sections for maintenance, based on GIS-driven analysis. With advancements in computer hardware and software, GIS is rapidly being adopted by government institutions to enhance pavement management systems, particularly by integrating PMS data within ArcGIS platforms (Al-Hassan and Aodah, 2022). Ibraheem and Falih (2012) emphasized the usefulness of GIS in supporting pavement management decision-making. In essence, GIS enables highway and transportation engineers to track, record, analyze, and address pavement-related issues with greater efficiency. GIS-based PM systems replicate the geographic nature of transportation assets—including pavement networks, utility systems, and roadway features—through their robust spatial capabilities.

Given these persistent infrastructure issues—ranging from environmental stressors and poor construction to inadequate monitoring and maintenance practices—a forward-looking, technology-driven approach to pavement management is urgently required in Nigeria. The ongoing deterioration of many road networks not only obstructs national progress but also poses serious threats to public safety and welfare. Recurring problems such as potholes, surface cracking, and general structural breakdowns—often left unaddressed due to the absence of systematic maintenance frameworks—reflect deeper inefficiencies in current road management practices. This project aims to address these gaps by leveraging the power of Geographic Information Systems (GIS) and Pavement Management Systems (PMS), particularly through tools such as ArcGIS. The unique advantage of these technologies lies in their capacity to digitally collect, visualize, and analyze pavement conditions within a spatial context—capabilities that traditional manual methods cannot provide with equivalent precision or efficiency. By incorporating GIS into pavement condition monitoring, this study will not only produce a digital database of road distresses but also provide a valuable decision-support tool for prioritizing rehabilitation efforts based on the severity, extent, and location of pavement deterioration.

### 1.3 Aim and Objectives

The aim of this study is to evaluate the pavement conditions of a section of the Road connecting the University of Benin Back Gate, with Ethiope River Road using Geographical Information System (GIS) for effective spatial analysis and the objectives of the study are to:

i. conduct a field survey to assess pavement condition and record the type, severity, and extent of distresses such as cracks, potholes, and surface wear using GIS techniques.
ii. evaluate the pavement quality using the Pavement Condition Index (PCI) and Pavement Condition Rating (PCR) methods.
iii. analyze and visualize the spatial distribution of pavement conditions using GIS software such as ArcGIS and Google Earth.

iv. identify the contributing factors to pavement deterioration, including drainage issues, and weather conditions.

## 1.4 Scope of Study

This study focused on evaluating the pavement condition of a section of the Road that connects UNIBEN Back Gate and Ethiope River Road (Ekosodin Road) using Geographical Information System (GIS). The scope covered the visual inspection and documentation of pavement distresses such as cracks, potholes, and surface wear along the selected road section. It includes the collection of spatial data, determination of road segment lengths and locations, and mapping of the road using GIS tools like ArcGIS and Google Earth. The analysis involved computing the Pavement Condition Index (PCI) to assess pavement quality and assign appropriate Pavement Condition Ratings (PCR). Additionally, the study investigated contributing factors to pavement deterioration, such as traffic load, poor drainage, and environmental conditions, with the aim of supporting effective maintenance and rehabilitation planning.

## 1.5 Justification of Study

The sustainability of road infrastructure is constantly challenged by various deteriorating factors, including traffic loads, material properties, environmental conditions, pavement age, structural design, construction quality, road geometry, and maintenance policies (Adeke et al., 2019). In civil engineering, road networks are fundamental to the transportation sector, underscoring the responsibility of transportation engineers to ensure that roads are adequately maintained to prevent structural failures. This is crucial, as the development status of any country is often gauged by the extent and quality of its road network (Patil and Patil, 2018). Environmental conditions, vehicle loads, material deficiencies, substandard construction practices, and aging infrastructure are primary contributors to pavement degradation (Fakhri and Desfoulani, 2017). In Nigeria, many road pavement projects are either abandoned or constructed without any provision for proper monitoring, maintenance, or management, resulting in widespread deterioration and compromising public safety and property. Furthermore, the use of inferior materials, poor supervision, and incomplete drainage infrastructure, often a result of high construction costs, further accelerate pavement failure. One of the most frequent and severe forms of failure is the development of potholes caused by water accumulation and heavy traffic loads. This deterioration is typically due to inefficient drainage systems that allow water to pool on pavement surfaces, weakening the structure over time. Surface drainage performance is measured by the pavement's ability to effectively shed water and prevent ponding, whether on the road surface or adjacent shoulders (Adebanjo, 2013). Failures in constructed pavements can also result from dynamic vehicle loads, poor subgrade preparation, inadequate mixing techniques, climate impacts, and several other variables. However, if maintenance and restoration efforts are implemented early, more than 50 percent of repair costs can be avoided (Arabani et al., 2017).

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# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Road Pavements and Types

A highway pavement is a structural system composed of multiple layers of engineered materials placed above the natural soil subgrade. Its primary function is to effectively distribute vehicular loads to the subgrade without exceeding its bearing capacity. In doing so, the pavement must also provide a surface with acceptable ride quality, adequate skid resistance, efficient light reflection, and minimal noise generation (Bhalavi and Verma, 2021). Historically, pavements were made primarily of gravel and stones. However, advancements in materials science led to the adoption of higher-quality materials, such as asphalt binders and Portland cement concrete, to enhance performance and longevity. Today, pavement design plays a critical role in ensuring urban infrastructure efficiency and the safety of road users (Shtyat et al., 2020). Pavements are generally classified into two main types: rigid and flexible. Rigid pavements are typically constructed using Portland cement concrete and behave like beams, bridging over minor irregularities in the supporting layers. In contrast, flexible pavements are composed of bituminous materials that closely conform to the subgrade and underlying layers, even with minor surface variations. A typical flexible pavement structure includes a bituminous wearing surface over granular base and sub-base layers composed of well-graded coarse and fine materials. Load transfer in flexible pavements is facilitated by aggregate interlock, friction among granular particles, and cohesion within fine materials (Garber and Hoel, 2009).

### 2.1.1 Flexible Pavements

In flexible pavements, wheel loads are transmitted primarily through grain-to-grain contact within the granular structure. Due to their lower flexural strength, flexible pavements behave like a deformable sheet, adjusting to traffic loads by flexing rather than resisting them rigidly (Bhalavi and Verma, 2021). The pavement structure functions as a series of flexible layers, where stresses are dispersed downward through inter-particle contact. These pavements are typically composed of crushed stone, gravel, and sand, all bound together with a bituminous binder. A standard flexible pavement system consists of a surface course, sub-base course, and a subgrade layer compacted to provide foundational support (Taher et al., 2020). The base and sub-base layers are constructed from crushed stone or gravel, either in an unbound granular form or stabilized with additives such as asphalt, lime, or cement to enhance structural integrity (AASHTO, 1993).

### 2.1.2 Rigid Pavements

Rigid pavements are typically constructed with a Portland cement concrete surface layer that incorporates transverse joints at specified intervals. This concrete layer is generally placed over a compacted subgrade and a granular base layer; however, in some cases, it may be placed directly on the subgrade without a base. Unlike flexible pavements, rigid pavements are engineered to distribute nonuniform stresses while maintaining uniform and minimal deflections. The high stiffness and thickness of the concrete slab allow it to behave like a rigid plate, efficiently spreading loads across a wider area (Styer et al., 2023). The structural rigidity of this pavement type is due to the inherent stiffness of its materials, enabling it to transfer wheel loads to the subgrade primarily through flexural strength (Wimsatt et al., 2009). Rigid pavements are composed of a mixture of coarse and fine aggregates, Portland cement, and water, and they are often reinforced with steel rods or mesh for added strength. While the initial construction cost of rigid pavements is higher than that of flexible pavements, their longer service life and lower maintenance requirements often make them more cost-effective over time. Additionally, rigid pavements exhibit superior structural integrity and durability under high traffic loads and challenging environmental conditions compared to their flexible counterparts (Taher et al., 2020).

### 2.1.3 Composite Pavements

Composite pavements represent a hybrid pavement type that integrates the benefits of both rigid (concrete) and flexible (asphalt) pavement structures. This system is commonly built by overlaying a flexible asphalt layer atop a rigid Portland Cement Concrete (PCC) base. The combination is designed to capitalize on the structural durability of rigid pavements and the smooth riding surface of flexible pavements, thereby improving overall performance, reducing long-term maintenance costs, and extending service life. Owing to their enhanced physical and functional characteristics, composite pavements can potentially offer a more cost-effective solution compared to conventional pavement types over their lifespan (Bano, 2023). Typically, composite pavements are employed as a rehabilitation technique, making use of existing concrete pavements by reinforcing them with an asphalt overlay (Styer et al., 2023).

### 2.1.4 Pavement Layers

Pavement structures consist of multiple layers, each serving a critical function in ensuring roadway strength, durability, and cost-effectiveness. The subgrade, or native soil, forms the base. If weak, it is stabilized with a capping layer using lime, cement, or other binders. Above this, a 150–200 mm thick subbase layer made of granular or bound materials offers foundational support and reduces deflection. The base layer, typically over 200 mm thick, provides main structural strength using asphalt, lean concrete, or aggregates. A binder course, 50–80 mm thick with finer aggregates, ensures a smooth foundation for the top surface. The surface or wearing course, a 20–50 mm layer of high-quality asphalt, resists traffic and weather, offering skid resistance and smoothness. Each layer is chosen based on performance, traffic, environment, and cost, working together to distribute loads, control moisture, minimize deformation, and ensure long-lasting road performance.

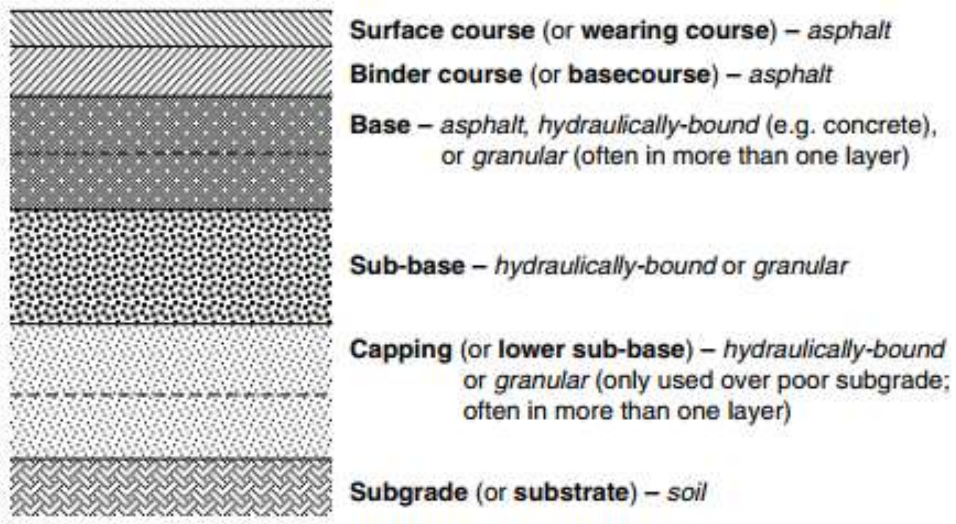


Figure 2.1: Schematic of a Flexible Pavement layer (Source: Principles of Pavement Engineering, 2008)

## 2.2 Requirements of a Good Pavement

According to Styer et al. (2023), pavements should be designed to adapt to changing traffic demands and environmental conditions while meeting user needs such as safety, durability, comfort, efficiency, sustainability, and cost-effectiveness. The study highlights how the structural designs of flexible, rigid, and composite pavements enhance load distribution, durability, and adaptability key characteristics of quality pavement systems. It also emphasizes the importance of drainage and friction. Proper drainage systems must accompany pavement construction to prevent water infiltration, which can weaken the subgrade and cause layer failure. Friction is equally vital for pavement performance and safety, contributing to vehicle control and reducing accident risks.

i. **Skid Resistance**: One of the most vital aspects of pavement design is ensuring adequate friction between vehicle tires and the road surface. This prevents skidding, especially in wet conditions, and enhances overall road safety.
ii. **Load Distribution and Stability:** Friction between pavement layers helps maintain structural integrity. If layers, such as asphalt and the base course, do not have sufficient friction, they can slide or separate under traffic loads, leading to premature failures.
iii. **Abrasion Resistance**: A good pavement resists excessive wear from traffic, weather, and environmental factors. The materials chosen for the surface layer should be durable enough to maintain friction over time without becoming overly polished or smooth.
iv. **Surface Texture:** Pavement texture affects friction levels. Rougher surfaces provide more grip and are preferred in areas with high traffic or adverse weather conditions.

This is why pavement maintenance often involves surface treatments to restore friction levels.

The choice of pavement type, whether flexible or cement concrete, therefore, has to be very carefully exercised. Pavement associated traffic safety factors include skid resistance, drainage against hydroplaning, and night visibility. Cement concrete pavement has distinct initial advantage over bitumen pavement in this regard, as surface texturing forms integral part of the normal construction practice for such pavements. They also have superior night visibility by virtue of their lighter color (Bhalavi and Verma, 2021). In summary, it can be said that characteristics of a good pavement includes good drainage facilities, friction resistance and good lighting as to enhance road safety.

According to Bano (2023) the perfect pavement should meet these certain criterions which includes:

i. Strong enough structurally to bear all kinds of pressures placed upon it;

ii. Sufficient thickness to transmit the wheel load strains to a safe value on the sub-grade dirt;

iii. Appropriate coefficient of friction to prevent cars from sliding;

iv. A smooth surface that keeps drivers comfortable even at high speeds, Produce least noise from moving vehicles,

v. Long design life with low maintenance costs;

vi. Impervious surface to protect sub-grade soil; and

vii. Dust-proof surface to prevent visibility reductions that could compromise traffic safety.

### 2.3 Pavement Design Considerations

In the design of Road Pavements there are some certain factors that must be taken into consideration in order in order for the pavement to be functional throughout its service life. As it has been observed in Nigeria as a developing country that pavements do not take time to start deteriorating even after it has been newly constructed. AASHTO guide for design of pavement structure state that, in the past, the typical analysis for pavement design was 20 years which was considered as the pavement life, nowadays, highway condition (location, used material and traffic volume) is considered when estimating the pavement life, generally, concrete pavement can be designed from 30 to 40 years, asphalt pavement can be designed up to 30 years (Taher et al., 2020). These factors must be put into place in order for the pavement to last throughout its service years. They include:

#### 2.3.1 Traffic Loading and Volume

One of the most critical aspects of pavement design is accounting for traffic loading and volume. Pavements are not static structures—they are continuously stressed by the movement of vehicles, and the nature of this loading plays a pivotal role in how pavements are designed, constructed, and maintained over their service life. Understanding the various components of traffic loading is essential for ensuring pavement durability, cost-effectiveness, and safety. Traffic loading and volume is influenced by some important factors which includes:

i. **Axle Load Magnitude:** The damage caused to pavements increases exponentially with axle weight. A single heavy truck can inflict as much damage as thousands of passenger cars. For instance, an 8,200-Kg axle exerts far more stress on the pavement layers than smaller loads, often accelerating fatigue and structural deterioration. As such, roads that are expected to serve heavy vehicles require thicker and more resilient pavement structures.

ii. **Traffic Volumes (ESALs):** Engineers convert the mixed types of vehicles using a road into a standard measure known as Equivalent Single Axle Loads (ESALs). This metric helps in estimating the cumulative loading the pavement will endure over its lifetime. Roads with high traffic volumes, especially those with a significant number of heavy vehicles, need stronger pavements to handle the sustained pressure and avoid premature failure.

iii. **Traffic Composition:** The mix of vehicle types using a road is just as important as the total number of vehicles. While passenger cars contribute little to structural pavement wear, heavy-duty trucks and buses impose substantial stresses. A road where only 10% of traffic is heavy trucks may still experience significant structural damage due to the outsized impact these vehicles have.

iv. **Load Repetition Frequency**: Pavement failures often result not from a single heavy load, but from the repetition of stress over time. Each vehicle that passes adds a tiny bit of wear, and over millions of repetitions, even moderate loads can lead to fatigue cracking and structural failure. Designers must estimate how frequently different loads will be applied throughout the pavement’s design life.

v. **Wheel Configuration and Tire Pressure**: How a load is distributed on the pavement also matters. Axle configurations (single, tandem, or tridem axles) and tire pressure influence the intensity and area of stress application. High tire pressures, particularly on single axles with narrow contact areas, create localized stresses that can lead to surface damage like rutting and cracking.

### 2.3.2 Material Properties

In pavement engineering, material selection is crucial to the performance and longevity of roads. Pavement materials must withstand traffic loads, environmental conditions, and aging. Key properties include strength and stiffness to resist deformation and distribute loads, and durability to withstand moisture, temperature changes, and chemical exposure. Moisture resistance is vital, as water infiltration can weaken bonds, degrade materials, and damage subgrades. Workability and proper compaction are also essential for ensuring pavement integrity and preventing early deterioration.

According to Styer et al. (2023), rigid pavements require materials with high compressive strength, stiffness, low permeability, and resistance to weather and chemicals. Additives like fly ash or slag enhance performance. Flexible pavements rely on materials with flexibility, fatigue resistance, good adhesion, thermal stability, and moisture resistance. Recycled materials like Warm Mix Asphalt and RAP are increasingly used to boost sustainability and performance. Proper compaction remains key for both pavement types.

### 2.3.4 Climatic and Environmental Conditions

In the construction of flexible pavements, asphaltic materials are used such as bitumen, road tars etc. When these materials are exposed to environmental conditions, naturally deterioration occurs causing the asphalt to lose its elasticity, plasticity and making it become brittle. This process is known as weathering. The ability of the asphalt to resist deterioration is known as durability. Oxidation of asphalt materials which is as a result of oxygen in the air readily attacking the asphalt materials and Volatilization which is as a result of loss of light hydrocarbons from the pavement both cause the asphalt to lose its plastic characteristics thereby causing deterioration.

Climate and environmental conditions are among the most influential factors in pavement design. Roads are exposed to the elements every day, and their performance over time depends heavily on how well they can withstand the local environmental stresses. Whether it's extreme heat, freezing temperatures, or heavy rainfall, each climate condition presents unique challenges that must be addressed in the design stage to ensure durability, safety, and cost-effectiveness.

i. **Temperature:** One of the most significant environmental influences is temperature variation. In hot climates, asphalt pavements can become soft, leading to surface deformation such as rutting under repeated traffic loads. On the other hand, in cold climates, pavements—particularly asphalt—can become brittle, making them more susceptible to thermal cracking. Concrete pavements, while more resistant to heat, are affected by expansion and contraction due to temperature changes, which can result in cracking or joint failure if not properly accounted for.

ii. **Freeze–thaw cycles**: This is a major challenge, especially in colder regions. When water infiltrates pavement layers and then freezes, it expands, exerting pressure on the surrounding material. This repeated freezing and thawing weakens the structure, causing cracks, potholes, and surface heaving. Pavements in such regions require careful material selection and insulation strategies to mitigate freeze-related damage.

iii. **Moisture and rainfall:** This plays a very critical role in pavement degradation. Excess water can reduce the strength of subgrade soils, cause stripping in asphalt pavements (loss of bond between the binder and aggregates), and lead to pumping in rigid pavements (where water and fines are ejected through joints and cracks). Effective drainage systems, moisture-resistant materials, and proper layer compaction are essential to address these issues in design.

iv. **Atmospheric Exposure:** This further impacts flexible pavements, as prolonged exposure can oxidize asphalt binders, making them brittle and prone to early cracking. This form of environmental aging gradually reduces the pavement's ability to flex and recover from loads, leading to surface defects.

v. **Wind and Dust:** In arid or desert regions, additional concerns arise from wind and dust. Fine dust particles can infiltrate the surface and base layers, weakening the pavement structure by reducing the interlock between aggregates. High wind speeds can also accelerate surface erosion, especially on unsealed or poorly maintained roads.

### 2.4 Materials used in Construction of Road Pavements

Materials used in road construction are of critical importance, as they directly influence the quality, safety, and durability of the pavement. These materials come in a wide variety of types, each with distinct properties and environmental implications. These materials include the natural soils, aggregates, binders**,** and admixtures, all of which play essential roles in forming a structurally sound and functional pavement. When properly selected and combined, these materials contribute to the development of high-quality road surfaces that are not only capable of withstanding traffic loads but are also safe for the vehicles that travel over them. Moreover, the environmental impact of these materials must be carefully considered to ensure sustainable and eco-friendly construction practices.

#### 2.4.1 Soil

Soil is a key material in road construction, serving as the foundation, subgrade, and even pavement in low-traffic rural roads, as well as forming highway embankments. Since all structures transfer loads to the ground, both soil and rock are vital foundation materials. To improve road performance, soils are often stabilized through compaction or additives to enhance strength and durability. Sub-base and base layers typically use mineral aggregates from rock sources. Because soil properties vary, thorough evaluation is necessary—especially for clay- and silt-rich soils, which are prone to moisture issues like erosion and shrinkage (Styer et al., 2023).

### 2.4.2 Granular Materials

Granular materials, commonly referred to as aggregates, include stones, gravel, crushed rock, and granites. These materials are primarily used in the base course layer of flexible pavements, where they provide load distribution and sub-surface drainage (Bhalavi and Verma, 2021). According to Nick Thom (2008), granular materials are unbound materials with relatively large particle sizes, often engineered or blended for specific performance needs—unlike natural soils. While more predictable than soil, their properties may still vary depending on source and composition.

Stone aggregate, also called mineral aggregate, is the most vital component in road construction. It ranges from fine (sand) to coarse (gravel) and is assessed for suitability, strength, and durability based on its geological origin and bonding characteristics (Bano, 2023). Aggregates form the bulk of road construction materials and influence the structural performance of both flexible and rigid pavements.

For effective pavement performance, aggregates must exhibit high strength, hardness, toughness, and durability to withstand traffic loads, abrasion, and environmental conditions. Well-graded aggregates enhance compaction and load distribution, while angular shapes improve interlock and resistance to deformation. Clean aggregates free from clay or organic matter ensure better bonding with bitumen or cement. Additionally, high specific gravity and low water absorption are crucial to minimizing moisture damage. Carefully selected and tested aggregates are key to building strong, durable, and cost-effective pavement structures.

### 2.4.3 Bitumen and Asphalt

According to Bano (2023), bitumen and asphalt, though often confused, are distinct materials. Bitumen is a semi-solid binding agent derived from the incomplete distillation of crude oil, composed mainly of carbon (87%), hydrogen (11%), and oxygen (2%). Asphalt, on the other hand, is a composite of sand, gravel, and bitumen, typically used in road construction as asphalt concrete, comprising about 30% aggregate and 70% asphalt. Its recyclability adds to its environmental appeal.

Bituminous materials used in highways are primarily categorized as asphalt and tar. Asphalt can originate from natural deposits or be a petroleum byproduct, available in forms like asphalt cement, emulsions, and cutbacks (slow, medium, or rapid-curing). Bitumen serves as a binder, while road tars which are coal derivatives are less weather-resistant and set quickly when exposed to air.

Bitumen functions similarly to hydraulic binders like Portland cement but differs in behavior. It remains viscous at service temperatures, allowing asphalt pavements to flex and adapt to temperature changes and minor ground movements without cracking. This eliminates the need for movement joints seen in concrete pavements. However, asphalt’s flexibility can cause rutting, though proper mix design helps control this. Its performance is measured not by tensile strength but by fatigue resistance—its ability to withstand repeated loading over time (Thom, 2008)

## 2.5 Pavement Deterioration

Pavement deterioration is the process of gradual decline of the condition of a pavement and its performance due to some certain factors which includes Traffic and vehicular load, climate and weather conditions, drainage, construction execution quality and the materials for construction. It is such that if the pavement is not properly managed and maintained these factors would accelerate the deterioration rate of the pavement.

According to Ahmad and Firincioglu (2019), pavements play a vital role in both local and national socioeconomic development. As a fundamental component of transportation infrastructure, roads are essential to mobility and economic activity. Pavement deterioration is influenced by a range of factors, including high traffic volume, heavy traffic loads, environmental conditions such as climate and moisture, the use of substandard construction materials, poor construction practices, inadequate maintenance, pavement age, and subgrade deficiencies. These factors contribute to both functional and structural failures, manifesting as issues such as surface depressions, potholes, cracking, rutting, and texture loss. Deterioration occurs as a result of the cumulative effects of traffic loads and environmental exposure. This degradation significantly impacts the road's serviceability, safety, and ride quality. Consequently, regular maintenance is essential to preserve pavement performance, ensuring continued safety, efficiency, and durability throughout its service life. Normally, new paved roads deteriorate very slowly in the first ten to fifteen years of their life, and then go on to deteriorate much more rapidly unless timely maintenance is undertaken Pavement performance depends on what, when, and how maintenance is performed. No matter how well the pavement is built, it will deteriorate over time based upon the mentioned factors. The most visible flaw or defect in the road surface is pavement distress which is one of the deterioration factors. Agency "nowadays collect periodic distress data with PMMS in their surveys. Mostly the surface distress is categorized into 4 sections which are disintegration pothole, surface deformation, cracking, and surface defects (bleeding). The timing of maintenance is very important, if a pavement is permitted to deteriorate to a very poor condition (Adlinge and Gupta, 2013). The study also categorized pavement deteriorations into four (4) major asphalt pavement distress and they are as follows:

**Types of pavement deterioration:**

a) Cracking

b) Surface deformation

c) Disintegration (potholes, etc.)

d) Surface defects (bleeding, etc.)

## 2.6 Cracking

Cracks are visible fractures that form on paved surfaces due to stress and environmental factors, signaling structural issues. Common causes include repeated heavy traffic (fatigue cracking), temperature changes (thermal cracking), moisture infiltration, freeze-thaw cycles, and poor construction practices. Additional contributors are material aging, oxidation, weak subgrades, chemical exposure, and design flaws. These factors lead to various crack types such as fatigue, longitudinal, transverse, block, slippage, reflective, and edge cracking. Effective design, construction, and maintenance are essential to minimize pavement cracking and extend service life.

### 2.6.1 Fatigue Cracking (Alligator Cracking)

Fatigue cracking, often referred to as alligator cracking**,** is characterized by a network of interconnected cracks that break the pavement surface into small, irregular, block-like segments resembling the skin of an alligator. This type of distress typically results from the repeated application of traffic loads, which gradually weaken the pavement structure, particularly the surface layer or the base. Over time, the accumulated stress from vehicle movement leads to structural fatigue and eventual surface disintegration. If left unaddressed, these cracks can progress into potholes, further compromising the safety and functionality of the road. Fatigue cracking is often indicative of underlying issues such as poor drainage or inadequate support from the base layer. Remedial measures vary depending on the extent of the damage: minor cases may be resolved with localized patching or area repairs, while more severe occurrences often necessitate full-depth reclamation or complete reconstruction. In all instances, ensuring proper drainage is critical to preventing recurrence and maintaining pavement longevity.

### 2.6.2 Longitudinal cracking

This refers to long, narrow cracks that run parallel to the centerline of the pavement. These cracks can arise from several causes, including frost heaving, construction joint failures, or stresses induced by repeated traffic loads. Identifying the underlying cause is essential for determining the most effective repair strategy. In many cases, if the initial crack is not properly addressed, additional parallel cracks may develop over time a process known as progressive deterioration. The presence of multiple longitudinal cracks often suggests that simple crack sealing may be insufficient, and more comprehensive rehabilitation measures may be required to restore pavement performance and prevent further damage.

### 2.6.3 Transverse Cracking

Transverse cracking consists of cracks that form roughly perpendicular to the centerline of the roadway. These cracks are typically spaced at regular intervals and share similar causes with longitudinal cracks, such as shrinkage and thermal stresses. Initially, transverse cracks appear as fine, narrow lines spaced widely apart, often more than 20 feet but they tend to widen and multiply over time if not properly treated. Without timely sealing and maintenance, secondary cracks can develop parallel to the original crack, worsening the damage. In colder climates, transverse cracking may also result from thermal contraction, particularly when the asphalt binder is too stiff, leading to low-temperature cracking. The underlying causes and repair approaches for transverse cracks generally align with those used for longitudinal cracking.

### 2.6.4 Block Cracking

Block cracking appears as a network of interconnected cracks that divide the pavement surface into roughly rectangular or irregularly shaped blocks. This type of cracking often results from the intersection of transverse and longitudinal cracks, but it can also be attributed to issues such as inadequate compaction during construction or aging of the asphalt binder, which causes shrinkage over time. Block cracking typically develops when the pavement loses flexibility and becomes brittle. In cases of low severity, the damage can often be addressed with a thin overlay or surface treatment. However, as the severity increases, more extensive measures such as milling and overlay, recycling, or even full-depth reclamation may be required—especially if the underlying base shows signs of structural failure. Proper evaluation is essential to determine the appropriate level of intervention.

### 2.6.5 Slippage Cracking

Slippage cracks are crescent-shaped cracks that typically form with both ends pointing in the direction of oncoming traffic. These cracks are caused by horizontal shear forces generated by braking or accelerating vehicles. They usually indicate a failure in the bond between the asphalt surface layer and the underlying layer, often due to the absence or improper application of a tack coat during construction. This weak bond allows the surface layer to slide or shift under traffic stress, resulting in visible slippage. Effective repair involves removing the affected area and repaving it, ensuring that a proper tack coat is applied to establish adequate adhesion between layers in the new pavement.

### 2.6.6 Reflective Cracking

Reflective cracking develops when existing cracks in an underlying pavement layer propagate upward through a newly applied hot mix asphalt overlay. These cracks are termed "reflective" because they mirror the pattern of the original cracks beneath the surface. Essentially, previously concealed or treated cracks reappear in the new layer due to continued movement or stress in the pavement structure. Reflective cracks are common in rehabilitation projects where overlays are used without fully addressing underlying issues. Repair methods are similar to those used for other types of cracking, but it is crucial to treat and seal existing cracks before applying any overlay or wearing course to reduce the likelihood of recurrence.

### 2.6.7 Edge Cracking

Edge cracking begins as crescent-shaped fissures along the pavement’s outer edge and, if left untreated, can grow inward and coalesce into patterns reminiscent of alligator cracking. This distress typically arises from inadequate shoulder support—often due to weak backfill materials or the presence of excess moisture—and can be exacerbated in curbed sections where subsurface water infiltrates and undermines the pavement edge. In its early stages, edge cracking can be mitigated through simple crack filling; however, as the cracks widen and extend, more extensive repairs such as patching or full-area replacement may become necessary. Regardless of repair method, controlling moisture ingress and reconstructing the shoulder with properly graded, well-compacted materials are essential to preventing recurrence.

## 2.7 Surface Deformation

Surface deformation occurs when pavement layers yield under stress, altering the road profile. Common examples include rutting, which forms wheel-path channels; shoving, seen as localized surface bulges at intersections or grades; corrugations (wash boarding) in low-speed zones; depressions, or bowl-shaped dips from weak subgrades; and swelling, where frost heave or moisture causes upward bulges. These distortions degrade ride quality, trap water, and hasten deterioration, making timely remedies like milling and overlay or subgrade stabilization essential. The basic types of surface deformation opined by Adlinge and Gupta (2013), are rutting, corrugations, shoving, depressions, and swell.

### 2.7.1 Rutting

Rutting occurs when pavement layers permanently deform under traffic, forming channels along the wheel paths that can trap water in severe cases. The rut's width indicates the depth of failure: narrow ruts reflect surface-layer issues, while wider ruts point to subgrade deficiencies. Inadequate compaction often precipitates this distress. Minor surface-layer rutting may be corrected with micro paving or paver-applied surface treatments; deeper ruts can be addressed by milling a truing and leveling course followed by an overlay. When the asphalt surface is unstable, recycling the existing material may be preferable. However, if the subgrade is at fault, full-depth reclamation or reconstruction is typically required.

### 2.7.2 Corrugation

Corrugation, often called "wash boarding" occurs when the asphalt surface deforms into regular ripples, typically in acceleration or deceleration zones. This instability can result from excessive asphalt cement, too much fine aggregate, or overly smooth coarse aggregate. Minor corrugations may be corrected with a surface mill or thin overlay, while more severe rippling often necessitates deeper milling before applying a new surface.

### 2.7.3 Shoving

Shoving is a plastic deformation of the asphalt surface that produces localized bulges, typically occurring for the same reasons and in the same locations as corrugations. Minor instances can be repaired by removing and replacing the affected area, whereas more extensive shoving may require milling the surface followed by an overlay.

### 2.7.4 Depressions

Depressions are small, localized, bowl-shaped areas—often accompanied by cracking—that create rough spots, pose hazards, and retain water. They form when the supporting layers beneath the surface consolidate or shift due to instability. Small depressions are repaired by excavating and rebuilding the affected area, while widespread or deep depressions typically necessitate full reconstruction.

### 2.7.5 Swell

Swelling is a localized rise or bulge on the pavement surface. It results from the expansion of the underlying layers, such as the base or subgrade. This expansion is often due to moisture intrusion or frost heaving. In some cases, highly plastic clay subgrades may expand similarly to frost heaves, particularly during warmer seasons. To correct swells, the affected subgrade material should be excavated and replaced with suitable material. If the swelling is widespread, full reconstruction of the affected area may be necessary.

## 2.8 Disintegration

Disintegration refers to the gradual breakdown of the pavement into small, loose fragments. If not addressed promptly during its early stages, the damage can worsen, eventually requiring complete reconstruction of the pavement. The most common type of disintegration are Potholes and Patches, though some studies do not consider patching to be a type of deterioration.

### 2.8.1 Potholes

Potholes are bowl-shaped surface failures caused by the progressive breakdown of pavement layers, often due to weak structural support and water infiltration. Common in poorly drained areas, they begin with surface damage and worsen under traffic loads. Timely repairs of underlying issues can prevent pothole formation. Repairs involve excavation and reconstruction, with larger areas possibly requiring full rehabilitation.

### 2.8.2 Patches

A patch refers to a portion of the pavement that has been removed and replaced, usually to fix pavement defects or to cover utility trenches. Some people do not consider patching as a type of deterioration. While this can be true for well-constructed, semi-permanent patches, temporary methods like the throw-and-roll patch simply cover the problem without addressing its root cause, such as a pothole. If a patch fails, it can contribute to further deterioration of the surrounding pavement. To properly repair a patch, a semi-permanent method should be used. In cases of widespread potholes, area repairs or reclamation may be necessary, and full reconstruction is only required when underlying base layer issues are present.

## 2.9 Surface Defects

Surface defects are issues that occur in the top layer of the pavement. They typically affect the texture, safety, and durability of the surface. The most common types of surface distress according to Adlinge and Gupta (2013) includes:

1. Raveling
2. Bleeding
3. Polishing

### 2.9.1 Raveling

Raveling is the gradual loss of pavement surface material caused by poor bonding between asphalt binder and aggregate. It begins with the detachment of fine particles, followed by larger aggregates, resulting in a rough and uneven surface. Traffic and freezing conditions can worsen the problem. In chip seals, raveling may result from poor construction practices and can sometimes lead to bleeding. It is typically repaired with a wearing course or an overlay

### 2.9.2 Bleeding

Bleeding is the accumulation of excess asphalt on the pavement surface, forming shiny, sticky patches of asphalt binder. This condition reduces skid resistance and can become dangerously slippery, especially when wet. It is typically caused by too much asphalt in the mix, using low-viscosity (overly fluid) asphalt, overly heavy prime or tack coats, or improperly applied seal coats. Bleeding is more common in hot weather, when the asphalt becomes more fluid and traffic pressure pushes it to the surface.

### 2.9.3 Polishing

Polishing occurs when traffic gradually wears down the surface aggregate, resulting in a smooth, low-friction surface. This can create hazardous driving conditions due to reduced skid resistance. The issue is typically corrected by applying a thin wearing course to restore surface texture and traction.

## 2.10 Causes of Failures in Pavements by Adlinge and Gupta (2013)

1. **Sudden Increase in Traffic Load:** When newly constructed roads experience higher traffic volumes than originally designed for often due to traffic diverting from nearby deteriorated roads as it leads to premature fatigue failure such as alligator cracking.
2. **Temperature Variations in Nigeria:** In many parts of Nigeria, especially the northern regions, high daytime temperatures followed by cooler nights cause expansion and contraction of pavement materials. These thermal stresses can lead to both bleeding and cracking of the pavement surface over time.
3. **Inadequate Shoulders:** Poorly constructed or unsupported road shoulders contribute to edge failures, as the pavement lacks lateral support.
4. **Weak Clayey Subgrade:** Subgrades with high clay content, common in several Nigerian regions, tend to retain moisture, leading to surface corrugation and increased unevenness.
5. **Poor Drainage:** Inadequate drainage systems, especially during the rainy season, allow water to infiltrate the pavement from the sides and top. This is particularly damaging in open-graded bituminous layers, where moisture weakens the bond between surface and base layers.
6. **Improper Temperature Control of Bituminous Mixes:** Overheating bitumen can reduce its binding properties, while placing the mix at too low a temperature results in poor compaction. Both issues can cause surface deformities such as longitudinal corrugations.

### 2.10.1 Methods of Determining Pavement Conditions

The purpose of pavement evaluation is to determine the current structural and functional condition of a roadway to guide maintenance and rehabilitation planning. It ensures safety, serviceability, and cost-effective resource allocation. Reliable evaluation supports long-term pavement management and infrastructure sustainability. According to Garber and Hoel (2009), the four key characteristics commonly used to evaluate the need for pavement rehabilitation include:

i. Pavement Roughness

ii. Pavement Distress

iii. Pavement Deflection

iv. Skid Resistance

### 2.10.2 Pavement Roughness (Rideability)

Pavement roughness refers to the surface irregularities on a roadway that affect ride comfort, vehicle performance, and overall user satisfaction. It is a critical parameter in assessing pavement serviceability and determining maintenance needs. Two important measures used to evaluate roughness are the Present Serviceability Rating (PSR) and the Present Serviceability Index (PSI). The PSR is a subjective rating system developed during the

AASHTO Road Test, where a panel of drivers assigns a score between 0 (impassable) and 5 (excellent) based on their perception of how well the pavement serves its intended purpose. This method relies on human judgment and simulates real-world user experience. In contrast, the PSI is an objective index derived from measurable pavement characteristics such as roughness, cracking, rutting, and deflection. It was designed as a practical alternative to the PSR, offering consistent, quantifiable data for evaluating pavement performance. As traffic loads increase and the pavement deteriorates over time, the PSI value decreases. For example, a new pavement may start with a PSI of 4.5, but as it ages and is subjected to repeated loading, the PSI may drop to around 2.0, a commonly accepted threshold that signals the need for rehabilitation. Overall, pavement roughness is not only a key indicator of ride quality and user safety but also an essential tool in pavement management for scheduling timely maintenance and ensuring the longevity of road infrastructure (Garber and Hoel, 2009). Pavement surface roughness is one of the most important indexes to evaluate pavement surface quality, and it has long been desired to propose a standard roughness index. The World Bank conducted a large-scale experiment on pavement surface roughness in Brazil in 1982. On this basis, the International Roughness Index (IRI) was proposed as a pavement roughness evaluation index. The IRI value is the cumulative vertical displacement values of a quarter car at a speed of 80 km/h , as follows.

$$\mathrm{IRI}=\frac{1}{n-1}\sum_{i=2}^{n} RSi \tag{2.1}$$

Here, n denotes the total number of position points, while RSi refers to the adjustment slope at the i-th point. Generally, lower IRI values indicate smoother pavement surfaces, and the IRI has no defined upper limit (Luo et al, 2022).

### 2.10.3 Pavement Distress (Surface Condition)

Pavement distress refers to the visible condition of a pavement surface, particularly in relation to its appearance and integrity. An ideal pavement is smooth, level, and free from any breaks or irregularities. However, a distressed pavement often shows signs of cracking, deformation, or surface deterioration. These primary forms of distress can be classified further. For instance, fractures may appear as cracks or spalling (surface chipping), with cracks categorized into types such as transverse, longitudinal, block, alligator, and generalized cracking. Deformation in pavements may be evident through ruts or surface corrugation. Surface disintegration may manifest as raveling (loss of aggregate), stripping (separation from the underlying layer), or polishing (wear-induced smoothness). The specific types of distress data collected for flexible and rigid pavements can differ across regions or states. These forms of distress have already been explained in detail previously (Garber and Hoel, 2009). Highway agencies typically evaluate the condition of flexible pavements by measuring various forms of cracking, with transverse, longitudinal, and alligator cracks being the most common indicators. Distortion is generally assessed by the extent of rutting, while disintegration is measured through the presence of raveling. Each state or federal agency uses its own procedures for conducting pavement distress surveys, usually guided by a procedural manual that defines each type of distress and provides instructions for rating them on a standardized point scale. Survey forms often distinguish between pavement types; for bituminous pavements, common observations include corrugations, alligator cracking, raveling, rutting, longitudinal and transverse cracking, and patching, whereas for Portland cement concrete pavements, the focus is on cracking, raveling, joint spalling, faulting, and patching. Data collection is typically carried out by trained observers who make subjective assessments based on predefined criteria, often supported by photographic evidence to ensure consistency and accuracy in evaluations (Garber and Hoel, 2009). Measurements are usually made on a regular schedule about every one to three years. After the data are recorded, the results are condensed into a single number called a distress (or defect) rating (DR). A perfect pavement is usually given a score of 100; if distress is observed, points are subtracted.

$$\text{DR} = 100 - \sum_{i=1}^{n} \text{diwi} \tag{2.2}$$

where:

di = the number of points assigned to distress type i for a given severity and frequency

n = number of distress types used in rating method

wi = relative weight of distress type i

A major challenge in conducting pavement condition or distress surveys is the variability in results, largely caused by the subjective nature of the evaluation methods. Additional sources of error include differences in the actual condition of the highway segments being assessed, modifications in survey procedures, and inconsistencies in the locations observed from year to year. Moreover, the safety of pavement evaluators working in active traffic environments is a significant concern.

The Pavement Condition Index (PCI) is a widely adopted pavement evaluation tool developed by the U.S. Army Corps of Engineers. It provides a numerical rating from 0 to 100 that reflects the overall condition of a pavement surface, based on a visual survey assessing the type, severity, and extent of surface distresses. Higher PCI values indicate better pavement conditions. The PCI method considers various types of distress, which may include cracking (such as alligator, longitudinal, and transverse cracks), rutting, raveling, patching, potholes, and surface wear, among others. Each type of distress is rated according to its severity, be it low, medium, or high and its extent on the pavement surface, allowing for a comprehensive assessment that informs maintenance and rehabilitation decisions. The Pavement Condition Index (PCI) is a standardized evaluation system used to assess the condition of road pavements based on the type, severity, and extent of observed damage. It serves as a valuable reference for planning and prioritizing pavement maintenance. The PCI scale ranges from 0 to 100, with the following condition categories: 0–10 (Failed), 10–25 (Very Poor), 25–40 (Poor), 40–55 (Fair), 55–70 (Good), 70–85 (Very Good), and 85–100 (Excellent). Damage severity is further classified into low (L), medium (M), and high (H) levels, providing a more detailed understanding of pavement deterioration (Isradi et al, 2019).

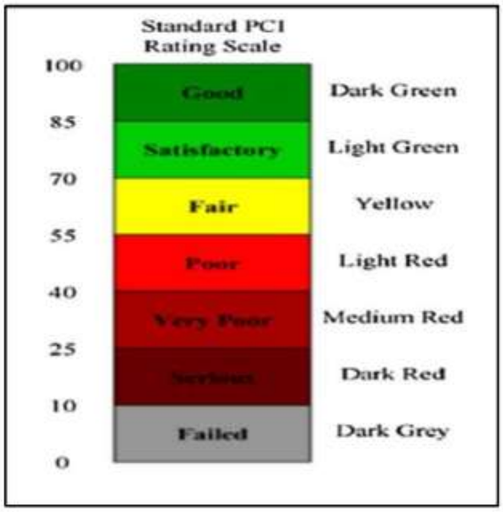


Figure 2.2: PCI Rating Scale (Abdulmajeed and Alaswadko, 2023).

The scale above is used to rate the conditions of pavements form excellent to the point of failure.

### 2.10.4 Pavement Deflection (Structural Condition)

Nondestructive structural evaluation operates on the principle that surface measurements can be used to infer the in situ structural condition of a pavement. The four main nondestructive testing methods include:

i. Measurements of static deflections
ii. Deflections from dynamic or repeated loads
iii. Impulse load deflections (such as from a falling weight)
iv. Nuclear density measurements

These methods are used to assess the compaction of pavement layers, mainly during construction. While deflection data are primarily used for design purposes, not for routine pavement management, some states apply this equipment for research and specialized studies. Most transportation agencies use falling weight deflectometers (FWD) for pavement evaluation, as the force impulses generated by falling loads closely replicate real traffic conditions. The load can be varied by adjusting either the mass or the height of the drop**.** FWDs record vertical peak deflections at the center of the loading plate and at several offsets from it, creating what is known as a deflection basin**,** which helps evaluate the pavement's structural behavior (Garber and Hoel, 2009).

### 2.10.5 Skid Resistance

The safety characteristics of a pavement are an important indicator of its condition, and highway agencies routinely monitor these factors to ensure roads operate at optimal safety levels. The primary measure of pavement safety is skid resistance; however, other contributing factors include rutting, which can result in water accumulation and increase the risk of hydroplaning, and the clarity of pavement markings. Skid resistance data are collected to evaluate how effectively a pavement reduces or prevents skid-related accidents. This information allows agencies to identify high-risk sections, prioritize maintenance or rehabilitation efforts, and assess the effectiveness of various pavement materials and surface treatments. The coefficient of sliding friction between a tire and the pavement is influenced by various factors, including weather conditions**,** pavement surface texture**,** tire condition, and vehicle speed**.** Because skidding behavior is not determined by pavement condition alone, it is essential to standardize testing procedures in order to isolate and evaluate the effect of the pavement itself. This ensures consistency and accuracy in measuring pavement friction. The fundamental equation used to determine the friction factor (f) is as follows:

$$\mathrm{f} = \frac{\mathrm{L}}{\mathrm{N}} \tag{2.3}$$

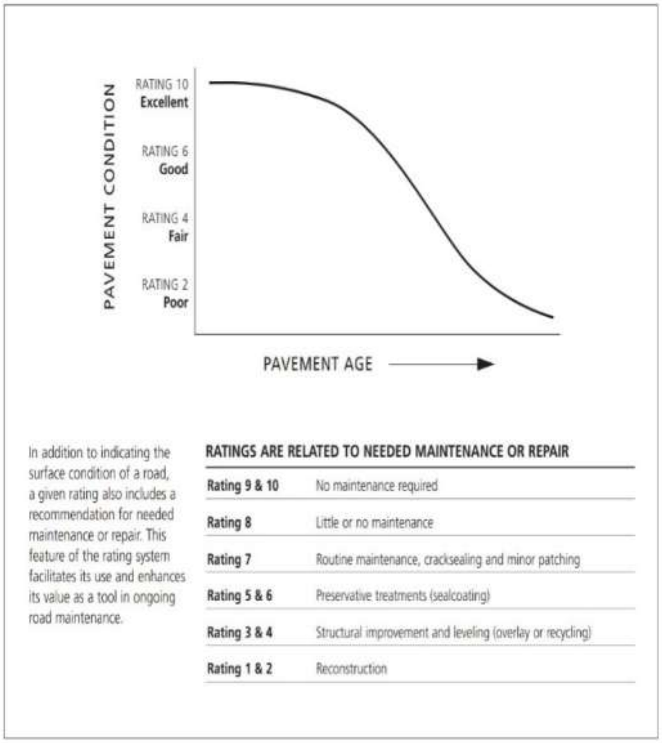
where,

$L$ = lateral or frictional force required to cause two surfaces to move tangentially to each other

$N$ = force perpendicular to the two surfaces (Garber and Hoel, 2009).

### 2.10.6 PASER (Pavement Surface Evaluation Rating)

PASER stands for Pavement Surface Evaluation and Rating. It is a visual inspection system used to assess the surface condition of road pavements, primarily for pavement management and maintenance planning**.** According to (Adanikin et al, 2022), the PASER system rates each segment on a scale of 1-10 with 1 being the worst condition, and 10 being the best condition (new pavement). The assessment not only involves the condition of the pavement but also involves the safety considerations, volume of traffic, pavement structural design and drainage availability and condition. The ratings directly correspond to the expected remaining service life as well as appropriate maintenance activities. The PASER method was originally designed as a walk-through inspection conducted annually or bi-annually to assess roadway conditions. Inspectors record the type, extent, and severity of visible surface distresses for each road segment. The extent is usually noted as a percentage of the surface area affected (e.g., 50%), while severity is described by measurable characteristics, such as depth for rutting or width for cracking. Based on these observations, each section receives a surface condition rating from 1 to 10, where lower scores indicate poorer condition. This rating is then linked to a recommended maintenance strategy for effective pavement management (Fox-Ivey et al, 2019).



In addition to indicating the surface condition of a road, a given rating also includes a recommendation for needed maintenance or repair. This feature of the rating system facilitates its use and enhances its value as a tool in ongoing road maintenance.

**RATINGS ARE RELATED TO NEEDED MAINTENANCE OR REPAIR**

| | |
|---|---|
| **Rating 9 & 10** | No maintenance required |
| **Rating 8** | Little or no maintenance |
| **Rating 7** | Routine maintenance, cracksealing and minor patching |
| **Rating 5 & 6** | Preservative treatments (sealcoating) |
| **Rating 3 & 4** | Structural improvement and leveling (overlay or recycling) |
| **Rating 1 & 2** | Reconstruction |

Fig 2.3: PASER Surface Ratings and Corresponding Maintenance Recommendations (Fox-Ivey et al, 2019)

### 2.10.7 Satellite-based Monitoring

Remote sensing**,** particularly satellite-based monitoring, is a technique used to gather information about the Earth’s surface without direct physical contact. This is achieved through the deployment of aerial or spaceborne platforms such as satellites, drones (UAVs), helicopters, or airplanes**.** These platforms are equipped with a variety of sensors that detect electromagnetic energy**,** ranging from visible light to infrared and microwave radiation, which is either reflected, emitted, or transmitted from surface materials.

In pavement management, remote sensing has emerged as a powerful and cost-effective tool for assessing the condition of large-scale roadway networks. It offers the advantage of efficient, safe, and frequent data collection**,** making it highly suitable for monitoring pavement performance over time.

The primary methods of remote sensing include:

i. **Multispectral Sensing** – Captures data across several spectral bands and is useful for detecting material properties and surface aging.
ii. **Hyperspectral Sensing** – Provides detailed spectral information, enabling advanced analysis of pavement materials and moisture content.
iii. **Thermal Infrared Sensing** – Measures surface temperature variations, which can indicate underlying structural issues or moisture intrusion.
iv. **LiDAR (Light Detection and Ranging)** – Uses laser pulses to create high-resolution 3D models of pavement surfaces for analyzing texture, rutting, and cracking.
v. **Radar Sensing (e.g., Synthetic Aperture Radar and Ground Penetrating Radar)** – Penetrates the surface to detect subsurface conditions like voids, layer separation, and moisture.

### 2.10.8 Visual Spatial Modelling (Photogrammetry)

Photogrammetry involves obtaining accurate measurements from photographs, typically by analyzing overlapping images to generate 3D surface models. In pavement engineering, it enables detailed visual and geometric analysis of surface conditions. UAV-based photogrammetry in particular has emerged as a practical and efficient tool for pavement condition assessment. UAVs equipped with high-resolution cameras are flown over road networks to capture overlapping aerial images. These images are then processed using Structure from Motion (SfM) algorithms to produce dense point clouds, digital surface models (DSMs), and orthophotos. These outputs allow for precise detection and quantification of surface defects such as cracks, rutting, potholes, and other forms of deformation.

One major advantage of UAV photogrammetry is its ability to cover large areas quickly while maintaining centimeter-level accuracy. This makes it especially useful for identifying early-stage surface distresses. The generated 3D models can be archived and revisited over time for monitoring deterioration trends. This supports preventive maintenance planning and helps extend pavement life cycles. Its growing adoption across various sectors is driven by rapid advances in UAV hardware and photogrammetric processing software. In comparison to traditional visual inspections, which are labor intensive, time consuming, and often subjective, UAV photogrammetry provides a more consistent, scalable, and cost-effective solution.

Tan and Li (2019) explored the application of UAV-based oblique photogrammetry for pavement monitoring. Using SfM techniques, their system generated accurate 3D models capable of identifying pavement defects such as potholes and bulges. The system achieved a vertical accuracy of around 1 cm. Their study demonstrated that UAV photogrammetry is a reliable and efficient method for automated pavement inspection, offering both high precision and practical value in road infrastructure monitoring.

## 2.11 Geographic Information System (GIS)

GIS (Geographical Information System) as a general technological framework is a powerful tool designed to collect, store, manage, analyze, and visualize geospatial (location-based) data. It integrates hardware, software, data, and human expertise to enable users to understand spatial patterns, relationships, and trends through digital maps, spatial queries, and analytical tools. At its core, GIS links spatial data (such as coordinates, shapes, and locations) with attribute data (descriptive information about those locations), allowing for advanced spatial analysis and informed decision-making. Geographic Information Systems (GIS) integrate hardware, software, and data to support the management, analysis, and graphical representation of all forms of geospatially referenced information. GIS enables users to visualize, interpret, query, and track data to uncover meaningful trends, patterns, and spatial relationships. These insights are commonly presented through maps, reports, and charts, facilitating clear and effective communication. By allowing complex data to be analyzed in a visual and intuitive format, GIS supports informed decision-making, enhances problem-solving, and promotes collaborative planning across a wide range of applications (Adeleke, et al).

Heywood et al. (2011) analyzed various academic definitions of GIS, identifying that the term consistently encompasses the following key elements:

i. A software-based system operating on computer platforms;

ii. Utilization of spatially referenced (geocoded) data;

iii. Capability to perform diverse data analysis tasks for deriving insights and informing decision-making.

Geographic Information Systems (GIS) was defined by Burrough as “a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes.” Since then, GIS has evolved to include two fundamental types of spatial data: vector and raster. Vector data represents discrete geographic features such as points, lines, and polygons, making it suitable for displaying and analyzing quantitative spatial information like roads, boundaries, and infrastructure. In contrast, raster data consists of pixel-based images and is typically used to represent continuous surfaces such as topography, satellite imagery, and aerial photographs. Together, these data types provide a comprehensive foundation for spatial analysis, mapping, and decision-making within GIS platforms.

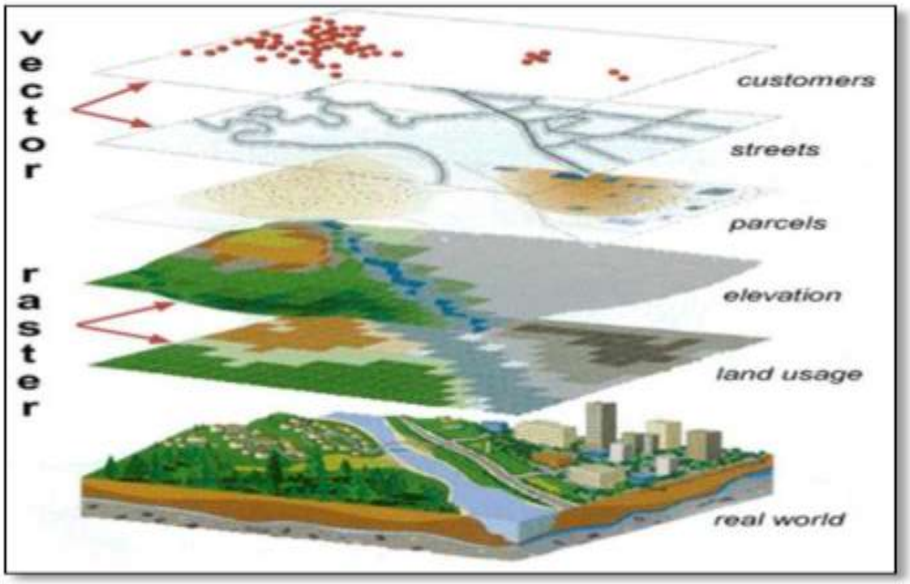


Figure 2.4: Example of GIS vector and raster data (Ahmad and Firincioglu, 2019)

### 2.11.2 History of Geographical Information System (GIS)

The development of Geographic Information Systems (GIS) dates back to 1855**,** when John Snow used a dot map to analyze the cholera outbreak in the UK, marking an early use of spatial data visualization (Gray, 2006). The modern, computer-based GIS began in the 1960s, with the creation of the Canadian Geographic Information System (CGIS) in 1964 by Roger Tomlinson**,** often referred to as the father of GIS**.** This system enabled the storage and analysis of geographic data and laid the foundation for future developments. In the 1970s**,** GIS tools became available to public and private sectors, and in 1981**,** ESRI released ArcInfo**,** one of the first commercial GIS software packages, leading to continued evolution and widespread adoption of GIS technology (Alfar, 2016).

### 2.11.3 GIS Components

According to Harvey (2015)**,** a Geographic Information System (GIS) consists of five fundamental components that work together to support spatial data management and analysis: software, data, people, hardware, and methods**.** The software provides the tools and functionalities needed for spatial analysis, mapping, and data visualization. Examples include ArcGIS and QGIS. Data is the core of GIS and includes both spatial data, such as coordinates and shapes, and attribute data, such as population or land use information. People are the users and analysts who apply GIS tools to solve real-world problems and make informed decisions. The hardware includes all physical devices required to run GIS applications, such as computers, servers, GPS units, and scanners. Lastly, methods refer to the procedures, models, and workflows that guide how GIS tools and data are applied effectively and consistently across various disciplines

#### 2.11.3.2 Hardware

GIS operates on a computer-based system, and its hardware forms the foundational infrastructure for processing and storing spatial data. Typically, GIS hardware includes desktop computers, servers, GPS units, and networked systems**.** In most organizations, GIS servers are configured as the central platform for data storage and application processing, from which network configurations are developed to support multi-user access and system integration (Ahmad and Firincioglu, 2019).

#### 2.11.3.3 Data

Data is arguably the most critical component of a GIS. It provides the factual foundation upon which spatial analysis and decision-making are based. GIS data includes both geographic (spatial) and tabular (attribute) information, which can be gathered from field surveys, remote sensing, government records**,** or purchased from commercial data providers. These datasets reflect real-world features and are essential for modeling environments, infrastructure, and socio-economic conditions (Ahmad and Firincioglu, 2019).

Data is one of the most critical and often most costly components of a Geographic Information System (GIS). All GIS data fall into two main categories: spatial data and attribute data. Spatial data define where a feature is located, while attribute data describe what the feature is, detailing its characteristics or properties. Together, these form geographic data, which link physical features on the Earth's surface with descriptive information. To enter this information into a GIS, a method called digitizing is commonly used. Digitizing involves the digital encoding of geographic features such as roads, buildings, or administrative boundaries. This can be done by tracing these features either directly on a computer screen using a scanned map as a reference or manually on a digitizing tablet using a paper map as the source. This process ensures accurate spatial representation and prepares data for further analysis within the GIS environment (Ali, 2020).

#### 2.11.3.4 People

While GIS offers advanced tools and technologies, its effectiveness ultimately depends on the people who manage, operate, and apply it. Skilled users**,** such as GIS analysts, planners, engineers, and decision-makers, interpret data, design workflows, and implement strategies that address real-world problems. Without the expertise and vision of people, GIS would have limited value, as it is the human element that transforms data into actionable insight (Ahmad and Firincioglu, 2019).

#### 2.11.3.5 Software

The software component of GIS provides the tools, functions, and user interface necessary for data input, processing, analysis, visualization, and output. GIS software enables users to manipulate geographic data, perform spatial queries, and generate thematic maps. Key software capabilities include:

i. Tools for data entry and editing
ii. Methods for spatial data storage and management
iii. Analytical functions for querying, modeling, and simulation
iv. Visualization tools for mapping and presentation

Popular GIS software platforms include ArcInfo (developed by ESRI), Intergraph (by Intergraph Corporation), and MapInfo (by MapInfo Corporation), among others. These programs are designed to be accessible, user-friendly, and adaptable to different application domains.

#### 2.11.3.6 Strategies (Method)

An effective GIS implementation is guided by well-defined strategies, which include operational models, organizational practices, and policy frameworks unique to each institution. These strategies shape how GIS is deployed, maintained, and aligned with broader business or governmental objectives. A planned approach ensures that GIS functions effectively, supports long-term goals, and adapts to changing technological and institutional requirements (Ahmad and Firincioglu, 2019).

## 2.12 Applications of Geographical Information Systems (GIS)

Geographic Information Systems (GIS) have evolved into a highly multidisciplinary field, becoming an essential component of modern education and a critical tool across various sectors. The growing demand for GIS professionals is driven by the rapid expansion of geospatial technologies, including GPS services, location-based applications, remote sensing, spatial statistics**,** and digital mapping**.** Initially limited to cartography and basic mapping tasks, GIS is now applied in nearly every discipline from urban planning, environmental management, and disaster response to healthcare, marketing, and social sciences**.** Its ability to integrate geography with diverse datasets enables users to visualize patterns, gain insights, and make informed decisions. In countries like Japan, government initiatives have emphasized the importance of geospatial literacy for a “Geospatially Enabled Society (Ahmad and Firincioglu, 2019).

## 2.13 Process of GIS

The GIS process includes five fundamental elements, with data acquisition being the first and most crucial step in building a functional geospatial system. Data acquisition involves the systematic collection of data tailored to the specific needs of a GIS application. As shown in Table 1, data can be obtained through multiple approaches:

i. **Primary data collection**, such as field surveys using large-scale maps and direct on-site inspections, and may also include aerial photography for more extensive coverage.
ii. **Secondary data acquisition**, which entails locating and retrieving existing spatial information. This can include topographic maps, satellite imagery, aerial and ground photographs, surveys, and various technical reports sourced from archives and institutional repositories**.**

### 2.13.2 Preprocessing

The second element of the GIS process is preprocessing, which involves manipulating and preparing raw data so it can be properly entered into the GIS system. This stage is divided into two key tasks. The first is data format conversion**,** where information is extracted from maps, photographs, and existing records, then digitized and stored in a computer database in a format compatible with GIS software. The second task is feature identification, which involves accurately recognizing and referencing the locations of relevant features within the original data sources. This ensures that all spatial elements are correctly aligned and integrated into the GIS, laying the groundwork for accurate spatial analysis and visualization (Ahmad and Firincioglu, 2019).

### 2.13.3 Data Management

The relational data model is commonly used for managing tabular data like bank accounts or phone records, but it is not well-suited for representing complex spatial data. Users must often convert intuitive spatial concepts into simplified, non-spatial formats, which limits effectiveness. In contrast, the object-oriented data model, built on classification, generalization, association, and aggregation, aligns more naturally with spatial thinking. Studies suggest that adopting object-oriented databases in GIS improves system clarity, simplifies maintenance, and extends the software's lifecycle (Ahmad and Firincioglu, 2019).

### 2.13.4 Manipulation and Analysis

Manipulation and analysis represent a core focus for most GIS users, as this is where spatial data is transformed into meaningful insights. This component includes analytical operations that interact with database content to generate new information or uncover spatial patterns. Although some users mistakenly believe this module alone defines a GIS, it is actually just one part of a larger system. Through manipulation and analysis, users can query, model, and interpret spatial relationships, making this function essential for informed decision-making (Ahmad and Firincioglu, 2019).

### 2.13.5 Product Generation

The final stage of the GIS process is product generation**,** where the outcomes of spatial analysis is transformed into usable outputs such as maps, statistical reports, charts, and other graphical representations**.** These products serve as decision-support tools, enabling users to communicate findings effectively and share insights with stakeholders. This stage translates complex GIS data into clear, actionable formats that support planning, policy-making, and operational tasks (Ahmad and Firincioglu, 2019).

## 2.14 Road Maintenance

Road maintenance is a critical component of road infrastructure management aimed at preserving pavement quality, ensuring safety, and extending service life. It encompasses all activities carried out to prevent, correct, or mitigate road surface deterioration due to traffic loading, weather conditions, and material aging. Road maintenance is generally categorized into three main types: preventive**,** corrective, and routine maintenance.

1. **Preventive Maintenance** involves proactive measures taken to slow down the rate of pavement deterioration before significant damage occurs. It includes activities such as crack sealing, surface sealing, and slurry sealing. Preventive maintenance is cost-effective and helps extend the functional lifespan of the road. Preventive maintenance may include:

   i. Crack sealing and filling
   ii. Surface sealing (e.g., fog seal, chip seal, slurry seal)
   iii. Thin asphalt overlays
   iv. Joint resealing (for concrete pavements)
   v. Drainage maintenance (to prevent water infiltration)

2. **Corrective Maintenance**, also referred to as reactive maintenance, is performed after defects or failures have developed. Common corrective actions include pothole patching, resurfacing, and structural repairs. This type of maintenance restores the road’s usability but may not address underlying causes of deterioration. Corrective maintenance activities include:

i. Pothole patching
ii. Skin patching and deep patching
iii. Base repairs and localized reconstruction
iv. Resurfacing and leveling
v. Pavement strengthening (e.g., overlaying with thicker layers)

3. **Routine Maintenance** consists of regular, scheduled tasks aimed at maintaining the road's usability and safety. This includes cleaning drainage systems, vegetation control, shoulder repairs, signage replacement, and debris removal. Routine maintenance ensures the road remains in acceptable condition for daily use.

i. Clearing and cleaning of side drains and culverts
ii. Vegetation control (e.g., grass cutting, tree trimming)
iii. Pavement marking renewal
iv. Sign and guardrail maintenance
v. Shoulder grading and repair
vi. Sweeping and debris removal

## 2.15 Review of Existing Related Studies

### 2.15.1 Studies Conducted in Developed Countries

Pinatt et al., (2020) in "Evaluation of Pavement Condition Index by Different Methods: Case study of Maringa, Brazil" analyzed the objective and subjective evaluations of pavement condition index using Urban Pavement Management Systems (UPMS) using GIS to identify the most damaged pathways in the state of Paran, Brazil. Evaluation of defects were identified visually using PCI method (Objective and Subjective) which were compared using coefficient of Pearsons correlation. Maps were generated in the ArcGIS 10.2 software and findings showed that 92.21% were classified as very good to fair, 7.94% were under poor or very poor and that the coefficient resulted in 0.95 between results of objective and subjective evaluations from Pearsons correlation representing a strong correlation between the data. The PCI can be determined quickly and simply through subjective evaluations for cities. Where maintenance is performed without planning, it is a simplified way to evaluate pavement and have good results. The use of GIS facilitates visualization of different sections.

Ahmed Elhadi (2009) in “GIS, a Tool for Pavement Management” with the objectives of revealing the role of GIS technology in enhancing Pavement Management System (PMS) components**,** specifically making the output from roughness (IRI) and structural integrity (FWD) tests more interpretable through dynamic color coding and sophisticated visualization techniques, and to demonstrate the importance of using GIS as a platform for PMS. The GIS tools primarily used included ArcGIS 9.2 for map creation and analysis, the Video DRS extension for ArcView for geo-referenced video review, and the ROMDAS Data View application for integrated data viewing. Other tools employed were the Road Measurement & Data Acquisition System (ROMDAS) with Laser Profilometers and GPS for roughness data collection, the Falling Weight Deflectometer (FWD) machine KUAB for structural evaluation, and DARWin 3.1 pavement design software for FWD data processing. The findings indicated that GIS-based maps significantly improved the interpretability of pavement condition data compared to tabular formats, allowing for easier identification of road sections requiring attention. The integration of IRI and structural capacity (FWD) data within a GIS environment, facilitated by GPS referencing, enabled a comprehensive assessment of pavement conditions at specific locations. The results showcased the production of GIS-based maps for IRI and FWD data**,** the classification and visualization of roughness levels, and the identification of road sections needing asphaltic overlay based on FWD analysis. The study concluded that GIS is an effective tool for enhancing PMS operations, providing improved visualization, data integration, and decision support capabilities for pavement maintenance and rehabilitation, representing a crucial step towards developing a comprehensive GIS-based PMS.

Hadidi et al., (2014) in "Utilizing Geographic Information System as a Tool for Pavement Management System" presented an analysis of the use of Geographic Information Systems (GIS) as a tool for PMS in Amman-Jordan, aiming to enhance the development and implementation of PMS. While the specific GIS tools used for analysis aren't explicitly detailed in the abstract or introduction, the study mentions the transfer of collected data into a GIS database to create a GIS model; other tools involved included field surveys for collecting quantitative data on pavement distresses and the calculation of the PCI based on distress density and severity using charts from reference. The findings indicated a significant increase in potholes and transverse cracking in Amman, with PCI values ranging from 5 to 96, averaging 56.95, signifying fair overall pavement conditions and highlighting worse conditions in the eastern part of the city. The results showcased a GIS model of Amman based on PCI values, visually representing pavement conditions across the city and enabling maintenance prioritization based on PCI ranking, along with associated cost estimations for preventive maintenance, overlay, and reconstruction strategies. The study concluded that GIS-based PMS is a crucial step for improving road infrastructure management, promising enhanced maintenance quality and reduced costs, and representing the future for infrastructure management.

### 2.15.2 Studies Conducted in Developing Countries

Al-neami et al., (2018) in “Assessment of Al-Amarah street within the Al-Kut city using Pavement Condition Index (PCI) and GIS Techniques” determined an estimate of flexible pavement conditions through visual surveys using Micro PAVER software 5.2 to ease PCI calculations based on the GIS data for the study area. Arc Map 9.3 was also applied as an integrated maintenance system for the annual road deteriorations and changes in PCI values yearly. This study also aimed at providing a simple way of presenting details of deteriorations on the satellite or geographical map of the road in each type of distresses. Findings revealed that determination of distress pavements can be carried out using visual rating and not only direct measurements thereby easing and simplifying PCI calculations. In order to reduce human computational errors, Micro PAVER 5.2 software was used to estimate the PCI, in which an average of 64 as the PCI for the case study was found indicating a fair and critical PCI.

Ahmad and Firincioglu (2019) in “Role of GIS in Enhancing the Pavement Management System” aimed at showing the benefits of using Geographical Information system (GIS) in Pavement Management Systems which involves Pavement Deterioration and Pavement Distress. In this study the most occurring surface distress was categorized into 4 sections which included disintegration Potholes, surface deformation, cracking and surface defect bleeding, with the cause of deterioration in pavement functionality including localized depression, rutting, cracks and texture loss. Findings show that GIS with PMS is demanding initially but significantly enhances road network management. It offers powerful visualization, speeds up processes and proves cost-effective than pavement maintenance and rehabilitation.

Kiema and Mwangi (2014) in “A Prototype GIS Based Road Pavement Information and Management System” had the objective of demonstration the effectiveness of GIS in making sound and timely decisions about road pavements to support efficient management which was achieved by developing a prototype GIS based PMS for the Nairobi Central Business District (CBD) as a case study. The geodatabase was developed in Microsoft Office Access and linked to spatial data in ESRI’S Arc View GIS 3.2. The data required in this study included Road inventories (pavement width, pavement lanes and numbers etc.), AADT, ESAL (Equivalent Single Axle Loads), Condition Rating Survey (CRS) and International Roughness Index (IRI) etc. Working on PIMS involved three (3) stages which were to capture spatial data, designed and create attribute tables and creating a user interface to access the created database. In conclusion, a GIS based model for PIMS was created, it also indicated the importance of software customization to cater for diversity in user requirements. Integrated user interfaces were also developed so those with limited GIS skills are able to freely interact with the system allowing the user to analyze and visualize data and information.

El Nthaga et al., (2025) in “An Integrated Remote Sensing and GIS Road Condition Assessment Framework” integrates Remote sensing and GIs to develop an innovative virtual road condition assessment framework combining distress evaluation with drainage analysis. This research was conducted on selected roads within Jomo Kenyatta University of Agriculture and Technology (JKUAT) which were Innovation and Technology streets respectively with the study involving the collection of spatial and non-spatial data. Pavement conditions were assessed using QGIS tools verified by PCI survey following ASTM guidelines. To enhance pavement condition assessment, data sets on curvature, flow accumulation and distress classification were combined to create the QPCI providing a quantitative measure of pavement condition and maintenance prioritizations. Drone images were processed using Open Drone Map to produce an Orthophoto and DSM facilitating pavement condition assessment. Innovation street, an asphalt-surfaced road spanning 240.9m was classified under ASTM D6433-07 and was divided into sections with 7 randomly selected sample units. The survey identified various distresses including potholes, alligator cracking, raveling etc. The failed sections of the road indicated it has reached the end of its life while serious section required immediate repairs. Technology Street, with an asphalt surface, was assessed over 191 meters using ASTM D6433-07. Eight sample units revealed various distresses like rutting, potholes, cracking, and weathering. The first half mostly showed failed to very poor conditions due to heavy traffic, environmental factors, and aging, while some sections remained satisfactory with fewer distresses. The second section of Technology Street, paved with block pavers and assessed under ASTM E2840-11 spans 326 meters with 13 random sample units analyzed. Distresses observed included damaged pavers, faulting, excessive joint width, and heave. Despite these, PCI ratings ranged from 93 to 99, indicating excellent pavement condition. The results were consistent with the QGIS distress classification, confirming the accuracy of the geospatial assessment. This study introduces a GIS and Remote Sensing-based framework for road condition evaluation, using the Quantum Pavement Condition Index (QPCI) to prioritize maintenance. It effectively identified critical areas like Innovation Street and parts of Technology Street, promoting sustainable and scalable road management practices.

### 2.15.3 Studies Conducted in Nigeria

Adanikin et al., (2022) in “Spatial Analysis of Road Pavement Condition and Maintenance Actions Using GIS” depicted how GIS can be employed to collect and analyze pavement conditions, promoting efficient roadway management and to prevent the widespread of deterioration, with Ilara-Mokin, Ondo State being the study area. It was revealed that the majority of the roads within the study area where in a good and fair condition which was determined by their PASER rating and that portions of the pavements failed due to the presence of alligator cracks and potholes at regular intervals. In summary GIS is a system that can be used to record, analyze and evaluate pavement conditions and problems

# CHAPTER THREE

## 3.0 METHODOLOGY

### 3.1 Location of Study Area

The University of Benin (UNIBEN), located in Ugbowo, Benin City, Nigeria, is a Federal Government-owned institution established in 1970. Strategically situated in the heart of Benin City, the university has an estimated population of over 70,000 students and features a vast internal road network that supports both academic and residential functions. This network comprises a mix of paved and unpaved roads that serve the transportation needs of students, staff, and visitors. Over the years, many of these internal roads have undergone several phases of rehabilitation and reconstruction to improve accessibility and functionality. For this project, the road selected for pavement condition assessment is the Ekosodin Road (6°24'20.21" NE to 5°37'18.18" NE) that leads to the Uniben Back Gate, which is a paved road located within the University of Benin's Ugbowo Campus, Benin City, Nigeria. It is connected to Ethiope River Road and intersects Mukoro Mowoe Street, forming a key internal junction. The road is of a length of approximately 0.25km, and supports moderate to high volumes of pedestrian and vehicular traffic, largely due to its proximity to student residences and commercial activity. The surface is asphalt, though signs of aging and surface wear are visible. There are no lane markings or clearly defined shoulders, and drainage infrastructure appears limited. Land use along the corridor is primarily residential with commercial activities, and the road serves as a key link between the campus and adjacent communities. The selected road for this study is shown in figure 3.1.

Figure 3.1 Road selected (Ekosodin Road) for study, within University of Benin Campus (Google Earth).

### 3.2 Equipment and Instruments for Pavement Inspection

1. Measuring Tape
2. Straight Edge or Ruler
3. Digital Camera or Smartphone
4. Chalk

### 3.3 Data Acquisition

According to ASTM D6433-07, the pavement condition evaluation followed a systematic process. The pavement network was divided into branches based on function, and each branch was further broken down into sections with uniform structural characteristics and usage. For accurate assessment, sample units were selected from each section. In the case of Portland

Cement Concrete pavements with joint spacing greater than 7.62m, each slab was subdivided into imaginary slabs not exceeding 7.62m, assuming the joints were in perfect condition. These sample units were clearly marked on-site using paint or referenced sketches to ensure accurate identification during inspections. Depending on available resources, either all sample units or a selected number were inspected. While inspecting every unit provided the most accurate results and supported detailed analysis such as maintenance planning, a smaller sample size could be used for routine pavement monitoring.

Pavement distress data was entered into the GIS software (ArcGIS), linking field observations with spatial features for georeferenced analysis. Google Earth Pro was also used to validate imagery, assist with feature digitization, and perform length and area measurements.

Once the number of sample units to be inspected was determined, a systematic random sampling method was applied to select them. Sample units were spaced equally throughout the pavement section, and the first unit was chosen at random.

$$\mathrm{i} = \frac{\mathrm{N}}{\mathrm{n}} \tag{3.1}$$

where:

$N$ = total number of sample units in the section, and

$n$ = number of sample units to be inspected.

### 3.4 Evaluation of Pavement condition

The first sample unit to be inspected was selected at random from within the range of sample units numbered 1 through *i*. After this initial random selection, additional sample units within the section were identified by adding successive increments of the interval *i* to the starting unit. These systematically spaced units were then inspected as part of the pavement condition assessment.

For asphalt pavements, each selected sample unit was individually inspected. Inspectors walked along the sidewalk or shoulder of the pavement to assess the condition, sketched the layout, and documented the branch, section, unit size, and whether the unit was a random or additional sample. They identified and recorded all types and severities of visible distresses, ensuring distress types were correctly classified 95% of the time. Linear measurements were considered accurate if they were within 10% when remeasured, and area measurements were considered accurate if within 20%.

For Portland Cement Concrete (PCC) pavements, inspectors also inspected each unit individually, noted slab layout, dimensions, and total number of slabs, and recorded all visible distresses along with their severity levels. They summarized the findings for each unit. This process was repeated for all selected units to enable accurate calculation of the Pavement Condition Index (ASTM D6433-07 and TM 5-623).

A simple procedure for the method of conducting the pavement evaluation may be summarized as:

Each selected road was subdivided into uniform sample unit that covered the entire pavement length for the flexible pavement. A manual walk-through inspection was carried out along each sample unit to observe and document visible pavement distresses. The evaluation followed the procedures outlined in ASTM D6433 and the TM 5-623.

For every segment, the type, extent (area or length), and severity of each observed distress were recorded using standardized data collection procedures.

### 3.4.1 Pavement Condition Index (PCI) for Flexible Pavement

The Pavement Condition Index (PCI) method was adopted in this study. The pavement was simply divided into sample units. The types and severities of pavement distresses were assessed through visual inspection of the sample units. The collected distress data were used to calculate the PCI for each sample unit, after which the overall PCI for the entire pavement section was determined. The calculated PCI values were then evaluated using the Pavement Condition Rating (PCR), which provides a verbal description of pavement condition as a function of the PCI value ranging from “Failed” to “Good” to identify the level and severity of distresses and to select appropriate maintenance or rehabilitation measures (Temimi et al., 2021).

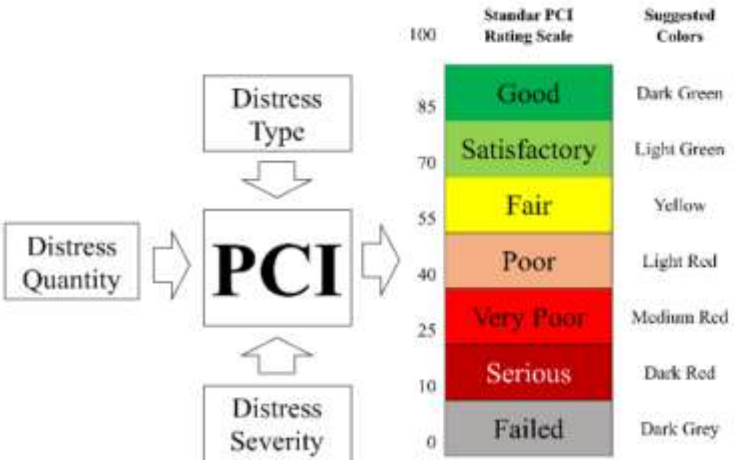


Figure 3.2: Pavement Condition Index (PCI), Rating Scale, and Suggested Colors (Gerardo, et al 2025)

### 3.4.2 Pavement Condition Rating

This method provided a consistent framework for identifying and describing pavement distresses according to their severity and extent. The Pavement Condition Rating (PCR) served as a numerical index reflecting the cumulative effect of various distress types on the overall condition of the pavement section. The calculation of the PCR involved the summation of deduct values, which represented the penalty associated with each type of distress (The Ohio Department of Transportation, 2006).

## 3.5 Spatial Analysis data and Visualization

Using ArcGIS software, the distress data, including the Pavement Condition Index (PCI) and Pavement Condition Rating (PCR) results, were spatially analyzed to visualize the distribution and severity of pavement distresses along Ekosodin Road, in accordance with ASTM D6433-2007 and TM 5-623 standards. PCI calculations were conducted for each sample unit based on the ASTM methodology, and the resulting PCI values were categorized using standard PCI rating scales ranging from “Very Poor” to “Excellent,” with each category represented by a corresponding color code. These PCI values were then integrated into the ArcGIS platform to produce detailed maps that accurately reflected the current pavement condition for assessment and decision-making purposes.

A simple procedure for the method of conducting the pavement evaluation may be summarized as:

Each selected road was subdivided into uniform sample unit that covered the entire pavement length for the flexible pavement. A manual walk-through inspection was carried out along each sample unit to observe and document visible pavement distresses. The evaluation followed the procedures outlined in ASTM D6433 and the TM 5-623

For every segment, the type, extent (area or length), and severity of each observed distress were recorded using standardized data collection procedures.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

During the field investigation of the Ekosodin road pavement conducted to evaluate its condition within the University of Benin, Ugbowo Campus, Benin City, it was observed that utilizing the curves from ASTM D6433-07 for determining the deduct values and corrected deduct values for the respective distress types was challenging. Therefore, the deduct value and corrected deduct value curves used in this study were adopted from TM 5-623, as they provided greater computational ease and clarity.

This chapter presents the findings and results obtained during the course of the research. The primary aim was to evaluate the overall condition of the Ekosodin road pavement leading to the University of Benin back gate and how the results obtained aligns with the specific objectives outlined earlier in Chapter One.

The data obtained from the study area for PCI computations followed the ASTM D6433-07 standard. However, as previously stated, the curves for deduct values and corrected deduct values were adopted from TM 5-623. The study area, which consisted of a 0.25 km stretch of road, was divided into five (5) sample units for PCI calculations. Each sample unit had its own PCI value, and the average of the five PCI values was computed to determine the overall PCI of the road section. The locations and positions of the respective pavement distresses—each corresponding to the computed PCI values—were incorporated into the GIS environment (ArcGIS 10.8/ArcMap) for spatial representation, visualization, and analysis.

The computations for the PCI and PCR of the Ekosodin Road leading to the Back Gate within the University of Benin, Ugbowo Campus, for each of the sample units are presented in the table below.

Table 4.1: PCI and PCR results for sample unit 1 of the Ekosodin road, within the University of Benin, Ugbowo campus.

Sample unit area = 275m$^2$

| Distress Type | Severity | Density (%) | Deduct Value | Corrected Deduct Value | PCI | PCR |
|---|---|---|---|---|---|---|
| Edge Cracking | L | 2.44 | 4 | 25 | 75 | Satisfactory |
|  | M | 0.98 | 8 |  |  |  |
|  | H | 2.19 | 4 |  |  |  |
| Patching | L | 0.055 |  |  |  |  |
|  | M | 3.56 | 18 |  |  |  |
| Potholes | H | 0.0101 |  |  |  |  |
| Total |  |  | 34 |  |  |  |

Where the letters L, M and H indicates Low, Medium and High Severity distresses types, respectively. Low severity distress shows minor surface defects with little impact on performance, medium severity distress reflects noticeable deterioration that affects ride quality but remains serviceable, while high severity distress indicates severe damage that compromises pavement safety and requires immediate repair.

Table 4.2: PCI and PCR results for Sample Unit 2

| Distress Type | Severity | Density (%) | Deduct Value | Corrected Deduct Value | PCI | PCR |
|---|---|---|---|---|---|---|
| Alligator Cracking | L | 1.65 | 14.3 | 61 | 49 | Poor |
| Longitudinal Cracking | L | 3.20 | 7.3 | | | |
| Potholes | L | 0.00268 | | | | |
| | M | 0.013 | | | | |
| | H | 0.267 | 74.7 | | | |
| Total | | | 96.3 | | | |

Table 4.3: PCI and PCR results for Sample Unit 3

| Distress Type | Severity | Density (%) | Deduct Value | Corrected Deduct Value | PCI | PCR |
|---|---|---|---|---|---|---|
| Longitudinal Cracking | L | 4.7 | 10 | 38 | 62 | Fair |
| | M | 8.28 | 28.3 | | | |
| Edge Cracking | L | 0.40 | 2 | | | |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Transverse Cracking | L | 0.25 | 6 |  |  |  |
|  | M | 1.51 | 12 |  |  |  |
| Alligator Cracking | M | 0.74 | 18.3 |  |  |  |
| Total |  |  | 74.8 |  |  |  |

Table 4.4: PCI and PCR results for Sample Unit 4

| Distress Type | Severity | Density (%) | Deduct Value | Corrected Deduct Value | PCI | PCR |
|---|---|---|---|---|---|---|
| Longitudinal Cracking | M | 6.5 | 25 | 45 | 55 | Fair |
| Transverse Cracking | M | 0.47 | 4 |  |  |  |
| Alligator Cracking | M | 0.29 | 11.4 |  |  |  |
| Edge Cracking | M | 4.20 | 16.4 |  |  |  |
|  | H | 0.99 | 14 |  |  |  |
| Total |  |  | 70.8 |  |  |  |

Table 4.5: PCI and PCR results for Sample Unit 5

| Distress Type | Severity | Density (%) | Deduct Value | Corrected Deduct Value | PCI | PCR |
|---|---|---|---|---|---|---|
| Edge Cracking | M | 18.5 | 27.4 | 68 | 32 | Very Poor |
| Longitudinal Cracking | L | 2.5 | 6 | | | |
| Potholes | M | 0.13 | 38 | | | |
| | H | 0.070 | 48 | | | |
| Total | | | 119.4 | | | |

In order to determine the overall PCI and PCR for the road section, the averages of the PCI and PCR values obtained from the individual sample units were calculated as follows:

$$\frac{S1 + S2 + S3 + S4 + S5}{\sum n}$$

Where S1, S2, S3, S4 and S5 represents the individual PCI of the respective sample units

And n is the total number of sample units, thus

$$\frac{75 + 49 + 62 + 55 + 32}{5}$$

= 54.6

From the results, it was observed that Sample Unit 1 had a PCI value of 75, indicating a Satisfactory pavement condition; Sample Unit 2 recorded a PCI of 49, corresponding to a Poor condition; Sample Unit 3 had a PCI of 62, reflecting a Fair condition; Sample Unit 4 recorded a PCI of 55, also indicating a Fair condition; and Sample Unit 5, which had the lowest PCI value among all the units, recorded a PCI of 32, signifying a Very Poor pavement condition. The PCI values and PCR of the respective sample units are shown from tables 4.1-4.5.

The overall PCI for the entire road section was obtained by averaging the PCI values of the five sample units, resulting in an overall PCI of 54.6. According to ASTM D6433-07, this value classifies the Ekosodin Road section as being in a Poor pavement condition.

Figure 4.1: Results obtained along Ekosodin Road, University of Benin, Ugbowo Campus, showing the spatial distribution of all distress points in the area (Google Earth).

Table 4.6: Spatial positions of all identified distress points along Ekosodin Road within the University of Benin (Google Earth).

| S/N | Distress Points | Latitude \| Longitude | UTM, ZONE (m) |
|---|---|---|---|
| 1. | PT 1 | 6° 24' 24.23" N \| 5° 37' 19.84" E | 790072.062E 708906.786N 31N |
| 2. | PT_2 | 6° 24' 24.18" N \| 5° 37' 19.97" E | 790076.132E 708905.335N 31N |
| 3. | PT_3 | 6° 24' 24.18" N \| 5° 37' 19.97" E | 790076.132E 708905.335N 31N |
| 4. | PT_4 | 6° 24' 24.09" N \| 5° 37' 19.86" E | 790072.647E 708902.661N 31N |
| 5. | PT_5 | 6° 24' 23.86" N \| 5° 37' 19.79" E | 790070.581E 708895.402N 31N |
| 6. | PT_6 | 6° 24' 23.88" N \| 5° 37' 19.88" E | 790073.223E 708896.091N 31N |
| 7. | PT_6 | 6° 24' 23.8" N \| 5° 37' 19.82" E | 790071.576E 708893.504N 31N |
| 8. | PT_7 | 6° 24' 23.73" N \| 5° 37' 19.75" E | 790069.195E 708891.445N 31N |
| 9. | PT_8 | 6° 24' 23.77" N \| 5° 37' 19.76" E | 790069.554E 708892.752N 31N |
| 10. | PT_9 | 6° 24' 23.7" N \| 5° 37' 19.69" E | 790067.351E 708890.528N 31N |
| 11. | PT_10 | 6° 24' 23.72" N \| 5° 37' 19.63" E | 790065.665E 708891.183N 31N |
| 12. | PT_11 | 6° 24' 23.56" N \| 5° 37' 19.53" E | 790062.658E 708886.111N 31N |
| 13. | PT_12 | 6° 24' 23.34" N \| 5° 37' 19.45" E | 790060.024E 708879.424N 31N |
| 14. | PT_13 | 6° 24' 23.26" N \| 5° 37' 19.46" E | 790060.381E 708876.826N 31N |
| 15. | PT_14 | 6° 24' 23.26" N \| 5° 37' 19.56" E | 790063.623E 708877.086N 31N |
| 16. | PT_15 | 6° 24' 23.2" N \| 5° 37' 19.66" E | 790066.512E 708875.031N 31N |
| 17. | PT_16 | 6° 24' 22.97" N \| 5° 37' 19.51" E | 790061.93E 708868.191N 31N |
| 18. | PT_17 | 6° 24' 23.02" N \| 5° 37' 19.35" E | 790057.041E 708869.682N 31N |
| 19. | PT_18 | 6° 24' 23.0" N \| 5° 37' 19.41" E | 790058.982E 708868.906N 31N |

| | | | |
|---|---|---|---|
| 20. | PT_19 | 6° 24' 22.99" N \| 5° 37' 19.39" E | 790058.418E 708868.726N 31N |
| 21. | PT_20 | 6° 24' 22.94" N \| 5° 37' 19.39" E | 790058.438E 708867.044N 31N |
| 22. | PT_21 | 6° 24' 22.87" N \| 5° 37' 19.36" E | 790057.464E 708864.937N 31N |
| 23. | PT_22 | 6° 24' 22.84" N \| 5° 37' 19.4" E | 790058.619E 708864.08N 31N |
| 24. | PT_23 | 6° 24' 22.84" N \| 5° 37' 19.35" E | 790057.003E 708864.138N 31N |
| 25. | PT_24 | 6° 24' 22.75" N \| 5° 37' 19.25" E | 790054.205E 708861.313N 31N |
| 26. | PT_25 | 6° 24' 22.73" N \| 5° 37' 19.28" E | 790055.083E 708860.72N 31N |
| 27. | PT_26 | 6° 24' 22.67" N \| 5° 37' 19.32" E | 790056.398E 708858.967N 31N |
| 28. | PT_27 | 6° 24' 22.64" N \| 5° 37' 19.22" E | 790053.326E 708857.999N 31N |
| 29. | PT_28 | 6° 24' 22.53" N \| 5° 37' 19.21" E | 790052.911E 708854.6N 31N |
| 30. | PT_29 | 6° 24' 22.37" N \| 5° 37' 19.24" E | 790053.911E 708849.515N 31N |
| 31. | PT_30 | 6° 24' 22.2" N \| 5° 37' 19.1" E | 790049.72E 708844.337N 31N |
| 32. | PT_31 | 6° 24' 22.1" N \| 5° 37' 19.07" E | 790048.64E 708841.188N 31N |
| 33. | PT_32 | 6° 24' 22.08" N \| 5° 37' 19.03" E | 790047.315E 708840.628N 31N |
| 34. | PT_33 | 6° 24' 22.06" N \| 5° 37' 19.01" E | 790046.941E 708840.073N 31N |
| 35. | PT_34 | 6° 24' 21.92" N \| 5° 37' 18.98" E | 790045.835E 708835.597N 31N |
| 36. | PT_35 | 6° 24' 21.95" N \| 5° 37' 19.0" E | 790046.438E 708836.773N 31N |
| 37. | PT_36 | 6° 24' 21.86" N \| 5° 37' 18.97" E | 790045.501E 708833.802N 31N |
| 38. | PT_37 | 6° 24' 21.84" N \| 5° 37' 18.86" E | 790042.228E 708833.077N 31N |
| 39. | PT_37.1 | 6° 24' 21.8" N \| 5° 37' 18.87" E | 790042.699E 708831.962N 31N |
| 40. | PT_37.2 | 6° 24' 21.66" N \| 5° 37' 18.82" E | 790041.16E 708827.561N 31N |
| 41. | PT_37.3 | 6° 24' 21.64" N \| 5° 37' 18.8" E | 790040.365E 708827.136N 31N |

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|---|---|---|---|
| 42. | PT_37.4 | 6° 24' 21.52" N \| 5° 37' 18.77" E | 790039.653E 708823.437N 31N |
| 43. | PT_37.5 | 6° 24' 21.47" N \| 5° 37' 18.79" E | 790040.215E 708821.968N 31N |
| 44. | PT_38 | 6° 24' 21.41" N \| 5° 37' 18.74" E | 790038.741E 708819.935N 31N |
| 45. | PT_38.1 | 6° 24' 21.35" N \| 5° 37' 18.67" E | 790036.537E 708818.076N 31N |
| 46. | PT_39 | 6° 24' 21.29" N \| 5° 37' 18.66" E | 790036.181E 708816.226N 31N |
| 47. | PT_39.1 | 6° 24' 21.24" N \| 5° 37' 18.64" E | 790035.635E 708814.751N 31N |
| 48. | PT_39 2 | 6° 24' 21.15" N \| 5° 37' 18.58" E | 790033.801E 708811.976N 31N |
| 49. | PT_40 | 6° 24' 21.03" N \| 5° 37' 18.59" E | 790034.008E 708808.292N 31N |
| 50. | PT_4.1 | 6° 24' 21.02" N \| 5° 37' 18.56" E | 790033.268E 708807.912N 31N |
| 51. | PT_40.2 | 6° 24' 21.0" N \| 5° 37' 18.54" E | 790032.54E 708807.355N 31N |
| 52. | PT_50 | 6° 24' 21.02" N \| 5° 37' 18.76" E | 790039.178E 708808.13N 31N |
| 53. | PT_51 | 6° 24' 20.89" N \| 5° 37' 18.52" E | 790031.816E 708803.854N 31N |
| 54. | PT_51 1 | 6° 24' 20.81" N \| 5° 37' 18.5" E | 790031.297E 708801.428N 31N |
| 55. | PT_51.2 | 6° 24' 20.74" N \| 5° 37' 18.43" E | 790029.227E 708799.315N 31N |
| 56. | PT_51.3 | 6° 24' 20.69" N \| 5° 37' 18.43" E | 790029.08E 708797.754N 31N |
| 57. | PT_51 4 | 6° 24' 20.59" N \| 5° 37' 18.39" E | 790027.988E 708794.794N 31N |
| 58. | PT_52 | 6° 24' 20.52" N \| 5° 37' 18.33" E | 790026.128E 708792.681N 31N |
| 59. | PT_52.1 | 6° 24' 20.5" N \| 5° 37' 18.35" E | 790026.895E 708792.021N 31N |
| 60. | PT_53 | 6° 24' 20.43" N \| 5° 37' 18.33" E | 790026.287E 708789.739N 31N |
| 61. | PT_53.1 | 6° 24' 20.3" N \| 5° 37' 18.32" E | 790025.765E 708785.785N 31N |
| 62. | PT_53.2 | 6° 24' 20.22" N \| 5° 37' 18.26" E | 790024.172E 708783.343N 31N |
| 63. | PT_53.3 | 6° 24' 20.14" N \| 5° 37' 18.26" E | 790023.996E 708780.918N 31N |

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| 64. | PT_54 | 6° 24' 20.3" N \| 5° 37' 18.4" E | 790028.399E 708785.755N 31N |
| 65. | PT_54.1 | 6° 24' 20.26" N \| 5° 37' 18.38" E | 790027.807E 708784.656N 31N |
| 66. | PT_55 | 6° 24' 20.0" N \| 5° 37' 18.26" E | 790024.207E 708776.515N 31N |
| 67. | PT_55 | 6° 24' 20.27" N \| 5° 37' 18.32" E | 790026.002E 708784.758N 31N |
| 68. | PT_55.1 | 6° 24' 20.18" N \| 5° 37' 18.27" E | 790024.433E 708782.072N 31N |
| 69. | PT_55.2 | 6° 24' 20.09" N \| 5° 37' 18.26" E | 790024.026E 708779.314N 31N |
| 70. | PT_55.3 | 6° 24' 19.97" N \| 5° 37' 18.22" E | 790022.926E 708775.767N 31N |
| 71. | PT_56 | 6 24' 19.92" N \| 5° 37' 18.21" E | 790022.603E 708774.139N 31N |
| 72. | PT_56.1 | 6° 24' 19.92" N \| 5° 37' 18.15" E | 790020.71E 708774.096N 31N |
| 73. | PT_56.2 | 6° 24' 19.84" N \| 5° 37' 18.08" E | 790018.553E 708771.518N 31N |
| 74. | PT_56.3 | 6° 24' 19.73" N \| 5° 37' 18.05" E | 790017.796E 708768.161N 31N |
| 75. | PT_56.4 | 6° 24' 19.62" N \| 5° 37' 18.09" E | 790018.919E 708764.869N 31N |
| 76. | PT_56.5 | 6° 24' 19.56" N \| 5° 37' 17.99" E | 790015.94E 708762.995N 31N |
| 77. | PT_57 | 6° 24' 19.66" N \| 5° 37' 18.15" E | 790020.75E 708766.173N 31N |
| 78. | PT_58 | 6° 24' 19.36" N \| 5° 37' 18.09" E | 790018.96E 708756.924N 31N |
| 79. | PT_58.1 | 6° 24' 19.31" N \| 5° 37' 18.05" E | 790017.672E 708755.434N 31N |
| 80. | PT_59 | 6° 24' 19.16" N \| 5° 37' 17.99" E | 790015.847E 708750.833N 31N |
| 81. | PT_60 | 6° 24' 18.99" N \| 5° 37' 17.89" E | 790012.941E 708745.406N 31N |
| 82. | PT_60.1 | 6° 24' 19.03" N \| 5° 37' 17.88" E | 790012.448E 708746.632N 31N |
| 83. | PT_60.2 | 6° 24' 18.84" N \| 5° 37' 17.81" E | 790010.551E 708740.879N 31N |
| 84. | PT_61 | 6° 24' 18.95" N \| 5° 37' 17.68" E | 790006.272E 708744.221N 31N |
| 85. | PT_61.1 | 6° 24' 18.95" N \| 5° 37' 17.71" E | 790007.402E 708744.139N 31N |

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| 86. | PT_61.2 | 6° 24' 18.8" N \| 5° 37' 17.66" E | 790005.908E 708739.572N 31N |
| 87. | PT_61.3 | 6° 24' 18.7" N \|5Â° 37' 17.63" E | 790004.85E 708736.579N 31N |
| 88. | PT_61.4 | 6° 24' 18.59" N \| 5° 37' 17.53" E | 790001.723E 708733.232N 31N |
| 89. | PT_61.5 | 6° 24' 18.5" N \| 5° 37' 17.54" E | 790002.136E 708730.478N 31N |
| 90. | PT_61.6 | 6° 24' 18.43" N \| 5° 37' 17.46" E | 789999.657E 708728.075N 31N |
| 91. | PT_61.7 | 6° 24' 18.31" N \| 5° 37' 17.44" E | 789999.001E 708724.365N 31N |
| 92. | PT_61.8 | 6° 24' 18.22" N \| 5° 37' 17.42" E | 789998.661E 708721.608N 31N |
| 93. | PT_61.9 | 6° 24' 18.13" N \| 5° 37' 17.4" E | 789997.932E 708719.037N 31N |
| 94. | PT_61.10 | 6° 24' 18.04" N \| 5° 37' 17.36" E | 789996.652E 708716.065N 31N |
| 95. | PT_61 11 | 6° 24' 17.9" N \| 5° 37' 17.28" E | 789994.237E 708711.98N 31N |
| 96. | PT_61 12 | 6° 24' 17.84" N \| 5° 37' 17.25" E | 789993.361E 708710.15N 31N |
| 97. | PT_60.3 | 6° 24' 18.85" N \| 5° 37' 17.84" E | 790011.468E 708741.227N 31N |
| 98. | PT_60.4 | 6° 24' 18.75" N \| 5° 37' 17.82" E | 790010.754E 708738.081N 31N |
| 99. | PT_60.5 | 6° 24' 18.66" N \| 5° 37' 17.75" E | 790008.543E 708735.281N 31N |
| 100. | PT_60.6 | 6° 24' 18.55" N \| 5° 37' 17.72" E | 790007.829E 708731.979N 31N |
| 101. | PT_60.7 | 6° 24' 18.46" N \| 5° 37' 17.64" E | 790005.231E 708729.166N 31N |
| 102. | PT_60.8 | 6° 24' 18.4" N \| 5° 37' 17.62" E | 790004.532E 708727.359N 31N |
| 103. | PT_60.9 | 6° 24' 18.29" N \| 5° 37' 17.59" E | 790003.807E 708724.035N 31N |
| 104. | PT_60.10 | 6° 24' 18.2" N \| 5° 37' 17.45" E | 789999.537E 708721.258N 31N |
| 105. | PT_60.11 | 6° 24' 18.15" N \| 5° 37' 17.53" E | 790001.992E 708719.6N 31N |
| 106. | PT_60.12 | 6° 24' 18.02" N \| 5° 37' 17.49" E | 790000.717E 708715.72N 31N |
| 107. | PT_60.13 | 6° 24' 17.93" N \| 5° 37' 17.47" E | 790000.177E 708712.951N 31N |

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| 108. | PT_62 | 6° 24' 17.81" N \| 5° 37' 17.43" E | 789998.902E 708709.071N 31N |
| 109. | PT_63 | 6° 24' 17.83" N \| 5° 37' 17.33" E | 789995.765E 708709.786N 31N |
| 110. | PT_63.1 | 6° 24' 17.64" N \| 5° 37' 17.23" E | 789992.663E 708703.872N 31N |
| 111. | PT_63.2 | 6° 24' 17.36" N \| 5° 37' 17.18" E | 789991.246E 708695.189N 31N |
| 112. | PT_63.3 | 6° 24' 17.1" N \| 5° 37' 17.12" E | 789989.426E 708687.256N 31N |

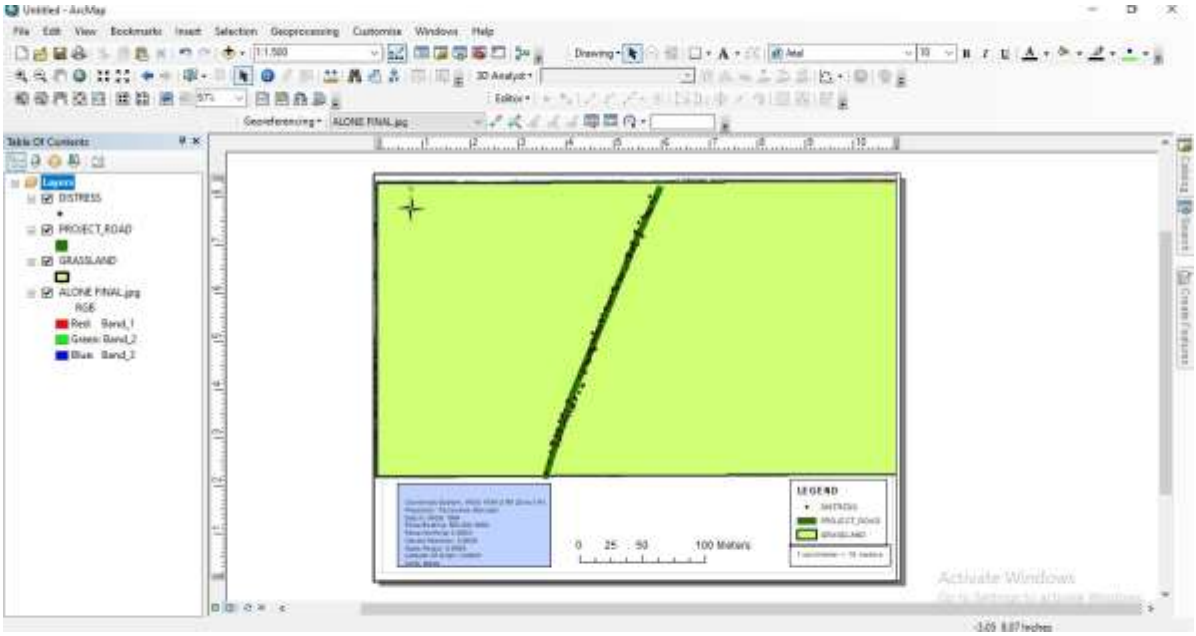

Figure 4.2: Digitized Road section of the Ekosodin Road pavement (ArcMap 10.8).

From the digitized map of the Ekosodin Road section shown above, it can be observed that the pavement distresses are distributed along both sides of the study area. The concentration of distress points appears to be higher toward the mid and lower portions of the road section, suggesting localized areas of pavement deterioration.

The spatial clustering of the distress points near specific portions of the roadway may reflect sections affected by drainage issues or traffic loading concentrations**.**

# CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATIONS

This research has evaluated the pavement condition of Ekosodin Road, leading to the University of Benin Back Gate, using the Pavement Condition Index (PCI) and Pavement Condition Rating (PCR) methods, integrated with Geographic Information System (GIS) technology. The main objectives of the study were to assess the existing pavement condition through field surveys, determine the PCI and PCR values for different sample units, visualize the spatial distribution of pavement distresses using ArcGIS 10.8, and provide data-driven recommendations for maintenance and rehabilitation. The evaluation process adhered to the ASTM D6433-07 standard, while deduct and corrected deduct value curves were adopted from TM 5-623 to enhance computational accuracy and clarity.

The pavement investigation covered a 0.25 km stretch of Ekosodin Road, which was divided into five (5) sample units for detailed analysis. Field surveys identified various distress types, including alligator cracking, longitudinal cracking, transverse cracking, edge cracking, potholes, and patching, each recorded according to severity levels—low, medium, or high. The computed PCI values for the five sample units were 75, 49, 62, 55, and 32, respectively. These correspond to Pavement Condition Ratings (PCR) ranging from “Satisfactory” to “Very Poor.” The overall PCI for the entire road section was obtained by averaging the individual unit PCI values, resulting in a value of 54.6. According to ASTM D6433-07, this value classifies the pavement as being in a “Poor” condition, indicating significant surface deterioration and moderate structural distress.

The spatial representation of the pavement condition was produced using ArcGIS 10.8 (ArcMap), which digitized the Ekosodin Road section and plotted all observed pavement distresses. From the resulting map it was observed that the distresses were unevenly distributed along the road, with higher concentrations toward the mid and lower sections. These clusters suggest potential structural weaknesses and inadequate drainage systems that have accelerated pavement deterioration. The GIS-based spatial visualization provided an effective tool for identifying distress patterns, supporting prioritization of maintenance interventions, and enhancing data-driven decision-making.

## 5.1 Conclusions

From the analysis, it can be concluded that the pavement of Ekosodin Road is in a poor structural and functional state. The overall PCI value of 54.6, coupled with high distress densities identified through GIS mapping, indicates that the road has experienced prolonged wear with minimal maintenance intervention. The results show that sections with moderate PCI values (50–70) are still serviceable but require immediate preventive maintenance, while sections with very low PCI values (below 40) are in a critical state, demanding structural rehabilitation or full-depth reconstruction. The integration of PCI, PCR, and GIS spatial analysis in this study provided a comprehensive and reliable framework for pavement evaluation, which can be applied to other internal road networks within the University of Benin and similar environments.

## 5.2 Recommendations

Based on these findings, several recommendations were made to guide pavement maintenance and rehabilitation planning. First, sections with PCI values between 50 and

70 should undergo preventive and routine maintenance measures such as crack sealing, pothole patching, and drainage improvement to slow further deterioration. Second, severely distressed segments, particularly those with PCI values below 40, should be prioritized for major rehabilitation or reconstruction. Such interventions should include milling, base course replacement, and resurfacing with asphalt concrete. Additionally, the observed concentration of distresses near the lower sections of the road indicates the need for improved drainage systems; therefore, side drains and proper slope regrading should be constructed or rehabilitated to enhance surface water runoff.

Furthermore, the study recommends the adoption of a GIS-based Pavement Maintenance Management System (PMMS) to facilitate continuous monitoring, condition mapping, and maintenance scheduling of internal road networks. This approach will enable the University management to track pavement deterioration trends and allocate maintenance resources more efficiently. Future studies should also incorporate traffic loading data and subsurface investigations to complement the surface distress assessment, providing a more holistic understanding of pavement performance. Regular condition surveys, coupled with preventive maintenance, will ensure that the pavement remains serviceable and cost-effective over its design life.

Overall, the results of this study clearly indicate that the Ekosodin Road pavement is in a poor condition and requires urgent maintenance and rehabilitation. Implementing the recommended measures will not only restore the structural integrity and functionality of the pavement but also extend its service life and enhance mobility within the University of Benin. The combined use of PCI, PCR, and GIS tools proved to be highly effective in this research and is therefore recommended as a standard approach for future pavement condition monitoring and management.

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# APPENDIX A

# DEDUCT VALUE CURVES FOR ASPHALT SURFACED PAVEMENT

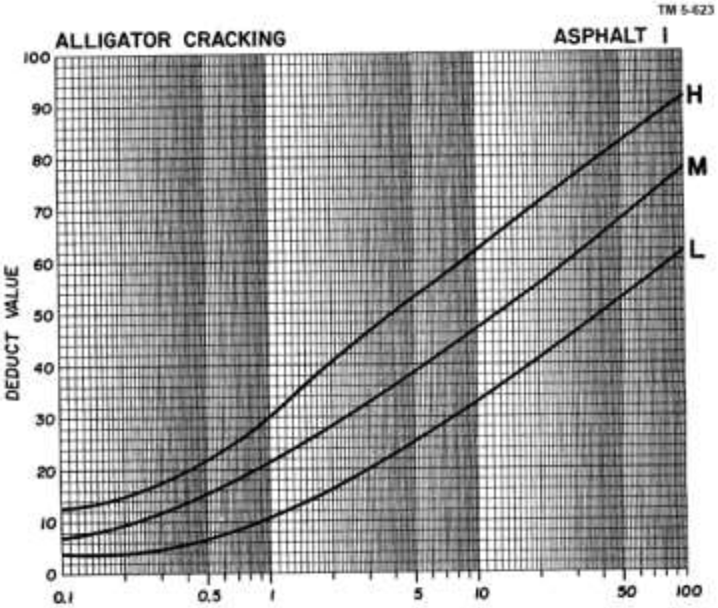

Figure A-1. Deduct value curves for alligator cracking (TM 5-623).

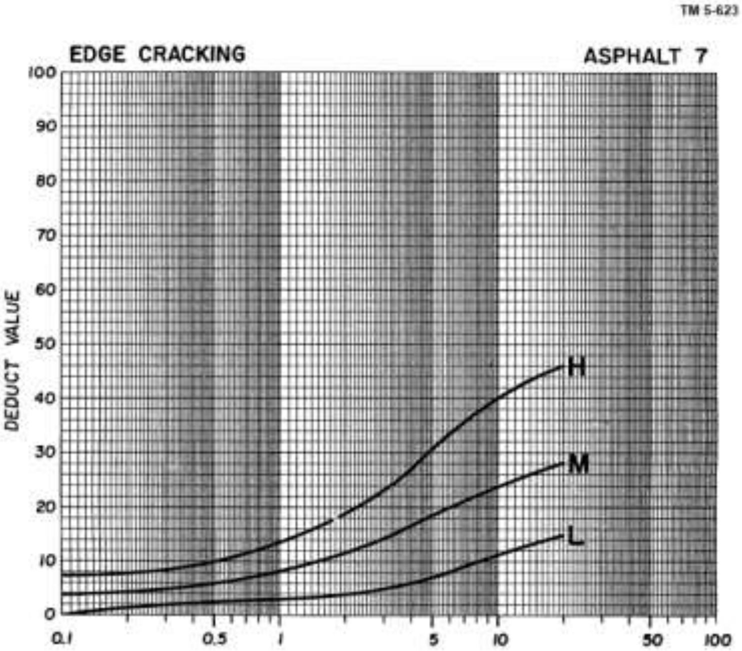

Figure A-2. Deduct value curves for edge cracking (TM 5-623).

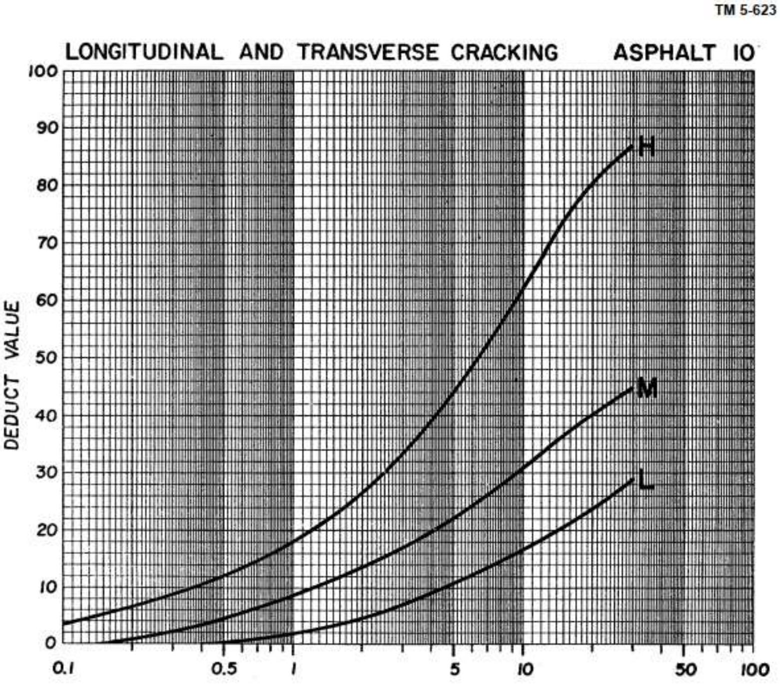

Figure A-3. Deduct value curves for longitudinal and transverse cracking (TM 5-623).

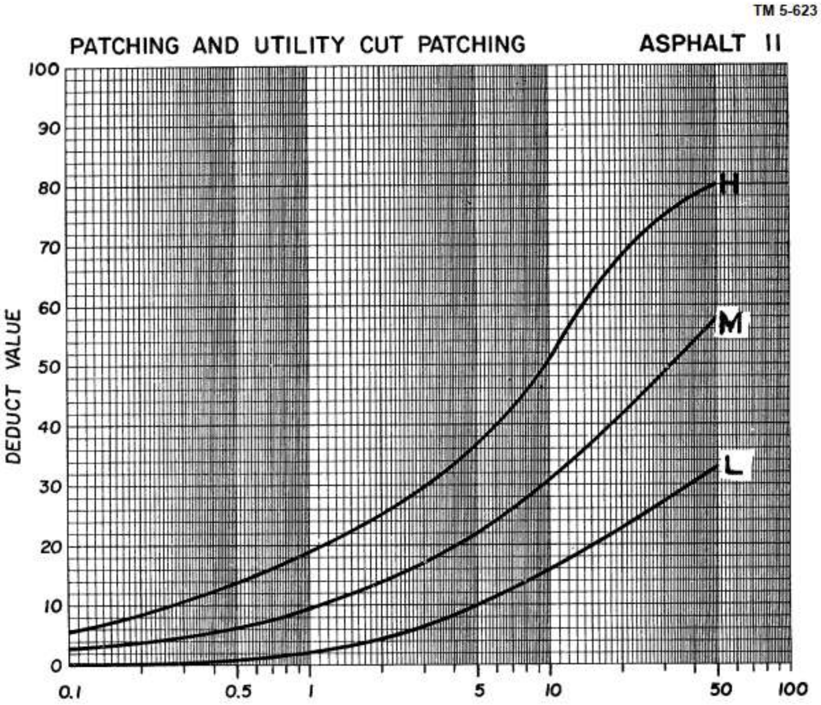

Figure A-4. Deduct value curves for patching and utility cut patching (TM 5-623).

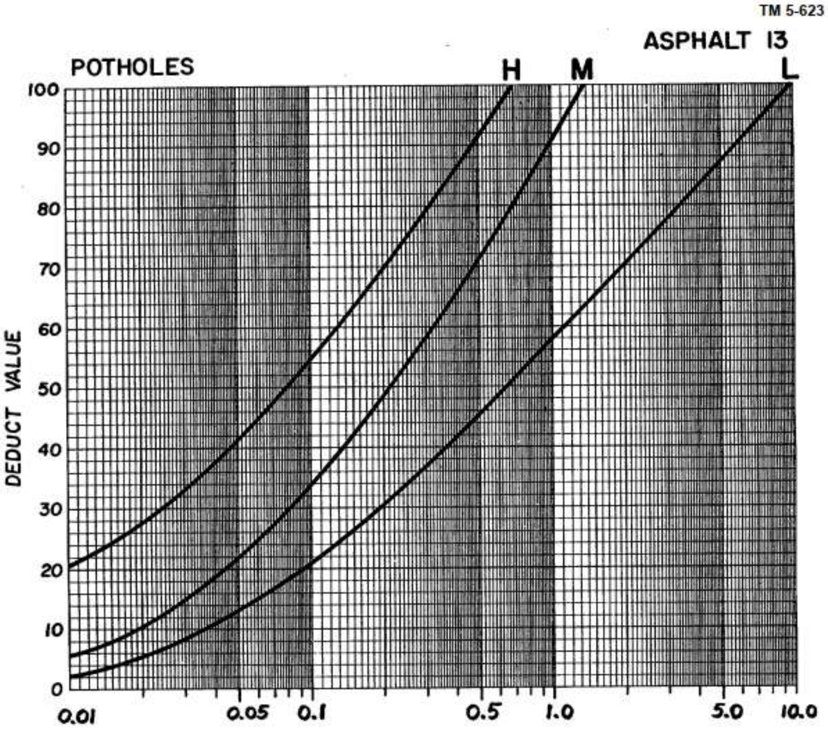

Figure A-5. Deduct value curves for potholes (TM 5-623).

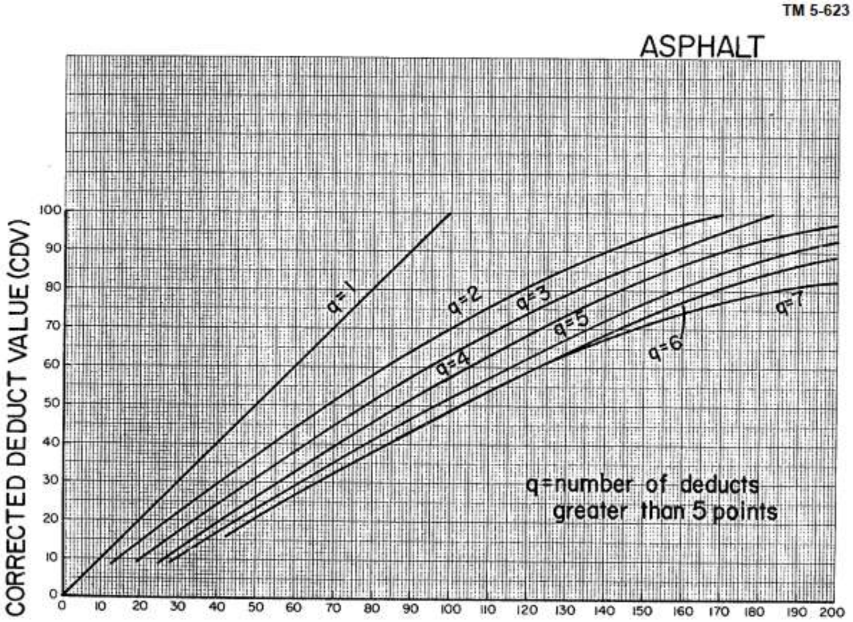

Figure A-6 Corrected deduct value curves for asphalt-surfaced pavements (TM 5-623).

# APPENDIX B

## DISTRESSES ALONG EKOSODIN ROAD WITHIN THE UNIVERSITY OF BENIN, UGBOWO CAMPUS

Plate 1: High severity Pothole in the study area

Plate 2: Medium severity Alligator crack along the road

Plate 3: Low severity Longitudinal crack

Plate 4: Medium severity Edge Crack

Plate 5: Low severity Transverse crack