BRIDGE MAINTENANCE MANAGEMENT GUIDELINE

EDITION 1

The Project for Strengthening of Capacity Development on Bridge Management System in the Republic of Kenya

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Edition 1

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This document has the status of a Guideline. Users shall apply the contents there-in to fully satisfy the requirements set out.

The content of the Guideline is based on current practice in Kenya and latest practices in the road sector – Nationally, Regionally and Internationally.

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ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AI	Artificial Intelligence
APRBP	Annual Public Roads and Bridges Programme
APRP	Annual Public Roads Programme
ARBICS	Annual Road and Bridge Inventory and Condition Survey
ARBWP	Annual Roads and Bridges Work Programme
ARICS	Annual Road Inventory and Condition Survey
ARWP	Annual Road Works Programme
ASTM	American Society for Testing and Materials
BCI	Bridge Condition Indicator
BCR	Bridge Condition Rating
BERP	Bridge Emergency Response Plan
BIM	Bridge Information Modelling
BMMG	Bridge Maintenance Management Guideline
BMMS	Bridge Maintenance Management System
BMS	Bridge Management System
CBA	Cost Benefit Analysis
CCTV	Closed-Circuit Television
DI	Damage Indicator
EACC	Ethics and Anti-Corruption Commission
EBK	Engineers Board of Kenya
FIDIC	International Federation of Consulting Engineers
FRP	Fiber Reinforced Polymers
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
IRT	Infrared Thermography
ISO	International Organization for Standardization
JICA	Japan International Cooperation Agency
JRA	Japan Road Association
KeNHA	Kenya National Highways Authority

KeRRA	Kenya Rural Roads Authority
KETRB	Kenya Engineering Technology Registration Board
KIHBT	Kenya Institute of Highways and Building Technology
KPI	Key Performance Indicator
KRB	Kenya Roads Board
KS	Kenya Standards
KURA	Kenya Urban Roads Authority
KWS	Kenya Wildlife Service
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LiDAR	Light Detection and Ranging
LRFD	Load and Resistance Factor Design
MDAs	Ministries, Departments and Agencies
ML	Machine Learning
MoRT	Ministry of Roads and Transport
MTRD	Material Testing and Research Directorate
NCA	National Construction Authority
NGO	Non-Governmental Organization
NDT	Non-Destructive Test
PBC	Performance Based Contracts
PDCA	Plan-Do-Check-Act
PDUs	Proffesional Development Units
PPE	Personal Protective Equipment
PPP	Public-Private Partnership
PPRA	Public Procurement Regulatory Authority
RAs	Road Agencies
RICS	Road Inventory and Condition Survey
RMLF	Road Maintenance Levy Fund
RRT	Rapid Response Team
SDGs	Sustainable Development Goals
SHM	Structural Health Monitoring
SOPs	Standard Operating Procedures
SWG	Sub-Working Group
TBMC	Total Bridge Maintenance Cost
UAV	Unmanned Aerial Vehicle
UNODC	United Nations Office on Drugs and Crime

DEFINITION OF TERMS

Abutment	Structural members located at both ends of a bridge that connects the embankment portion of the approach road to the bridge. It supports the load from the superstructure and retains the earth material.
Annual Bridge Maintenance Action Plan	This is an asset management plan that contains bridge maintenance interventions, budget allocations and responsibility assignments within a road network. This plan should be structured in the format proposed in the ISO 55000.
Annual Public Roads Programme	This is a consolidated national roads programme that outlines the road maintenance, rehabilitation, and development works to be undertaken by road agencies in Kenya during a financial year and the allocated funds.
Annual Road Works Programme	This is a detailed plan developed by road agencies that specifies the types of work to be done on the roads, the amount of funding allocated for each, and the roads that are prioritized for maintenance in a financial year. The ARWP is developed by road agencies and reviewed by Kenya Roads Board (KRB).
Baseline inspection	An initial inspection conducted on a new bridge or an existing bridge to determine the primary condition in order to obtain information for BMS database and for future maintenance.
Bearing	It is a device which transmits the vertical and horizontal actions from the superstructure to the substructure, and allows for movements between the superstructure and the substructure. Bearings allowing both rotation and longitudinal translation are called expansion/movable bearings, and those, which allow rotation, only are called fixed bearings.
Bridge	A structure, that can be accessed by traffic, with the function of aiding crossing over a waterway, road or any other obstacle. In the context of this manual, it also includes box culverts, viaducts and tunnels.
Bridge inspector	A professional responsible for inspecting bridges to ensure their safety and structural integrity.
Budget levelling	It is a strategic approach to managing financial resources to ensure consistent and stable flow of funds over a specific period i.e. fiscal year or a maintenance cycle to ensure that the amount of money committed does not exceed the available budget.
Condition rating	This is a status indicator for bridge elements based on location, severity and element importance assigned after detailed inspection.
Contractor	The entity engaged by the Employer through a due contract for the implementation of a supply, maintenance and/or repair assignment.
Damage	Defects due to external forces, e.g., flood, vehicle load, vehicle collision, earth pressure, vandalism etc.
Deck slab	A structural member that directly supports vehicles, pedestrians, etc. passing through a bridge and transmits loading to the main girder (main structure).

Defect	Collective term for initial flaw, damage and deterioration.
Deterioration	Defects caused by changes in condition with age, e.g., carbonation, Alkali-Silica Reaction (ASR), salt damage etc.
Engineer	The technical representative of the Employer with responsibilities and obligations under the maintenance contract.
Implementers	The organizations involved in the inspections and maintenance/repair of bridges. In maintenance of bridges, the implementers are the road agencies, engineering consultants and contractors engaged in the construction, repair and maintenance of structures/roads.
Inspection	Diagnostic examinations on a bridge to discover any anomalies on the structural members.
Life Cycle Cost	This is an estimate of the cost that will be undertaken from the selected option of a structure or repair option during its service life. It includes the cost of planning, purchase, installation, operation, maintenance and decommission at the end of the structure service life.
Maintenance	The actions taken to keep the condition of a structural element to perform to its level of service satisfactorily during its service life.
Painting	A layer of material applied on bridge elements for protective and/or aesthetic purposes.
Pier	A substructure member which supports the superstructure at intermediate points and transmits the load to the foundation.
Repair	This is the reinstatement of a damaged member or structure to its designed or as-built condition.
Road Administrator	For the purpose of this manual, the road administrator consists of MDAs and County Governments that are responsible for ensuring that road and road infrastructure is managed effectively and efficiently.
Road Agencies	Public entities that are in charge of road related functions.
Road Authorities	State corporations established to manage, develop, rehabilitate and maintain specific sections of the road network in Kenya.
Stakeholders	Person(s) with interest in the use and maintenance of bridges. They include the road agencies, engineering consultants, contractors, road users and the communities affected by the presence and usage of the bridge.
Substructure	Structural members that transfer the load from the superstructure, through the bearings, to the ground. It is a general term for bridge abutments, piers, and foundations.
Superstructure	Supports the weight of objects passing through the bridge and transmits it to the substructure. It consists of main girder, deck slab, cross beam, lateral bracing, diaphragms, etc.
Works	Combination of materials, skill and manpower and or equipment systematically executed as per the described methodology and in accordance with the Specifications for construction, repair, maintenance, strengthening, reinstatement and decommissioning of bridges.

FOREWORD

Kenya has an estimated road network of 239,122 Km (RICS 2023), of which 164,966 Km of the network is classified while 74,155 Km remains unclassified. The classified network consists of 44,849 Km National Trunk Roads which are developed, maintained, and rehabilitated by the National Government while 120,337 Km County Roads are under the jurisdiction of the County Governments.

The classified road network has approximately 1,581 bridges and 3,506 box culverts that are overseen by the Road Authorities, and 1,536 bridges and 1,557 box culverts overseen by the County Government.

The figures provided for road network are subject to review when the next RICS is conducted after five years.

The elements of the road network include the road pavement, embankments, drainage structures, tunnels and road furniture but the drainage structures, particularly bridges and box culverts form critical part of the network which can paralyse its functionality and lead to economic losses. It is, therefore, the responsibility of the National and County Governments to properly manage and maintain the drainage structures to ensure proper functionality of the road network.

I am very pleased to have been able to implement a project aiming to guide the management and maintenance of bridges in general as part of JICA's technical cooperation project. We carried out a wide range of activities including the development of various manuals e.g. Bridge Maintenance Management Guideline, implementation of pilot projects on site, and establishment of a human resource development training program. In future, it is necessary to aim for a longer life and reduction of life cycle cost through preventive maintenance. Bridge maintenance is not a "reactive maintenance" approach, where repairs are made after damage becomes severe, but rather a "proactive maintenance" that involves monitoring the bridge to ascertain its condition and carrying out diligent repairs before damage becomes severe, which extends the lifespan of the bridge and reduce the life cycle cost. Allocating limited budgets effectively and carrying out efficient bridge maintenance is a challenge shared by all countries.

This guideline serves as a guidepost and by regularly updating its content and continuing to improve bridge maintenance implementation methods; a good bridge maintenance practice will be possible.

Finally, we would like to express our sincere gratitude to the working members who input their valuable time to diligently deliberate in the creation of these guidelines, and to all the related parties who provided their cooperation.

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State Department for Roads (SDR)
Kenya Roads Board (KRB)
Kenya National Highways Authority (KeNHA)
Kenya Rural Roads Authority (KeRRA)
Kenya Urban Roads Authority (KURA)
Kenya Wildlife Service (KWS)
Kenya Institute of Highways and Building Technology (KIHBT)
National Construction Authority (NCA)
Materials Testing and Research Directorate (MTRD)

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1 INTRODUCTION

1.1 OVERVIEW

Bridges are indispensable components of road networks that play a pivotal role in enhancing connectivity, reducing congestion and fostering economic growth in the country. Their significance can be illustrated through various measurable metrics below:

a) **Traffic flow and congestion:** Bridges enable vehicles on the road network to pass through obstacles efficiently and reduce congestion on alternative routes, resulting in a significant reduction of travel times.

b) **Connectivity and accessibility:** Bridges provide direct routes that minimize detours and improve the overall accessibility of a location. This improvement is reflected in the accessibility index, which measures how easily different parts of a city or region can be reached.

c) **Economic enhancement:** Bridges facilitate trade by connecting markets and reducing transportation costs, which leads to an increase in national and regional Gross Domestic Product (GDP). They also boost property values due to improved accessibility.

d) **Safety and emergency response:** Well designed and maintained bridges provide direct and safer routes for emergency vehicles, reducing response times and potentially saving lives.

e) **Environmental contribution:** Bridges contribute to reduction in vehicle emissions by decreasing congestions and travel times. They also promote efficient land use by reducing the need for alternative routes around natural obstacles.

According to Road Inventory and Condition Survey (RICS) 2023, the total number of bridges in Kenya was 8,180 with 69%, 15% and 16% in good, fair and poor conditions respectively.

The implication of this state of bridge conditions necessitates the need for a structured maintenance management regime. If the bridges were left to deteriorate, they would significantly disrupt economic activities or even halt them entirely. Ensuring that bridges remain safe and operational is vital for public safety, economic progress and environmental sustainability.

From the foregoing, it can therefore be safely established that the primary goal of bridge maintenance management is to guarantee safety, functionality, sustainability, and cost-effective performance throughout the bridge's lifespan, maximizing the public's benefit. This approach incorporates proactive, preventive and corrective, methods to address effects associated with aging infrastructure, environmental factors, traffic loads and inadequate maintenance regimes.

To achieve this, it is crucial to follow a structured process of regular inspection, diagnosis and design, maintenance planning and budgeting, procurement, repair execution and confirmation of execution.

1.2 PURPOSE OF THE GUIDELINE

This guideline establishes the Bridge Maintenance Management System as a systematic solution to bridge maintenance management in Kenya and demonstrates the linkage between the maintenance systems in existence anchored in bridge maintenance manuals, scientific management process and standard practices for sustainable bridge maintenance management.

1.2.1 Objectives

1.2.1.1 The main objective

To guide the establishment of the Bridge Maintenance Management System by conserving the structural integrity and safety of all bridges in the Republic of Kenya.

1.2.1.2 The specific objectives

a) To establish the Bridge Maintenance Management System; a systematic approach to sustainable bridge maintenance management

b) To highlight the maintenance management value contained in all the developed bridge maintenance management manuals.

c) To outline an efficient planning and allocation of resources for maintenance.

d) To propose an enhanced performance monitoring scheme.

1.2.2 Target Audience

This guideline is developed to ensure that the following stakeholders in the road sub-sector managing the bridge assets in Kenya have their maintenance management operational functions coordinated in a harmonious manner:

a) Road agencies and County Governments,

b) Engineering and Consulting Firms,

c) Construction Companies,

d) Policy Makers and Planners,

e) Educational and Research Institutions,

f) Private Investors,

g) Non-Governmental Organizations (NGOs),

h) Local Community.

1.2.3 Expected Outcomes

It is expected that this guideline will systematize the maintenance management process as given below:

i. A sustainable Bridge Maintenance Management System in Kenya,

ii. Improved structural integrity and safety by ensuring that all bridges are regularly inspected and maintained,

iii. Extended service life of bridges by implementing effective maintenance practices to prolong the lifespan of bridges, ensuring cost-effectiveness and sustainability,

iv. Optimized resource allocation through efficient utilization of available resources for maintenance activities,

v. Enhanced performance monitoring by establishing a robust system for continuous assessment of bridge conditions that facilitate timely interventions,

vi. Increased public confidence by building public trust in the safety and reliability of the bridge infrastructure through consistent and transparent maintenance practices.

1.3 SCOPE AND APPLICATION

This guideline addresses the maintenance management of all bridges in the Republic of Kenya. It should be applicable to all sustainable maintenance management practices as set out in the developed manuals, standards of practice and developed best practices.

1.3.1 Types of Bridges

This document guides the bridge maintenance management of all the categories of bridges in Kenya.

1.3.2 Applicable Maintenance Activities

This guideline is developed in line with earlier developed manuals and encompasses all maintenance activities from the inspections, repairs and their execution processes. All repairs shall follow the prescribed activity flow process in the *Bridge Repair Manual* (Edition 1, Section 3, pp. 63 – 269).

1.3.3 Application of the Guideline

This guideline shall be applicable to all bridge maintenance management activities.

1.4 BRIDGE MAINTENANCE MANAGEMENT SYSTEM (BMMS)

This guideline proposes a systematic process of bridge maintenance management which combines scientific processes, best practices and execution excellence. This combination is termed the BMMS and it seeks to encompass value generation processes for bridge condition sustenance.

1.4.1 Objectives of the BMMS

The objectives of the BMMS are to:

a) Ensure structural safety and integrity of bridges,

b) Ensure cost effectiveness by optimizing resource allocation and maintenance activities,

c) Extend the service life of bridges,

d) Enable automation and data-driven decision making in bridge maintenance,

e) Ensure compliance with National and International standards and regulations on bridge maintenance management,

f) Aid in performance monitoring and reporting,

g) Aid in risk management associated with bridge deterioration and failures,

h) Promote stakeholder engagement.

1.5 COORDINATED USE OF REFERENCE DOCUMENTS

This guideline outlines the contents of all developed bridge maintenance manuals in Kenya in order to ensure consistency in understanding, usage and application of the maintenance management principles.

This guideline acts as a reference document to the developed manuals but shall in no way reduce their application. It also acts as a guiding post for readers and users on the key focus areas and the priorities at every stage of the maintenance management process.

1.5.1 Importance of Coordinated Use of Reference Documents

1.5.1.1 Maintaining the Consistency of Practice

Cross-referencing of standards ensures that knowledge sharing and collaboration with the standard organizations is maintained for consistency of practice. This guideline acknowledges Kenya Standards (KS), AASHTO, ASTM International and other standards used for the development of the manuals.

1.5.1.2 Harmonizing Technical Guidelines

This guideline provides uniformity in maintenance management priorities, processes and procedures to aid the technical teams on best practises in bridge maintenance.

1.5.1.3 Avoiding Redundancies

The guideline highlights key areas and concerns in bridge maintenance to avoid repetition and overstatement of critical facts.

2 INSTITUTIONAL FRAMEWORK AND ROLES

2.1 OVERVIEW

Effective maintenance management of bridges in Kenya requires a coordinated effort by multiple parties. Each party plays a distinct role in the planning, execution, and oversight of bridge-related projects, with collaboration between stakeholders in the road sub-sector.

Each stakeholder's responsibility is critical to ensuring that bridges are maintained in a sustainable, safe, and functional manner for the benefit of the public as explained below:

a) The Government provides the regulatory framework,

b) Contractors and consultants bring technical expertise,

c) Local communities ensure responsiveness to local needs,

d) The private sector contributes through funding and innovation.

2.2 INSTITUTIONAL SET-UP FOR BRIDGE MAINTENANCE

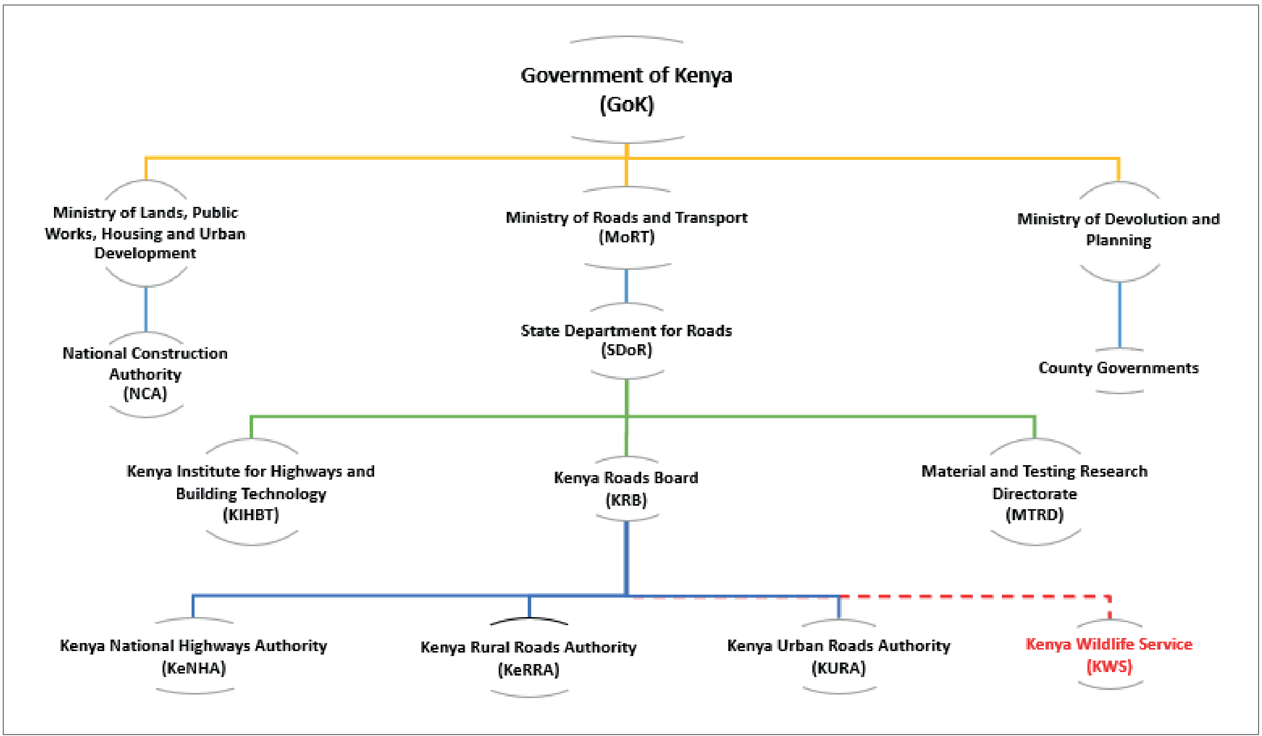

Figure 2.1 Institutional set up for bridge maintenance

2.2.1 Bridge Management Entities

2.2.1.1 National Institutions

The Kenyan Government, through various Ministries, Departments and Agencies (MDAs), plays a pivotal role in the maintenance management of bridges. The institutions, listed below, are responsible for setting policies, regulating construction and maintenance activities, and ensuring compliance with National and International standards:

a) Ministry of Roads and Transport (MoRT),
b) Kenya Roads Board (KRB),
c) Kenya National Highways Authority (KeNHA),
d) Kenya Urban Roads Authority (KURA),
e) Kenya Rural Roads Authority (KeRRA),
f) Kenya Wildlife Service (KWS),
g) Material Testing and Research Directorate (MTRD),
h) Kenya Institute of Highways & Building Technology (KIHBT),
i) National Construction Authority (NCA).

2.2.1.2. County Governments

The County Governments are responsible for ensuring that all bridges under their jurisdiction are well-maintained and safe for use enhancing connectivity to the national roads network.

2.2.1.3 Other Stakeholders

Other stakeholders include international partners such as Japan International Cooperation Agency (JICA) and the World Bank, contractors, local communities, private investors among others.

The mandates of these entities are given in Table 2.1.

Table 2.1 Mandates of bridge management entities

Bridge Management Entity	Mandates
MoRT	a) Sets policies and frameworks for the construction, management, and maintenance of roads and bridges across the country. b) Collaborates with KRB, KeNHA, KURA, KeRRA, MTRD and KIHBT to ensure alignment of national standards and priorities for road and bridge infrastructure.
KRB	a) Oversees the road network in Kenya and coordinates their development, rehabilitation and maintenance. b) Administers the Road Maintenance Levy Fund (RMLF) which is a key source of funding for road and bridge maintenance in Kenya. c) Monitors the use of funds and assesses the performance of road network through conducting technical and performance audits and fund inspections.

Bridge Management Entity	Mandates
KeNHA	Management, development, rehabilitation and maintenance of national trunk roads and bridges.
KURA	Management, development, rehabilitation and maintenance of national urban roads and bridges.
KeRRA	Management, development, rehabilitation and maintenance of rural roads and bridges.
KWS	Management, development and maintenance of roads and bridges in national parks and national game reserves.
MTRD	Ensures materials used in bridge construction and repairs meet local and international standards.
KIHBT	Provides training and capacity building on bridge maintenance management.
NCA	Oversees the construction industry and coordinate its development. Registration of contractors.
County Governments	Management, development, rehabilitation and maintenance of county roads and bridges.
Contractors	Implementation of bridge maintenance projects. Adherence to safety and environmental regulations during bridge maintenance activities.
Consultants	a) Designing new bridge projects and specifying maintenance strategies for existing ones. b) Supervise bridge construction and maintenance projects to ensure that they meet the required technical and safety standards.
Users and Local Communities	a) Involved in monitoring and reporting. b) Engaged in decision-making processes regarding bridge construction or rehabilitation through public participation forums.
Private Sector	a) Collaborate with government agencies on bridge maintenance projects through Public-Private Partnerships (PPPs). b) Innovation and Technology Providers introduce new technologies and innovations in bridge asset management.
International Partners	a) Fund bridge construction and maintenance. b) Finance capacity development on bridge management system.
Researchers	a) Conduct research and innovations on bridge maintenance. b) Give current trends on bridge maintenance management. c) Contribute to capacity building programs.

2.3 INTER-AGENCY COLLABORATION AND COMMUNICATION

2.3.1 Communication Channels

This involves meetings, emails, social media, and newsletters to keep stakeholders informed and engaged.

2.3.2 Joint Inspections and Reviews

This involves collaborative efforts between various stakeholders to ensure that thorough and effective assessments are included in implementation bridge maintenance management.

2.3.3 Data and Information Sharing

This involves exchange of bridge maintenance data with stakeholders to improve decision making, consistency, effectiveness and efficiency in bridge maintenance management. This enhances collaboration amongst the stakeholders.

2.4 STAKEHOLDER ENGAGEMENT

This is the process of engaging individuals, groups, or organizations that have an interest or affected by a project, decision, or activity. It aims to ensure that their opinions and concerns are considered and addressed. In bridge maintenance management it is expected that all relevant stakeholders should be identified, communicated to, consulted and their opinions considered.

2.4.1 Feedback Mechanisms

To ensure that all stakeholders' feedback is considered at all levels of bridge maintenance, it is important that feedback mechanisms are established, revised and maintained as discussed below:

a) Regular surveys and questionnaires should be distributed periodically to gather insights from stakeholders.

b) Public meetings and workshops should be organized regularly to discuss ongoing projects, gather feedback, and address concerns.

c) Stakeholder committees comprising representatives from various stakeholders should be formed to provide regular feedback and recommendations.

d) Social media engagement should be embraced to actively monitor and respond to online concerns from the stakeholders.

3 OVERVIEW OF REFERENCE DOCUMENTS

3.1 OVERVIEW

This chapter provides connection of the application of bridge maintenance management manuals. It gives an outline of the manuals as reference documents, introducing their contents, relevance and application in the bridge maintenance management process.

3.2 REFERENCE DOCUMENTS

3.2.1 Inspection Manual for Bridges – Principal

Inspection Manual for Bridges provides the principal framework for the systematic inspection, assessment, and reporting of bridge conditions in Kenyan road network. It is intended to standardize inspection methods, bridge terminologies, defect identification and safety procedures to align with best practises.

The manual is applicable to the principal/baseline inspection, routine inspection, periodic inspection, special inspection and emergency inspection of all bridges in the Republic of Kenya.

3.2.2 Bridge Inspection Manual for ARBICS and PBC

This manual focuses on maintenance of an up-to-date database of bridge inventories and inspections through Annual Road and Bridge Inventory and Conditions Survey (ARBICS) by the road agencies.

It also supports implementation of Performance Based Contracts (PBC) that emphasizes on frequent routine inspections for purposes of timely interventions.

The manual is applicable to routine inspection of all bridges in the Republic of Kenya.

3.2.3 Bridge Inspection Handbook

This handbook is used as an onsite guide to bridge inspections for the purpose of continuous updating of bridge inventory and condition status and monitoring of maintenance performance.

This handbook is applicable to principal, periodic, routine and emergency inspections.

3.2.4 Bridge Repair Manual

This manual gives practical guidance on how to carry out repair works on bridges, for both preventive and reactive maintenance works. It is expected that all road agencies, county governments, contractors and other entities who manage and maintain bridges will make use of this manual to guide their repair works and employment of value for money principles in structures maintenance.

With this manual, it is expected that the culture of preventive maintenance will be strengthened to ensure safety, uninterrupted connectivity and good conditions of bridges at all times. The manual categorises interventions by bridge material and defects types ensuring tailored, effective restoration efforts.

3.2.5 Standard Specification for Bridge Repair in Kenya

The standard specification outlines procedures for undertaking each category of work (extents and breakdown considerations made), proposed standards references for both materials and processes, and outlines a measurement and payment consideration to be applied to each material and work.

3.2.6 Cost Estimation Manual for Bridge Repair Works

This manual details how to cost the bridge repairs from first principles taking into consideration the best practices, locally available resources and their prices. The content of this manual serves as a guide to the construction industry including policymakers, road agencies, county governments, private consultants, and contractors during the project cycle of bridge maintenance management.

The manual should be read jointly with the Standard Specification and Bridge Repair Manual to understand the quality of materials and standard of workmanship when carrying out bridge repair.

3.3 INTEGRATION MATRIX

This matrix serves as a practical guide for engineers, technicians, and decision makers by providing clarity on which documents to consult during key stages of bridge maintenance cycle. By presenting a structured overview of document interlinkages, it facilitates cross referencing, eliminates duplication, enhances procedural consistency, and promotes the efficient use of resources as given in Table 3.1.

Table 3.1 Integration metrics

No.	Stage / Function	Bridge Inspection and Repair Training Material	Inspection Manual – Principal	Inspection Manual – ARBICS & PBC	Bridge Inspection Handbook	Bridge Repair Manual	Bridge Repair Specifications	Cost Estimation Manual
1	**Capacity development**	✓ (Knowledge in bridge inspection and repair)	✓ (Inspection process)	✓ (Inspection process)	✓ (Inspection process)	✓ (Repair strategies)	✓ (Specification metrics)	✓ (Derivation of Rates)
2	**Planning & Programming**	✓ (Procedures and methods)	×	✓ (For ARBICS /PBC work plans)	×	×	×	✓ (For budgeting)
3	**Routine & Principal Inspection**	✓ (Planning and equipping)	✓ (Standard procedures)	✓ (Contract-specific formats)	✓ (Field guidance)	×	×	×
4	**Diagnosis of Defects**	✓ (Defect rating)	✓ (Assessment basis)	✓ (Performance triggers)	✓ (Visual cues, defect signs)	✓ (Repair strategies)	×	×
5	**Cost Estimation**	✓ (Value for money)	×	×	×	✓ (For quantities)	✓ (Unit specifications)	✓ (Rate application)
6	**Repair & Rehabilitation**	✓ (Workmanship knowledge)	×	×	×	✓ (Methods)	✓ (Material/method standards)	×
7	**Quality Assurance/ Quality Control**	✓ (Quality value)	×	✓ (For ARBICS /PBC KPIs)	✓ (Documentation tips)	✓ (Quality checks)	✓ (Test methods)	×
8	**Oversight & Supervision**	✓ (Leadership and Governance)	×	✓ (KPI checks & tools)	✓ (Inspector checklists)	×	×	×

Legend:

✓ – Document is applicable and actively used

× – Document is not directly applicable

4 BRIDGE INVENTORY AND DATA MANAGEMENT

4.1 OVERVIEW

Bridge inventory and data management refers to the systematic process of collecting, storing, analysing, and maintaining data on bridges to ensure their safety, longevity, and optimal performance. It has a core function in bridge maintenance management system that helps to ensure public safety and serviceability, prioritize repair and rehabilitation, support budget planning and resource allocation, comply with regulatory requirements and plan on emergency response.

4.2 ESTABLISHING AND UPDATING THE BRIDGE INVENTORY

4.2.1 Baseline Data Collection

An accurate bridge inventory is the foundation of effective maintenance management. Initial data collection is primarily conducted during principal inspections or baseline inspections, and involves recording:

a) Identification information (bridge name, bridge code, Global Positioning System {GPS} location, ownership and maintenance responsibility).

b) Geometric and material data (bridge type, construction material, number of spans, total lengths, widths and height clearance).

c) Structural system descriptions (superstructure and substructure details).

d) Initial defect conditions and soundness evaluations.

e) Traffic and data usage (Average Daily Traffic {ADT}, Truck traffic percentage, Load posting {maximum legal load}).

f) Condition and safety ratings (structural condition ratings, bridge health index, inspection intervals and results, scour and seismic vulnerability).

g) Construction and maintenance history (year of construction, major repairs and rehabilitation dates, retrofit history, inspection records).

Field inventory forms are used to ensure standardization across regions. They play a crucial role in bridge inventory and management systems through collecting standardized, comprehensive, and up-to-date information about each bridge structure to support effective decision-making in inspection, maintenance, repair, and asset management.

Ref: Inspection Manual for Bridges (Edition 1, Appendix 2-8-2B, pp. 222 - 264).

4.2.2 Periodic Updates

Periodic update refers to the regular updating of bridge data to ensure it reflects the most current condition, configuration, and usage of the bridge. This process is critical for maintaining a reliable and actionable Bridge Management System (BMS), complying with regulations, and supporting asset management decisions. The purpose of periodic updates is to ensure:

a) Data accuracy: Reflect changes in bridge condition, traffic patterns, or structural modifications.

b) Support decision-making: Updated data informs maintenance, rehabilitation, and replacement decisions.

c) Maintain compliance with the standards and government regulations.

d) Enable risk management: Early detection of deterioration or safety hazards.

The following data should be updated regularly for an efficient bridge maintenance management system:

a. Inspection data

i. Condition ratings (superstructure and substructure).

ii. New defects or deteriorations (cracks, corrosion, spalling, etc.).

iii. Load capacity and posting load limitation information.

iv. Scour susceptibility and waterway adequacy.

b. Inventory data

i. Completed repairs are verified and updated (widening, strengthening, replacements).

ii. Geometric attributes (lane width, approach alignment).

iii. Materials used and protective systems (e.g., coatings).

iv. Ownership and functional classification changes.

c. Operational data

i. Significant environmental or usage changes.

ii. Traffic volumes (ADT).

iii. Truck percentages and weight restrictions.

iv. Accident history and vulnerability.

The frequency of updates is determined by several interrelated factors that focus on safety, regulation, structure condition, and current operational processes and the purpose for which the data is required. The updates can be done through routine inspections, special inspections, emergency inspections, post-repair or rehabilitation updates or administrative updates (when ownership, functional classification, or route designations change). Routine inspections are typically conducted annually for ordinary bridges and complex bridges.

Ref: Inspection Manual for Bridges (Edition 1, Section 4.2, pp. 122).

4.2.3 Methods of Data Collection and Update

The following methods are used in data collection for inventory and data update. Proper consideration on the level of inspection details required should be made to enable selection of an appropriate inspection method.

Ref: Inspection Manual for Bridges (Edition 1, Section 7, pp. 159-217).

a) Field Inspections

i. Visual Inspections: Field engineers or inspectors visually inspect the bridge.

ii. Condition Rating Systems: Bridge condition is often rated based on predefined criteria and rating systems.

b) Remote Sensing and Unmanned Aerial Vehicles - UAVs (Drones)

i. Drones (UAVs): Equipped with cameras and sensors.

ii. Light Detection and Ranging (LiDAR): Light Detection and Ranging technology can create highly accurate 3D models of bridges.

iii. Thermal Imaging: Infrared cameras can detect temperature differences caused by defects.

c) Mobile and GPS-Based Data Collection

i. Mobile Data Collection Apps: Inspectors can use specialized mobile apps to enter data directly into the Bridge Management System (BMS).

ii. GPS Coordinates: GPS technology ensures the exact location of bridges and related features are accurately recorded.

d) Sensors and Structural Health Monitoring (SHM)

i. Embedded Sensors: Sensors (e.g., strain gauges, accelerometers, and displacement transducers) are placed on bridge components.

ii. Long-Term Monitoring: Continuous monitoring systems can provide insights into changes over time.

e) Photogrammetry and 3D Scanning

i. Photogrammetry: By taking photographs from multiple angles, inspectors can create a 3D model of the bridge.

ii. 3D Laser Scanning: High-precision laser scanning equipment can capture millions of data points to create accurate 3D models of the bridge.

f) Geographic Information Systems (GIS)

i. GIS Data: GIS platforms allow for the spatial representation of bridge data.

ii. Remote Sensing Data: Satellite or aerial imagery can be used for large-scale asset management.

g) Public and Automated Reporting Systems

i. Crowdsourced Data: In some cases, the public can report issues or damages through apps or websites.

ii. Automated Damage Detection: Software that uses AI or machine learning to automatically identify bridge damage from images or videos.

Methods of periodic updates involve various techniques and technologies used to collect, process, and manage data for bridges. The goal is to ensure that bridge condition and operational data remain accurate and up to date. The following methods should be applied:

a) Routine Inspections and Reassessments

i. Condition Rating Recalculation: As new inspections occur, the ratings for each bridge component should be recalculated.

ii. Component-level Updates: Specific bridge components should be updated based on the latest inspection results.

b) Integration with Other Data Systems

i. Data Synchronization: Data from different sources (e.g., inspections, sensors, traffic data) should be synchronized and consolidated in the Bridge Management System.

ii. Automated Updates: The bridge management systems should allow for automatic updates from external data sources (e.g., real-time traffic monitoring systems, weather sensors).

c) Post-Event Inspections

i. Event-Driven Data Updates: Following significant events (e.g., earthquakes, floods, vehicle collisions) post event updates should be drafted.

ii. Emergency Inspection Data: Temporary structural issues (e.g., cracks or movement) identified during emergency events should be flagged for follow-up inspections.

d) Maintenance and Repair Logs

i. Repair Updates: As maintenance or repair activities are carried out, records should be added to the system (e.g., replaced bearings, resurfaced deck).

ii. Work Orders and Scheduling: When repairs are scheduled or completed, the system should be updated to reflect the completion status of the work.

e) Data Validation and Quality Control

i. Cross-Verification: Periodically, data collected from different methods (e.g., manual inspections, drone images, sensors) should be cross-verified using available relevant software to ensure consistency and accuracy.

ii. Data Audits: Regular audits of the system should be undertaken to ensure that data is up-to-date, and that new information is properly integrated without errors.

f) Data Versioning and Historical Tracking

i. Version Control: A version control system should be established to maintain a historical record of all updates, ensuring that any changes in data (e.g., condition updates, repairs) are logged and traceable.

ii. Change Logs: Each data update is recorded with metadata about when it occurred, who performed it, and the reason for the update.

4.2.4 Field Verification

Field verification in bridge inventory and management is a critical process that ensures the accuracy of recorded bridge attributes, reliability, and completeness of data used for decision-making, maintenance, and safety assessments of bridges.

4.3 BRIDGE MANAGEMENT SYSTEM

Bridge Management System (BMS) is a digital system designed to store, manage, analyse, and retrieve data related to the lifecycle of bridges—from design and construction to inspection, maintenance, and decommissioning.

Ref: Inspection Manual for Bridges (Edition 1, Section 5.11, pp. 150-151).

The Bridge Management System supports the following:

a) Inventory management,

b) Condition assessment,

c) Maintenance scheduling,

d) Load capacity analysis,

e) Lifecycle cost estimation,

f) Data-driven decision-making,

g) Predictive analysis of deteriorations.

The system follows a relational database structure linking inventory data, inspection records, data evaluation, decision making on maintenance options, implementation of selected interventions, and logging of and updating information for specific bridge IDs.

4.3.1 User Access Levels

User access levels are critical for ensuring that data is properly secured, that the right personnel have the appropriate level of access, and that there is proper oversight and control over the system. Role-based access control should be implemented to manage who can view, edit, or manage various aspects of the system based on their roles. The BMS should have the following user access levels:

a) Admin Access Level

Responsibilities:

i. Full system control: Admins can access all features of the system, including configuration settings, user management, data backup, and more.

ii. User management: Ability to create, update, or delete user accounts and assign roles.

iii. System configuration: Modify system settings, define workflows, customize reporting templates, or change data entry forms.

iv. Audit logs: Access system logs to monitor who made what changes, ensuring accountability.

Permissions:

i. View, modify, delete, and approve data in all tables (e.g., bridges, inspections, defects, maintenance records).

ii. Manage user roles and permissions.

iii. Configure system settings, security, and backups.

iv. Generate all types of reports (e.g., condition assessments, maintenance needs).

v. Manage integrations with other systems (e.g., Geographic Information System {GIS}, traffic management systems).

b) Bridge Manager Access Level

Responsibilities:

i. Bridge management: Oversee all bridges within a jurisdiction. These users are typically engineers or planners responsible for bridge maintenance and safety.

ii. Inspection management: Assign inspection tasks, review inspection data, and make decisions on prioritization of repairs or maintenance based on condition assessments.

iii. Data analysis and reporting: Use the system to generate reports on bridge conditions, maintenance schedules, and asset lifecycles.

iv. Assignment of roles to the bridge inspectors.

Permissions:

i. View and update bridge-related data (e.g., inventory, condition assessments, inspection schedules).

ii. Approve or reject maintenance work orders and inspections.

iii. Generate reports (e.g., bridge health, compliance, load ratings).

iv. Manage bridge components (e.g., add/update component details like deck type, materials, etc.).

v. Access condition and defect data and make data-driven decisions.

vi. Create and assign inspector roles in the system.

c) Bridge Inspector Access Level

Responsibilities:

i. Field inspections: responsible for conducting bridge inspections in the field, using tools such as mobile apps, drones, or handheld devices.

ii. Data entry: Input data, while at the bridge location, into the system regarding the condition of the bridge.

Permissions:

i. View only the bridges assigned to them (usually a specific geographical area or set of bridges).

ii. Add inspection records and update condition ratings.

iii. Submit data on bridge components, defects, or environmental conditions.

iv. Upload media: Ability to upload inspection images, videos, and reports.

v. Limited editing: Only able to modify their own records or data they've created during inspections (e.g., mark defects, rate components).

Note: Inspectors typically cannot delete data or make significant system-wide changes.

d) Maintenance Technician / Contractor Access Level

Responsibilities:

i. Repairs and maintenance: These users handle the actual physical maintenance or repair work on the bridges (e.g., contractors, technicians).

ii. Maintenance records: Input data related to the repairs and maintenance work they perform on the bridges.

Permissions:

i. View the bridges assigned to their work order or area.

ii. Update work orders with completion status, maintenance details, and completion dates.

iii. Upload documentation: Enter maintenance work details, upload before/after photos of repairs, and maintain work logs.

iv. Limited access: No access to view or edit inspection or structural data beyond the scope of their work orders.

e) ***GIS Specialist / Data Analyst Access Level***

Responsibilities:

i. Geospatial data management: These users work with GIS tools to manage bridge location, mapping, and related spatial data.

ii. Data mapping: Map the data on geospatial systems to be viewable in GIS platforms.

Permissions:

i. View all geospatial data associated with the bridge inventory (location, adjacent roads, environmental conditions).

ii. View bridge metadata (e.g., age, condition, inspections, and maintenance data).

iii. Update geospatial information, including new data layers, mapping coordinates, and links to external systems (e.g., traffic, environmental data).

iv. Generate spatial analysis and maps, create geospatial reports, and integrate with GIS platforms.

f) ***External Stakeholder / Auditors Access Level***

Responsibilities:

i. View-only access: These users might include external stakeholders, such as public authorities, auditors, or the general public, who need to review bridge data for transparency or other purposes.

ii. Audit: External users (e.g., government auditors, regulatory bodies) who verify compliance, check maintenance logs, and ensure adherence to safety standards.

Permissions:

i. Read-only access: Can only view information, such as bridge inventory, inspection summaries, and public safety data.

ii. No edit rights: Cannot change, update, or delete any data in the system.

iii. Audit logs: The auditor should have access to system logs to review user actions and data changes.

iv. Generate reports: Stakeholders can view pre-defined reports (e.g., safety, inspections) but cannot create custom reports. Auditors can create reports relevant to audits, compliance checks, and safety reviews, but cannot modify data.

4.3.2 Data Backup and Recovery

Periodic backups and mirrored server setups ensure that:

a) Inspection records are protected from accidental loss,

b) Data remains accessible during disaster recovery operations,

c) Version control prevents overwriting critical field data.

It is recommended that there is daily incremental backups and weekly full backups for the BMS servers.

4.4 GIS INTEGRATION AND MAPPING

4.4.1 Spatial Data Standards

Each bridge is geo-referenced during inspections using GPS-enabled devices, with coordinates recorded in decimal degrees for GIS compatibility.

4.4.2 Layer Management

GIS databases manage layers such as:

a) Bridge location points,

b) Condition grades,

c) Priority maintenance status,

d) Emergency inspection markers.

4.4.3 Visualization and Reporting

Through GIS mapping, decision-makers can:

a) Visualize deteriorating bridge clusters,

b) Map priority bridges for rehabilitation,

c) Generate dynamic inspection dashboards.

4.5 DATA SHARING AND ACCESS CONTROLS

Efficient maintenance planning requires inter-agency data sharing, achieved through:

a) Signed data sharing agreements,

b) Access-controlled BMS dashboards,

c) Annual joint data review workshops

Strict controls ensure sensitive data such as bridge vulnerability reports are only accessible to authorized personnel.

5 BRIDGE INSPECTION AND CONDITION ASSESSMENT

5.1 OVERVIEW

Inspection and assessment of the condition of an existing bridge is very important in maintaining the structural integrity, functionality, and safety of the bridge. The process involves inspection of bridge elements, identification of defects, and evaluation of the severity of the defects to determine the overall condition rating of the bridge.

5.2 KEY ASPECTS OF BRIDGE INSPECTION AND CONDITION ASSESSMENT

The following are the key aspects of bridge inspection and condition assessment:

a) Type of inspection: Bridge inspections can range from basic visual inspections to detailed and specialized inspections. *Ref*: *Bridge Inspection Manual for ARBICS and PBC* (Edition 1, Section 1.7.3, pp. 5).

b) Inspection personnel: Accurate and consistent assessment of the condition of bridges requires qualified bridge inspectors. *Ref*: *Bridge Inspection Manual for ARBICS and PBC* (Edition 1, Section 1.8, pp. 9–10).

c) Defect identification: A variety of defects such as cracks, corrosion, spalling, and other damages should be accurately identified by the bridge inspectors. *Ref*: *Inspection Manual for Bridges* (Edition 1, Section 3, pp. 42–109).

d) Condition rating: Assessment and rating of defects should be done based on the severity to ascertain the overall condition rating of the bridge. *Ref*: *Bridge Inspection Manual for ARBICS and PBC* (Edition 1, Section 1.10, pp. 12–14).

e) Data management: Inspection data collected should be stored, preferably, in digital formats and used to track trends and inform maintenance decisions. *Ref*: *Inspection Manual for Bridges* (Edition 1, Section 5.11, pp. 150).

f) Corrective actions: Recommendations for maintenance, repair, or rehabilitation should be made based on the condition assessment and overall rating of the bridge. *Ref*: *Inspection Manual for Bridges* (Edition 1, Section 4.17, pp. 121).

g) Technological advancements: Advanced technology such as Non-destructive testing (NDT) methods and Bridge Information Modelling (BIM) should be embraced to improve inspection efficiency and accuracy. *Ref*: *Inspection Manual for Bridges* (Edition 1, Section 7.2, pp. 159).

h) Importance of repeatable assessments: It is crucial to have consistent and accurate assessments of bridge elements through successive inspections to track deterioration and develop effective maintenance strategies. *Ref*: *Bridge Inspection Handbook* (Edition 1, Section 1.1, pp. 2).

i) Integration with Bridge Management Systems: Integration of bridge inspection data with the Bridge Management Systems (BMS) is necessary to support bridge maintenance planning and management. *Ref*: *Inspection Manual for Bridges* (Edition 1, Section 5.11, pp. 150–151).

5.3 TYPES OF INSPECTIONS

The types of bridge inspections are:

a) Baseline inspection is the initial inspection conducted on a new or existing bridge to determine the primary condition in order to obtain information for BMS database or for future maintenance.

b) Routine inspection is performed annually or periodically to assess bridge condition. It includes PBC and the proposed ARBICS.

c) Periodic inspection is done every five years and incorporates detailed checks and non-destructive testing.

d) Special inspection which is triggered by defects identified during prior inspections or incidents.

e) Emergency inspection is an immediate check that is conducted to ascertain the effects of either unexpected load, collision, vibration, or adverse climatic condition that is imposed on bridge elements.

Ref: *Inspection Manual for Bridges* (Edition 1, Section 1.6, pp. 3–4).

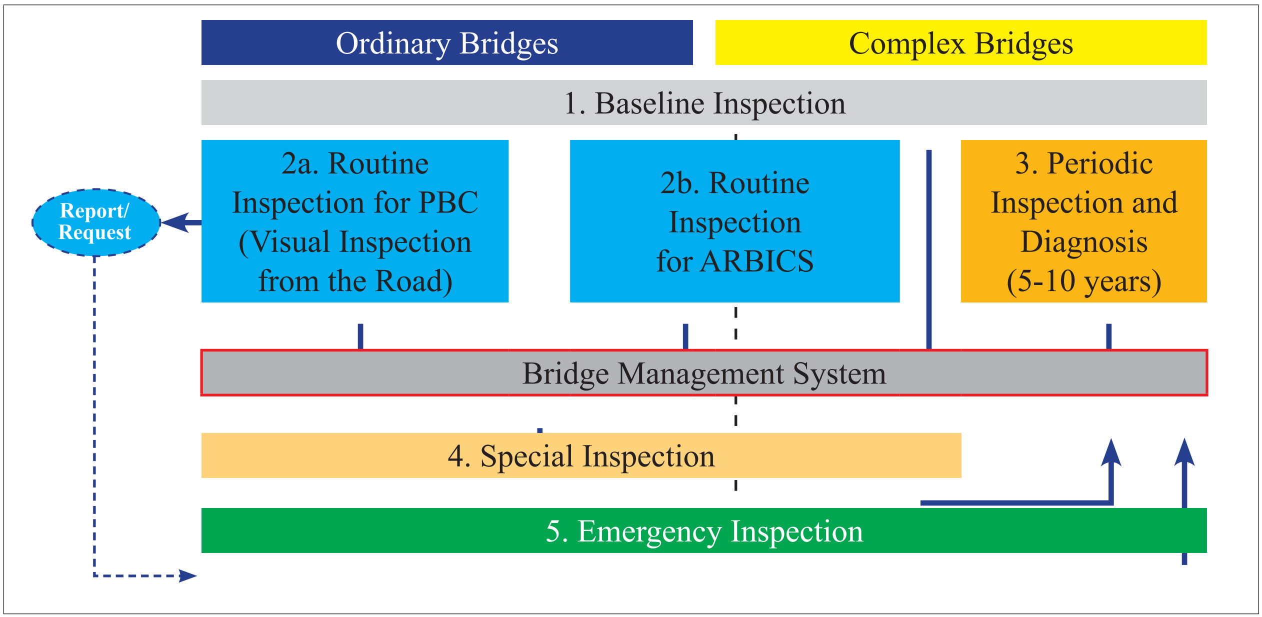

Figure 5.1 Inspection structure for ordinary and complex bridges

5.4 INSPECTION FREQUENCIES AND TRIGGERS

Baseline, routine, and periodic inspections are normally scheduled while special and emergency inspections, which are triggered by special outcomes and unexpected damages, are not scheduled.

The inspections shall be conducted based on the type and condition triggers and the frequency of these inspections shall range from routine annual checks to five-year periodic inspections.

Ref: *Inspection Manual for Bridges* (Edition 1, Section 4.2, pp. 122–125).

5.5 USE OF INSPECTION MANUALS AND HANDBOOK

The inspection teams shall use standard manuals and handbook to guide the inspection process and identification of defects. These manuals include Inspection Manual for Bridges, Bridge Inspection Manual for ARBICS and PBC and Bridge Inspection Handbook.

5.6 STANDARD RATING SYSTEM FOR CONDITION ASSESSMENT

Each bridge element should be rated based on the extent and severity of defects. The ratings shall be combined and analysed using algorithms to produce a Bridge Condition Rating (BCR) score that ranges from 0 - 100.

A colour coding should be adopted to represent the bridge condition rating with blue denoting Good while red denoting Critical, as shown in Table 5.1.

Table 5.1 Bridge condition rating

Defects Level on Structure elements	Action/Response time		Overall Condition Category
N	80-100	Long-term action	N (No damage)
N, DL I	60-79	Mid-long-term action	O (Observe)
DL I, DL II	40-59	Mid-term action Require preventive measures	D (Damage)
DL II, DL III	20-39	Short-term action (Requires prompt action)	SD1 (Severe damage level I)
DL III	0-19	Bridge collapsed/Immediate urgent action (Require emergency measures)	SD2 (Severe damage level II)

Ref: *Inspection Manual for Bridges* (Edition 1, Section 6, pp. 155).

5.7 METHODS OF CONDITION ASSESSMENT

The methods of assessing the condition of an existing bridge or bridge elements include the following:

a) Visual inspections involve assessment of bridge elements like decks, piers, and abutments to identify defects through observation.

   Ref: *Bridge Inspection Handbook* (Edition 1, Section 2, pp. 4).

b) Destructive test involves destroying a small portion of the structure to investigate the properties and deterioration of the material.

   Ref: Inspection Manual for Bridges (Edition 1, Section 7, pp. 202–217)

c) Non-destructive testing involves carrying out tests without destroying any part of the structure.

Ref: *Inspection Manual for Bridges* (Edition 1, Section 7, pp. 159–202).

5.8 FACTORS INFLUENCING BRIDGE CONDITION

The factors that influence the condition of a bridge over time include the following:

a) Design and construction: Inadequate design and construction execution leads to deterioration of bridge elements.

b) Material degradation: Common materials used for construction of bridges such as concrete and steel deteriorate with time due to various factors like carbonation, chloride attack, and freeze-thaw cycles.

c) Traffic loads: All bridges are designed to support a particular traffic loading and excess loading from heavy vehicles can cause extra stress and damage bridge elements.

d) Environmental factors: These include climatic conditions, air pollution, and contact with aggressive chemicals that negatively impact bridge condition.

5.9 DOCUMENTATION AND REPORTING REQUIREMENTS

Accurate documentation and consistent reporting are essential components of effective bridge maintenance management. They ensure that inspection data is accessible, reliable and actionable in a manner that supports maintenance planning, budgeting, and execution.

5.9.1 Standard Inspection Reports

Every bridge inspection must be supported with an inspection report that contains the inspection findings. The inspection report should follow the formats provided in the Bridge Inspection Manuals and should include the following information:

a) General details such as bridge name, location, code, and GPS coordinates,

b) Inspection type and date,

c) Names and designations of bridge inspectors,

d) Bridge elements assessed,

e) Observed defects supported with sketches and photos,

f) Level of defects for each bridge element,

g) Maintenance recommendations,

h) Any immediate safety concerns,

i) Proposed timeline for remedial action.

Ref: *Inspection Manual for Bridges* (Edition 1, Section 4.1.5, pp. 119–121).

The requirements, output, and references for each type of inspection are given in Table 5.2.

Table 5.2 Bridge inspection requirements, output, and references

Type of Inspection	Documents Required	Reports to be produced	Reference	Submission Timeline
Baseline	As Built Drawings	Inventory Summary Report	Inspection Manual for Bridges	Twenty (20) working days after completion of the activity
Routine Inspection for PBC	Weekly Patrol Checklist	Correctly Filled Check-list	Bridge Inspection Manual for ARBICS and PBC	Immediately after the inspection is completed
Routine Inspection for ARBICS	Summary of the weekly patrol checklist	ARBICS Report	Bridge Inspection Manual for ARBICS and PBC	Ten (10) working days after completion of the activity
Periodic	Previous Principal and Routine Inspection Reports	Principal Inspection Report	Inspection Manual for Bridges	Twenty (20) working days after completion of the activity
Special	Previous Principal and Routine Inspection Reports	Special Inspection Report	Inspection Manual for Bridges	Ten (10) working days after completion of the activity
Emergency	Previous Principal, Routine and special (if any) Inspection Reports	Emergency Assessment Report	Inspection Manual for Bridges	Immediate notification Within 48Hrs

5.9.2 Photographic Evidence

Photographic records of the observed defects are necessary, and each inspection finding should be accompanied by a geotagged, time-stamped, and high-resolution image with sketches, where possible. Short video clips may be included to aid in diagnosis in case of special or emergency inspections.

The photographic images should be able to highlight the following:

a) Cracking patterns i.e. hairline and structural,

b) Corrosion, spalling, or exposed reinforcement,

c) Deformation or movement of bearings, joints, and decks,

d) Water-related damages such as scour, and erosion.

5.9.3 Digital Entry and Central Archiving

Inspection data should be entered into the Bridge Management System (BMS) while the inspection team is on site. The system should be configured to automatically tag the location and timestamp of each data entry at the time of upload.

The key features of digital entry include:

a) Editable bridge inspection forms,

b) Condition history tracking,

c) Document upload of photos, drawings, sketches, and drone footage,

d) Auto-flagging for critical condition ratings,

e) Maintenance activity linkage.

5.9.4 Data Validation and Quality Control

To following should be done to ensure credibility of the data:

a) The reports must be reviewed by the supervising engineer to ascertain the accuracy and description of details.

b) Discrepancies between field notes and final reports must be flagged and reconciled before approval.

5.9.5 Reporting to Stakeholders

Quarterly summary reports should be generated for internal planning and to inform decision making at the operational and strategic levels. The reporting formats should be consistent to allow easy aggregation and comparison across networks, regions, or asset categories.

These summary reports should include:

a) Number and type of inspections completed,

b) Summary of defects by type and region,

c) Priority maintenance list,

d) Progress on remedial actions,

e) Budget implications.

5.10 DIGITAL TOOLS AND TECHNOLOGY

Digital tools and technologies are important in inspecting and assessing the condition of bridges and offer significant efficiency and advantages over traditional methods. The digital tools are divided into two main categories.

5.10.1 Data Collection and Analysis Tools

a) Remote sensing tools: Detailed 3D models of bridges and their surroundings can be provided via remote and non-contact inspections by use of techniques such as LiDAR, radar, and satellite imagery.

b) Unmanned Aerial Vehicles (UAVs): These are equipped with high-resolution cameras and sensors such as drones that can access areas that are difficult to reach and capture detailed imagery and create 3D models of bridges.

c) Infrared Thermography (IRT): This is a non-contact method for detecting temperature variations in an object or surface using infrared radiation. It can detect subsurface delamination and other issues in concrete bridge decks more accurately than visual inspections.

d) Geographic Information Systems (GIS): These tools provide a spatial framework that allows efficient data collection, analysis, and mapping.

5.10.2 Efficiency and Accuracy Tools

a) Automated data processing: Artificial Intelligence (AI) algorithms reduce manual workload and errors by providing automated processing of inspection data, identification of defects, and generation of reports.

b) Cloud-based platforms: These platforms facilitate communication between field and office and enable quick decision-making by providing real-time data synchronization and sharing.

5.10.3 Benefits of Digital Tools and Technology

The main benefits of digital tools and technology include the following:

a) Enhancement of bridge safety via early detection of potential defects that prevents failures of bridge elements.

b) Reduction of long-term costs by embracing bridge maintenance interventions based on accurate data.

c) Increase efficiency by automating data collection and processing which streamlines the inspection process and saves time.

d) Enhancement of informed decision making by provision of objective data and analysis capabilities.

6 BRIDGE MAINTENANCE PLANNING AND PROGRAMMING

6.1 OVERVIEW

Bridge maintenance planning and programming entails scheduling inspections, maintenance interventions, and repairs with an aim of optimizing resources, minimizing disruptions, saving future repair costs, extending lifespan and enhancing the safety of bridges. This is a systematic process that combines various factors such as critical analysis, risk management, and life-cycle cost analysis.

6.2 MAINTENANCE CYCLE

The maintenance cycle is given in Figure 6.1.

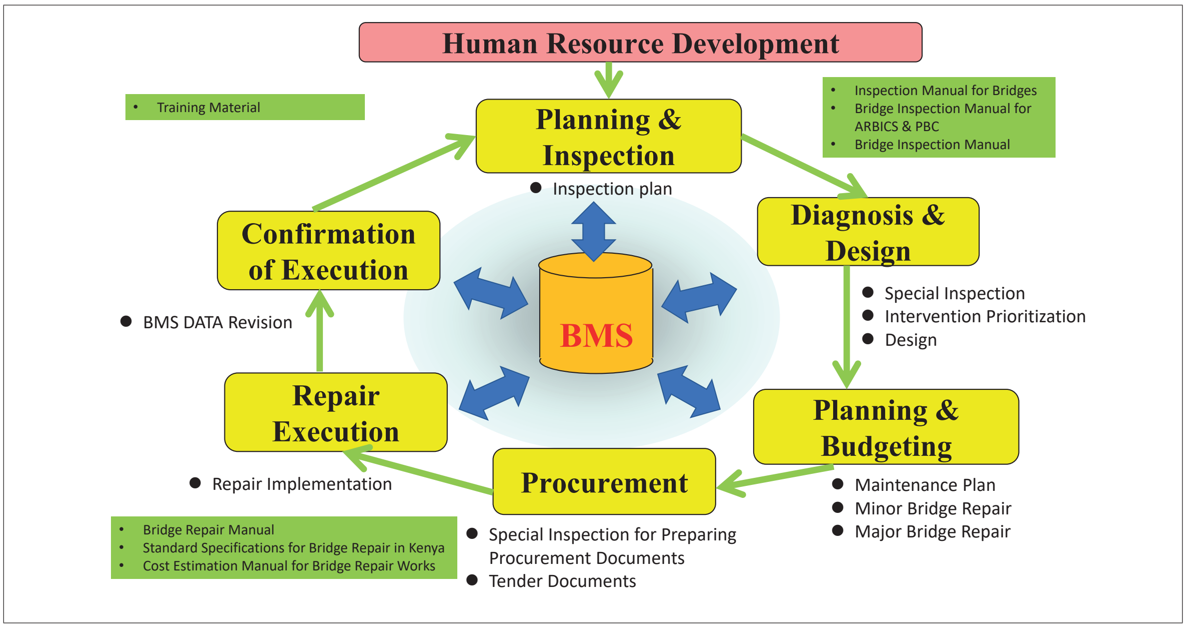

Figure 6.1 Maintenance cycle

6.3 PRIORITIZATION CRITERIA

The criteria for prioritization of maintenance interventions should follow the assigning of weights as guided below:

a) Bridge Condition Rating (35%),

b) Safety & Crash Risk (25%),

c) Traffic Volume & Classification (20%),

d) Detour Availability (15%),

e) Environmental (5%).

6.4 ANNUAL AND MULTI-YEAR MAINTENANCE PROGRAMS

Annual Plans should be used to address urgent and routine repairs whereas multi-year plans are used when budget constraints require phased implementation, especially for long-term interventions.

Budget leveling should be used to distribute costs over time as illustrated in Figure 6.2.

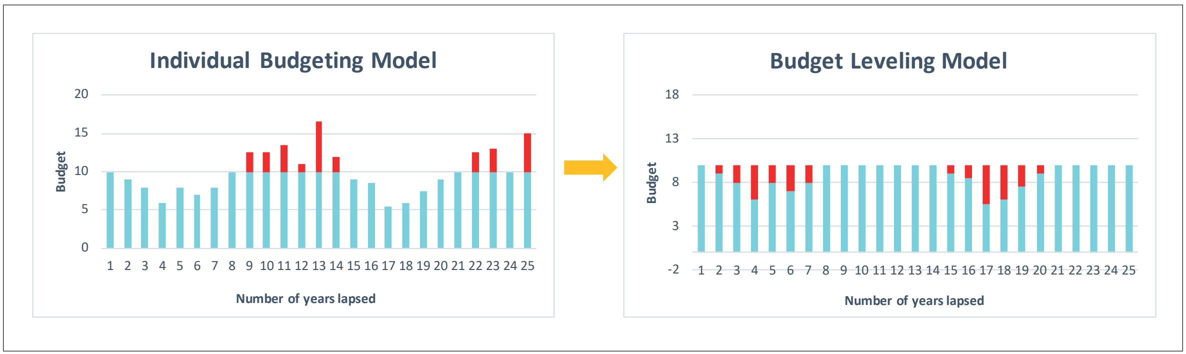

Figure 6.2 Budget leveling of bridge costs

6.5 MAINTENANCE TYPES

The types of bridge maintenance are:

a) Routine maintenance is required for a daily upkeep task.

b) Preventive maintenance is an early intervention conducted to prevent further deterioration of defects.

c) Corrective maintenance entails interventions applied to fix known defects.

d) Emergency maintenance provides immediate response to hazards that compromise the structural integrity of bridge elements.

e) Rehabilitation is an intervention applicable for major repair of bridge elements.

Note: Reconstruction is applicable when the cost of maintaining or rehabilitating a bridge is not financially viable compared to the cost of constructing a new bridge and when the functionality of the bridge becomes inadequate.

6.6 COORDINATION WITH OTHER INFRASTRUCTURE PROJECTS

Bridge maintenance should be synchronized with road maintenance, rehabilitation, or upgrading and with other infrastructure projects to reduce costs, unify designs, and minimize traffic disruptions.

7 BRIDGE REPAIR AND REHABILITATION PROCEDURES

7.1 OVERVIEW

Bridge repair and rehabilitation procedures are planned maintenance interventions ensuring the restoration of functionality, safety and durability of bridge elements that have deteriorated as a result of age, environmental factors, overloading among others. The procedures discussed herein are aligned with the contents of the **Bridge Repair Manual – Edition 1** to enhance ease of reference and use.

7.2 MAINTENANCE AND REPAIRS

7.2.1 Minor Maintenance and Repairs

These are routine and corrective interventions that do not significantly alter the structural composition of bridge elements but address surface or superficial deteriorations as listed:

a) Cleaning by removal of dirt, vegetation, and debris using brushes, water jets, or pressure washers.

b) Touch-up painting by application of anti-corrosion primer and finish coatings on exposed steel surfaces.

c) Epoxy coating on cracks to seal of non-structural cracks to prevent water ingress and further deterioration.

d) Plastering using mortar to restore minor damaged areas.

e) Removal of obstructions by clearing blockages in weep holes, scuppers, or expansion joints.

f) Partial replacement of stone masonry in localized failed masonry units.

g) Partial replacement of gabion wire mesh and stone to repair of damaged sections of slope protection.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.1, pp. 65 – 83).

7.2.2 Major Repair Methods in Concrete Bridges

These are specialized interventions targeting structural deficiencies in reinforced or pre-stressed concrete components as listed:

a) Epoxy injection to seal structural cracks using pressure-injected epoxy resin.

b) Patching to restore spalled or deteriorated concrete with mortars.

c) Caulking to fill joints and gaps using flexible sealant materials.

d) Carbon fibre sheet bonding on deck slab using fibre-reinforced polymer sheets for strengthening of deck slabs.

e) Steel plate bonding to provide external strengthening using adhesively bonded or mechanically fastened steel plates.

f) Partial deck slab replacement of the deteriorated portions of deck slabs.

g) Waterproofing on deck slab to prevent water ingress.

h) Fast setting concrete for deck repairs to reduce downtime.

i) Protective mortar and coating for surface protection from environmental exposure.

j) Recasting concrete/grout on damaged structural elements.

k) Carbon fibre sheet/plate bonding to girders to enhance flexural strength.

l) Jacketing with concrete to restore capacity.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.1, pp. 83–135).

7.2.3 Major Repair Methods in Steel Bridges

This section addresses rehabilitation techniques specific to steel superstructures and substructures as listed:

a) Repainting using protective paint systems.

b) Steel plate adding to reinforce weakened members.

c) Carbon Fibre Plate (CFP) bonding for flexural reinforcement.

d) Replacement of High-Tension Bolts (HTB) to restore connection integrity.

e) Anti-corrosion paint to arrest corrosion progression.

f) Stop hole technique to arrest propagation of fatigue cracks.

g) Repair of heat-damaged steel to restore structural integrity of members.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.2, pp. 136–158).

7.2.4 Major Repair Methods in Timber Bridges

This section outlines approaches for restoring deteriorated or damaged timber bridge components as listed:

a) Split banding and anti-split bolts to restore strength.

b) Repair of timber stringers and corbels to restore structural integrity.

c) Replacement of timber planks, crossheads, and decks to restore structural integrity.

d) Installation of flashing to protect surfaces from moisture ingress.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.3, pp. 158–180).

7.2.5 Major Repair Methods in Masonry Bridges

These methods focus on structural stabilization and restoration of masonry arches and abutments as listed:

a) Repointing and stone replacement.

b) Repair of cracked blocks and mortar.

c) Bulging wall and abutment stabilization for structural realignment.

d) Arch crack repair strengthening of arch barrels and ring stones.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.4, pp. 181 – 195).

7.2.6 Major Repair Methods in Expansion Joints

These methods focus on repair and restoration of the expansion joints in bridges as listed:

a) Asphaltic plug joint repair to rebuild joint seals.

b) Partial or full replacement of expansion joints.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.5, pp. 196 – 203).

7.2.7 Major Repair Methods in Bridge Bearings

These methods focus on repair of bridge bearings as listed:

a) Jack up girder to lift the superstructure for bearing replacement.

b) Extension of bearing seats for better load distribution.

c) Repainting of bearings to arrest propagation of corrosion.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.6, pp. 203 – 215).

7.2.8 Major Repair Methods in Underpinning Foundations

These techniques enhance load carrying capacity of foundations by strengthening and stabilizing as listed:

a) Pit/mass concrete underpinning.

b) Pile and jack pile underpinning.

c) Root/angle piling and pynford stool techniques.

d) Underpinning columns and piers.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.7, pp. 215 – 231).

7.2.9 Major Repair of Settlement of Bridge Approach Slabs

The following are methods for restoring the initial alignment of the bridge approach slab:

a) Mud/Slab jacking.

b) Polyurethane raising techniques.

Ref: Bridge Repair Manual (Edition 1, Section 3.3.8, pp. 232 – 235).

7.2.10 Emergency Bridge Repair

These are unplanned or urgent interventions resulting from extreme floods and collisions.

Ref: Bridge Repair Manual (Edition 1, Section 3.5, pp. 237 – 239).

7.2.11 Repair and Restoration of Protection Works

The following are methods employed to restore damaged protection works on embankments, slopes and river beds around bridge foundations:

a) Slope protection reinstatement with foundation supported by piles.

b) Gabions.

c) Slope patching.

d) Nylon fibre gabion.

e) Jacketing.

f) Grassing.

g) Stone pitching/revetment.

h) Reinstatement of damaged or scoured river bed level using ground sill.

Ref: Bridge Repair Manual (Edition 1, Section 3.6, pp. 239 – 265).

7.2.12 Underwater Repairs

The following methods are used to repair bridge elements submerged in water:

a) Pressure crack sealing.

b) Concrete repair underwater.

Ref: Bridge Repair Manual (Edition 1, Section 3.7, pp. 266 – 269).

7.3 STANDARD BRIDGE REPAIR PROCEDURES

7.3.1 The Standardization of the Bridge Repair Process

Standardizing bridge repair process in Kenya has been the significant objective of this guideline. The repair manual proposes procedures and materials required to ensure that consistent and effective repairs are effected when works are being done. This process covers the use of standardized materials, adopting best practices for specific and common damage types identified in each case, and ensuring quality control throughout the process of repairs.

7.3.2 The Uniqueness of Bridges

Bridges are built at various locations that often poses different conditions and challenges to the structure. The types of repairs for each bridge should be selected based on the location, the performance of the bridge and the level of performance to be achieved after effecting remedial measures. These matters can only be evaluated after careful examination of the site and understanding of the bridge function.

This is the reason why an experienced engineer should, based on this uniqueness, select the appropriate repair method and material to each bridge from the repair manual by carefully considering each type of defect, damage and deterioration. Repair methods and procedures shall be effective against investigated defects, damage and deterioration and sufficiently durable in principle.

7.3.3 The Performance Requirements of Bridge Repairs

The performance requirements expected from the bridge repair process of an ordinary bridge are given in Table 7.1.

Table 7.1 Performance measures

No	Performance	Requirements
1	Safety (Structural stability)	Relates to safety of the bridge against sectional and fatigue fracture with respect to the stability.
2	Serviceability	Relates to the performance that enables the bridge user to have comfort (e.g. riding quality) and to the functional requirement of the bridge (e.g. impermeability and sound proofing).
3	Durability	Related to the resistance of the structure to time-based deterioration of performance due to the degradation of bridge elements.
4	Hazards for third party	Related to damage to third parties caused by structures such as the falling of cover concrete lumps or bolts and the noise that is caused while the structure is in service.
5	Aesthetic and landscape appearance	Related to harmonization with the surrounding environment including the effects of stain from rust and cracks due to the deterioration.

7.3.4 An Outline of the Repair Process

For each of the bridge repair works, an outline has been adopted that covers the following:

a) Definition: Covers an overview of the items of work to be done under the repair method.

b) Scope of work: Covers the extents of the repair works and the specific items that will be affected.

c) Required materials, tools/equipment and personnel: Proposes the required materials, tools/equipment and personnel to be employed into the works.

d) Preparation works: Deals with the preparatory works including traffic management during works.

e) Safety considerations: Covers the provision of environmental, occupational, safety and health regulations during execution of works.

f) Work sequence: Provides the best practices in execution of repairs.

g) Monitoring and evaluation: Provides for periodic inspections and proposal for mitigation measures.

h) Measurements and payments: Covers measurement and payment for works.

8 COST ESTIMATION AND BUDGETING

8.1 OVERVIEW

Cost estimation is the process of predicting the total financial resources needed to complete a project. It is a critical activity that influences planning, budgeting, procurement, cost control, and long-term financial sustainability. It should involve accurate forecasting of direct and indirect costs, overheads, profits, and contingency reserves.

Accurate cost estimation in bridge maintenance planning should be guided by current market rates, well-scoped maintenance work plans, and current legislations to ensure better decision-making, effective selection of contractors, tracking of maintenance costs, and prevention of cost overruns during the implementation of maintenance plans.

8.2 ROLE OF COST ESTIMATION

8.2.1 Key Roles

A detailed breakdown of the roles of cost estimation is given below:

a) Budgeting and Planning:

   i) It helps in the creation of realistic budget estimates to complete a project within the scope and timeline.

   ii) By estimating the costs of various project components, managers can allocate labour, materials, and equipment effectively to realise efficient execution of projects.

   iii) It provides means for evaluating the feasibility and economic viability of projects.

b) Facilitation of Procurement:

   i) It forms a basis for regulating the bids by suppliers and ensures that the procuring entity has the negotiating power for better terms and pays fair prices for goods and services.

   ii) Cost estimation guides the selection of suppliers and enables organizations to choose competitive bids and reliability.

c) Cost Control and Risk Management.

   i) Estimated costs are a baseline for monitoring actual costs throughout the project lifecycle to mitigate any discrepancy and avoid cost overruns.

   ii) Cost estimation projects profit margins and ensures that projects remain financially viable.

8.2.2 Key Consideration for Effective Cost Estimation

The following are the key considerations for effective cost estimation:

a) Effective scoping of works,

b) Building of unit rates from first principle,

c) Reliance on current market prices for equipment, labor and material,

d) Contingencies to cover for variation of prices.

8.3 COSTING TEMPLATES AND TOOLS

Various costing templates and tools play a vital role in bridge maintenance management to estimate project costs, track expenses, and optimize budgeting.

These tools range from simple excel spreadsheets to more complex software applications including cost estimation manuals, budgeting tools such as excel spreadsheets and software applications, and life-cycle cost analysis techniques.

8.3.1 Unit Rate Databases

There is a need to have a standardized database for unit rates that are region-based and applicable for a particular period. These databases provide a detailed breakdown of costs per unit of work and include unit prices of construction material, labor, and equipment, making it easier to calculate the overall cost of a project.

The databases can be in the form of manuals or automated computer software or applications that are subject to review after a given period. An example of a database is the Cost Estimation Manual for Bridge Repair Works, July 2024.

8.3.2 Software Applications

Software applications automate the cost estimation process, improve accuracy, and enhance efficiency.

a) Automation and efficiency

i) The software automates calculations, reducing manual computations and save time.

ii) It streamlines the process, allowing project managers to generate estimates consistently for different projects.

iii) Real-time data analysis and projection capabilities enable proactive cost management and ensures that projects stay within budget.

b) Accuracy and precision

i) Software integrates different data sources to refine the accuracy of estimates.

ii) These applications are applicable to different industries and project types, offering tailored solutions for specific needs.

iii) Features such as customizable templates, integration with other business software, and reporting tools further improve the accuracy and precision of cost estimations.

8.4 BUDGET PLANNING AND APPROVAL PROCESS

The budgeting process for bridge management currently involves assessing maintenance needs, prioritizing repair interventions, estimating costs, and allocating funds accordingly.

Assessment of the maintenance needs of bridges and box culverts on the road network is done concurrently with that of the classified road network in Kenya through Annual Road Inventory and Condition Survey (ARICS). However, there is a need to conduct an independent investigation of bridges through the proposed ARBICS.

The prioritization of the maintenance interventions is based on the ARICS data, which formulates the development of the Annual Road Works Programme (ARWP) for each road agency.

8.4.1 Sources of Funding for Bridge Maintenance

The main source of funding for bridge maintenance in Kenya is the Road Maintenance Levy Fund (RMLF).

Other funding mechanisms may include the following:

a) Annual budget allocation from the National Treasury.

b) Public-Private Partnerships (PPPs).

c) Tolls on certain roads, subject to adoption of the road tolling policy.

d) External funding from development partners.

8.4.2 Budgeting Cycle and Approval Workflows

The budget allocation criteria for maintenance of classified road network in Kenya and preparation of the Annual Public Roads Programme (APRP) are guided by the Kenya Roads Board Act.

Inclusion of budgeting for bridge maintenance as a standalone item in the APRP would require collaboration between the MoRT, KRB, and RAs; an undertaking that would require a review of the KRB act to adopt the Annual Public Roads and Bridges Programme (APRBP) and Annual Roads and Bridges Work Programme (ARBWP).

This guideline proposes a schedule for preparation of the proposed ARBWP for the classified road network as illustrated in Figure 8.1.

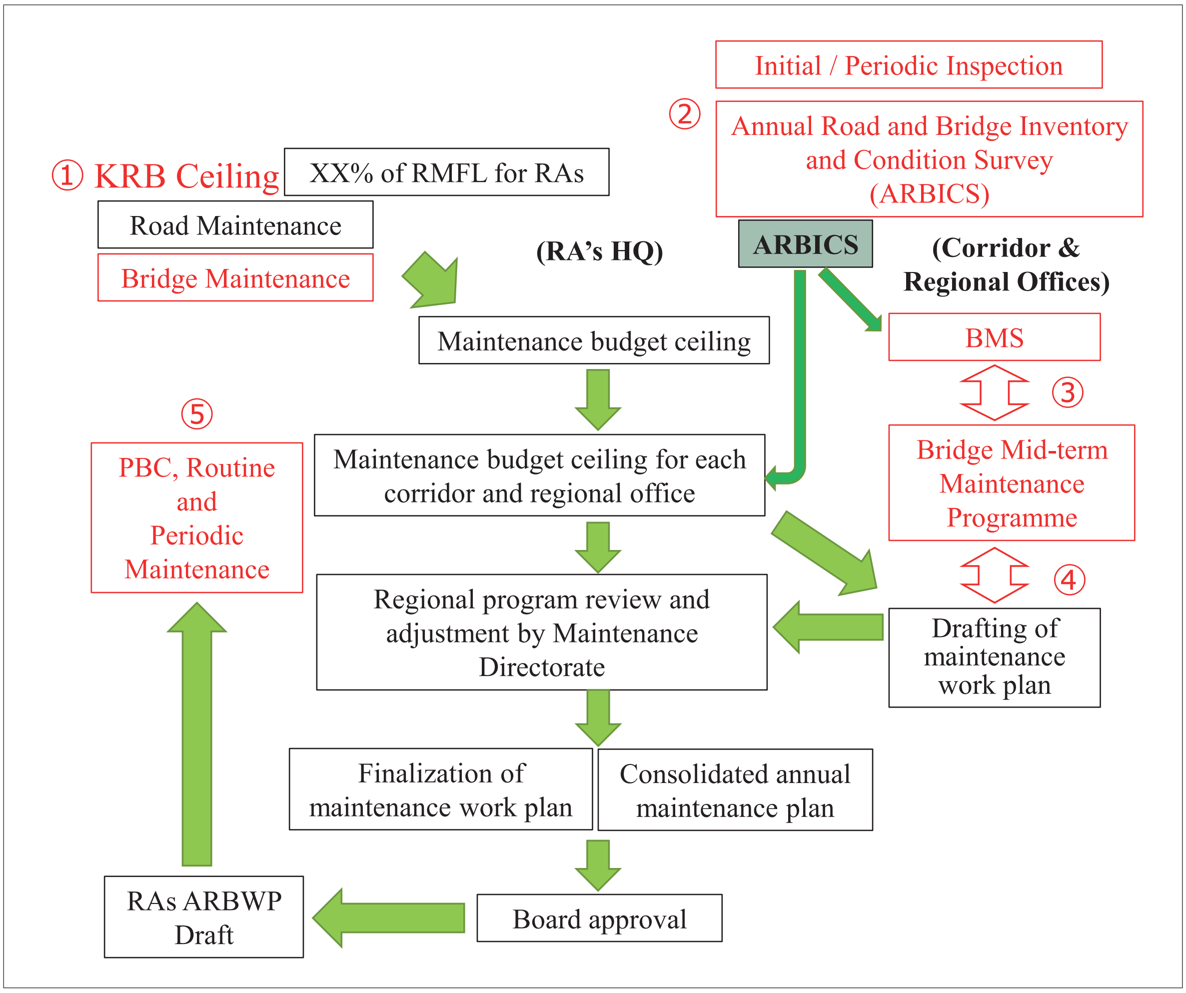

Figure 8.1 Proposed flowchart for preparation of the annual budget and APRBP

The elements of bridge management and planning that have been incorporated into the flow chart in Figure 8.1 include the following:

a) Item 1: Directive by KRB, in the ceiling letter, for RAs to allocate a planning considered percentage of their budget to undertake bridge maintenance.

b) Item 2: Undertaking a separate and detailed bridge inspection under ARBWP.

c) Item 3: Preparation of bridge midterm intervention programme.

d) Item 4: Drafting a bridge maintenance work plan based on BMS data.

e) Item 5: Conducting prioritised bridge maintenance interventions in each financial year.

8.5 LIFECYCLE COST ANALYSIS AND CONSIDERATION

8.5.1 Lifecycle Cost Considerations

This involves analysis and assessment of the total cost of owning and operating a bridge over its lifespan.

The key components of lifecycle cost analysis and considerations for bridges include:

a) *Initial construction costs*

This includes all cost components related to the initial construction of the bridge such as design, materials, equipment, labor, land, and other expenses.

b) *Routine maintenance costs*

These are costs required to maintain the bridge in good operating condition such as painting, patching cracks, and cleaning debris.

c) *Major repair costs*

These are costs required for addressing major deteriorations of bridge elements such as deck replacement, pier repair, or abutment repair.

d) *Rehabilitation or upgrading costs*

These are the costs required for complete rebuilding or upgrading of the bridge.

e) *End-of-life costs*

These are the expenses associated with demolishing the bridge at the end of its service life, including disposal or recycling of materials.

8.5.2 Maintenance versus Replacement Costs

Bridge maintenance focuses on preserving the existing structure through interventions such as cleaning, crack sealing, repairs, rehabilitation, and upgrading. Replacement, on the other hand, involves demolishing and disposing of the existing bridge and building a new one, which is much more costly and disrupts traffic movement.

Bridge maintenance cost, in general, is less than bridge replacement cost and the lifecycle cost of a well-maintained bridge can still be significantly lower than the bridge replacement cost after a period of neglect or severe damage.

8.5.3 Economic Evaluation Tools

These are methods that assess the economic viability and value of interventions, programs, or projects. They assist decision makers in comparing costs and benefits to ensure that an informed maintenance management resource allocation is made.

The four main types of economic evaluation tools are discussed:

a) *Cost-minimization analysis*

This tool makes economic evaluation on an assumption that interventions have the same benefits and aims to identify the least expensive option. It aims to compare costs when the outcomes of different interventions are similar.

b) *Cost-effectiveness analysis*

This approach compares the costs of different interventions with their respective effectiveness, always measured in terms of a common unit of effectiveness, like a unit of crack control or a unit of pothole patching. It helps determine the interventions that are the most cost-effective in achieving desired outcomes.

c) *Cost-benefit analysis*

This is a comparison of the benefits of an intervention, both direct and indirect costs, in monetary terms. It mainly assesses if the economic value of an intervention justifies its costs, considering the overall return on investment.

d) *Multi-criteria decision analysis*

This approach considers multiple factors such as cost, safety, environmental impact, among others when making decisions about bridge maintenance.

These tools assess the long-term financial implications of various maintenance management interventions like repair, rehabilitation, or replacement.

8.6 COST OVERRUNS AND CONTINGENCY MANAGEMENT

8.6.1 Cost Overruns

Cost overrun occurs when the actual maintenance management cost exceeds the initially estimated or budgeted cost. This results in financial strain potentially causing cashflow challenges and delaying project completion and sometimes termination and litigation.

The following factors are the major causes of construction cost overruns:

a) Poor planning and inaccurate estimation of initial maintenance management cost due to inadequate scoping of works, insufficient data, and underestimation of resources.

b) Changes in the scope of the maintenance management due to evolving project requirements or clients' requests.

c) Unforeseen circumstances like delays resulting from extreme weather conditions, material shortages, or unexpected ground conditions.

d) Poor communication between stakeholders, such as architects, contractors, and clients.

e) Poor risk management due to failure to identify and address potential risks during the planning, design and implementation phases.

f) External factors such as economic instability, political changes, or regulatory hurdles.

g) Poor project management such as inadequate scheduling, resource allocation, or supervision.

h) Insufficient planning for contingencies to accommodate unexpected situations or unforeseen challenges.

8.6.2 Contingency Management

The following ways can assist in managing contingencies:

a) *Accurate cost estimation and risk assessment*
   i) Conduct comprehensive investigation and analysis during project planning and design to improve the accuracy of cost estimations.
   ii) Engage key stakeholders in the cost estimation process to gain diverse perspectives and insights.
   iii) Anticipate potential challenges and develop contingency plans to address unforeseen circumstances.
   iv) Systematically identify potential risks, quantify their impacts, and develop mitigation strategies.

b) *Contingency planning allocation*
   i) Allocate a contingency fund to cover unexpected costs and mitigate the impact of potential risks.
   ii) Ensure that the contingency fund aligns with the risks identified in the project's risk register.
   iii) Develop contingency plans for different scenarios, such as delays, material shortages, or design changes.

c) *Monitoring and control*
   i) Implement real-time monitoring of project metrics, including timelines, resource utilization, and costs.
   ii) Utilize project management tools to track progress and identify deviations promptly.
   iii) Conduct regular reviews of project metrics and resource allocation to ensure adherence to the budget.

8.6.3 Risk Based Costing

This entails estimating the total project cost by incorporating potential risks and uncertainties, culminating in a cost range rather than a fixed figure. It extends beyond a simple cost estimation and considers variation in quantities, unit price, impact of potential risks and possible mitigation strategies.

The procedure for risk-based costing in bridge maintenance management relies on uncertainties identification, analysis, costing, sensitivity analysis and quantification of the magnitude of possible risk. Its key components include:

a) *Base cost*

   This is the cost of the project if everything goes according to the initial plan. It mainly includes the cost of labor, materials, and equipment.

b) *Risk cost*

This is the cost associated with potential risks such as delays, material shortages, or safety issues.

c) *Escalation cost*

This is the cost of inflation and other factors that may increase the cost of the project over time.

d) *Other uncertain costs*

This is the cost of unanticipated events, such as political changes or unforeseen site conditions.

The following examples of risks can be associated with bridge maintenance:

a) *Geotechnical risks*

Unstable soil conditions or unforeseen hard rock or fossil fuels can lead to delays and cost overruns.

b) *Weather-related risks*

Severe weather conditions such as flooding and storms can damage infrastructure and disrupt construction activities.

c) *Material supply risks*

Shortages of essential materials like steel or bearing can delay projects and increase costs.

d) *Environmental risks*

Impacts on water and air quality or wildlife can lead to regulatory delays and additional costs.

8.6.4 Cost Control Strategies

Cost control is the process of managing and monitoring a budget to ensure that expenses remain within predetermined limits. It incorporates various techniques and strategies to reduce unnecessary spending and improve efficiency, ultimately leading to cost savings.

Effective cost control in bridge maintenance involves a multi-faceted approach that includes the following:

a) Preventative measures

i) *Regular inspections and monitoring*

Proactive inspections that include visual inspection, non-destructive testing (NDT) and embracing bridge management systems (BMS), help identify potential problems early and prevent costly repairs later.

ii) *Targeted maintenance*

This is a focused maintenance of critical bridge elements and prioritizing maintenance tasks based on risk assessment and expected deterioration rates.

iii) *Optimizing work orders*

Development of standardized work orders with clearly defined tasks, required materials, and estimated costs streamlines the maintenance process.

b) *Optimizing work processes*

i) *Eliminate reactive maintenance*

Reduce and discourage reliance on emergency repairs and implement preventative maintenance programs and address minor issues before they escalate into major problems.

ii) *Cost-effective material choices*

Select durable materials that offer a good balance of performance and cost, considering factors like corrosion resistance and longevity.

iii) *Negotiate contracts*

Negotiate favorable contract terms to manage costs and ensure timely delivery.

c) *Leveraging technology*

i) *Bridge management systems*

Bridge maintenance system automates data collection, analysis, and reporting, and provides valuable insights into bridge condition and maintenance needs.

ii) *Embracing construction management software*

Adopt and use software to track costs, manage contracts, and monitor project progress, to keep project costs within budget.

d) *Long-term value*

i) *Phased maintenance strategies*

Phasing maintenance programs that address different components of the bridge at different times can optimize resource allocation and minimize disruption.

ii) *Continuous improvement*

Regularly review maintenance practices and identify areas for improvement to enhance efficiency and reduce costs.

9 PERFORMANCE, MONITORING AND EVALUATION

9.1 OVERVIEW

Performance monitoring and evaluation in bridge maintenance should involve continuous assessment of the structural performance and conditions of bridges to guarantee safety and longevity. This process should embrace visual inspections, non-destructive testing, and structural health monitoring, to detect potential issues and track deterioration over time.

The goals of performance monitoring and evaluation in bridge maintenance management should be early identification and solving of potential issues, prevention of catastrophic failures and optimization of maintenance interventions.

9.2 PERFORMANCE INDICATORS

These are quantifiable measures that assess the performance, condition, or health of a bridge or a bridge element.

The types of indicators that are relevant in bridge maintenance management include the following:

a) Bridge Condition Indicators (BCIs) quantify the condition of a bridge by combining the condition ratings of individual bridge elements assigned during inspections.

b) Damage Indicators/Indices (DIs) derived from Structural Health Monitoring (SHM) data that can be correlated with the presence of damage.

c) Reliability and Risk Indicators assess the structural reliability, cumulative probability of failure, and other factors related to the long-term performance of the bridge.

d) Economic Indicators relate to the cost of construction and maintenance, in reference to the resulting benefit.

e) Social and Environmental Indicators consider the social and environmental impact of a bridge.

9.3 MONITORING TECHNIQUES

9.3.1 Bridge Site Visits and Examination of Executed Works

This involves the inspection of ongoing maintenance works, completed works, review of work methodologies and procedures and adherence to the specifications.

9.3.2 Visualization Dashboard

A visualization dashboard provides a central and interactive view of key metrics and data related to bridge health, inspection, and maintenance. It allows for efficient tracking of bridge infrastructure, facilitating maintenance scheduling and reducing the risk of unexpected failures.

Examples of visualization dashboards used in bridge maintenance include the following:

a) Bridge inspection data such as defects and maintenance schedules.

b) Sensor data monitors bridge performance based on data like temperature, vibration, and strain.

c) BIM models visualize the bridge structure and its components.

d) Key performance indicators such as inspection frequency, defect severity, and maintenance cost.

e) Trend Analysis such as deterioration rates or traffic patterns

9.3.3 Benchmarking and Trend Analysis

Benchmarking assesses performance against industry best practices, identifies areas of improvement, and optimizes resource allocation. Trend analysis, on the other hand, predicts future bridge condition using historical data and optimizes maintenance scheduling to reduce costs and improve efficiency.

9.3.3.1 National versus Regional Benchmarking

National benchmarking focuses on a broad overview of the overall performance and aims at the identification of national trends and areas for improvement. It provides a broad overview of performance across the entire country and highlights the overall performance of the bridges in the entire road network, making it useful in developing national guidelines and standards for bridge maintenance. However, it might not capture the subtle regional differences in condition of bridges, traffic loading, and climate; therefore, having little relevance to local decision making and application to specific regional contexts.

Regional benchmarking, on the other hand, offers a more subtle perspective on bridge maintenance performance and allows comparison within specific geographic areas within the country and development of specific regional maintenance strategies. It is more relevant for regional decision making but less comprehensive at national level, making it less representative of the overall national performance since regional differences can be significant.

The best approach to benchmarking bridge maintenance performance depends on the specific goals and objectives of the organization in reference to the two benchmarking approaches.

9.3.3.2 Year-On-Year Performance

This entails assessing the condition of bridge elements and making comparisons across the years. It assists in determining the effectiveness of maintenance interventions used in preserving bridges and highlights deterioration trends of bridge elements.

The following are examples of performance tracking:

a) Tracking the percentage of bridges in poor condition helps identify trends in infrastructure deterioration and can be used to assess the effectiveness of maintenance interventions.

b) Assessing and assigning the condition ratings to bridge components can help identify areas requiring attention and track the effectiveness of maintenance activities.

c) Monitoring maintenance costs over time can help identify trends in maintenance expenses and track the effectiveness of different maintenance strategies.

d) Tracking the number of repairs completed each year can help assess the efficiency of maintenance activities and identify areas where improvements can be made.

9.3.4 Predictive Analysis

This entails application of data driven methods to predict potential challenges, optimize maintenance plans, and control costs. Real-time data collected from sensors are analyzed using algorithms to highlight irregularities and predict failures.

The following procedures are applicable for predictive analysis in bridge maintenance.

a) Data collection: Sensors that measure moisture, temperature, crack size, and vibration are installed on bridge elements to record real-time data of the condition of the bridge.

b) Data analysis: Analysis of real-time data is conducted using applicable algorithms to highlight patterns and predict possible structural deterioration or damage.

c) Predictive modeling: Models are built to predict the possibility of specific failures or rate of degradation.

d) Maintenance planning: Maintenance plans are developed based on predictions to solve the identified failures or degradation before they lead to major structural failures.

e) Cost reduction: The predictive maintenance aims to reduce the overall cost of bridge maintenance by preventing unplanned and unnecessary repairs.

9.4 PERFORMANCE EVALUATION

Performance evaluation in bridge maintenance management identifies deficiencies, optimizes maintenance strategies, and prioritizes resource allocation to enhance safety, reliability, and longevity of bridges. It helps in achieving the desired performance levels, controlling costs, and extending the service life of bridges.

9.4.1 Types of Evaluation

a) Needs analysis: Analysis and priorities of needs to inform planning for an intervention.

b) Process evaluation: Nature and quality of implementation of an intervention.

c) Outcome and impact evaluation: Results of intervention or repairs undertaken.

d) Value for money evaluation: Examine the relationship between the cost of an intervention and the value of its impact positive or negative.

e) Synthesis of multiple evaluations: Combined evidence from multiple evaluations.

9.4.2 Assessing Bridge Maintenance Management System Effectiveness

This involves evaluating how well a Bridge Maintenance Management System (BMMS) performs its core functions to ensure safe and cost-effective operation of bridges.

The indicators for assessing system effectiveness are:

a) Visual inspection of bridges: Number and frequency of inspections.

b) Non-destructive testing: Number and location of tests.

c) Structural health monitoring: Specific parameters identified and number of reports.

d) Destructive testing: Number, locations and remedial works.

e) Cost-Benefit Analysis (CBA): Number of CBA reports and analytic comparisons.

f) Repair execution: Number, locations and change in condition of bridge elements.

9.4.3 Guiding policy adjustments

This involves reviewing and updating regulations, guidelines, and procedures to improve bridge maintenance management.

9.4.4 Resource allocation insights

Effective resource allocation in bridge maintenance management based on optimized recommendations from Cost Benefit Analysis (CBAs).

9.5 REPORTING AND REVIEW MECHANISM

This is a structured process of documenting conditions of bridge elements, maintenance interventions, outcome of repairs, and a review process to assess the effectiveness of maintenance plans, highlight trends, and ascertain the long-term performance of bridges.

9.5.1 Periodic Reporting

The following are the periodic reports applicable in bridge maintenance management:

a) Bridge inspection reports contain information on the conditions of bridge elements including the identified defects, severity rating, and the recommended interventions. They are vital in assessing real-time bridge conditions and prioritizing maintenance intervention.

b) Bridge Management System (BMS) reports provide comprehensive overview of bridge data from inspection reports, maintenance records, and material databases. The reports facilitate efficient management of bridge assets, monitoring performance, and managing budgets.

c) Detailed investigation reports are vital for in-depth assessments of specific bridge issues, potentially involving structural analysis or material testing.

d) Maintenance and repair reports document bridge maintenance and repairs activities such as costs, materials used for the works, and inspection results.

e) Budgeting, value for money and cost reports provide information on the cost for repair and maintenance and cost optimization for bridge management.

9.5.2 Stakeholder Review Workshops

This entails gathering various parties concerned to discuss and refine the processes of bridge maintenance management. The outcomes of the workshops are very crucial and ensure that bridge maintenance strategies are effective, safe, and aligned with the expected outputs.

Key stakeholders should be identified from both internal and external parties. The internal parties include maintenance staff such as engineers, technicians, inspectors and projects managers while the external parties include designers, consultants, contractors, suppliers of materials, regulatory bodies, road users, and local community representatives.

The stakeholder workshops provide a platform for open discussions and feedback on the existing maintenance management system resulting in the following key benefits:

a) Early identification of potential inefficiencies such as need for safety improvement or adoption of new technologies.

b) Fostering better communication and collaboration among stakeholders, enhancing understanding of individual roles and responsibilities, improved decision making, and better alignment of maintenance strategies with overall bridge maintenance management goals.

c) Monitoring and evaluating the effectiveness of bridge maintenance programs, improving the quality of maintenance works by incorporating feedback and lessons learnt from various stakeholders.

9.5.3 Audit and Feedback Loops

Audits assess the adequacy of inspection procedures, data accuracy, timeliness of maintenance and repairs, effectiveness of bridge management practices, and identify areas for improvements.

Feedback loops, on the other hand, utilise information gathered from audits and inspections to enable continuous improvement in maintenance strategies and future decision making, ultimately resulting into a better bridge maintenance management.

9.6 PROPOSED PERFORMANCE CRITERIA

Proposed performance criteria for bridge maintenance management should consider both structural integrity and operational effectiveness, incorporating measures like safety, traffic capacity, and cost-effectiveness, environmental impact, and aesthetic considerations.

a) Structural performance and safety

i) Load-carrying capacity: The ability to carry the anticipated loads.

ii) Safety: Ensure the safety of all users.

iii) Structural integrity of bridge elements.

iv) Durability: Ability to withstand imposed load and environmental factors over longer period of time.

v) Reliability: Continuous uninterrupted traffic flow.

vi) Resilience: Withstand natural disasters.

vii) Life cycle cost: Considering the long-term cost of maintenance, repairs, and potential replacements.

b) Operational effectiveness

i) Traffic flow: Adequate capacity and minimal traffic delays.

ii) Serviceability: Ease of accessibility and user comfort.

iii) Maintenance backlog: Tracking the completion of scheduled maintenance interventions.

iv) Maintenance efficiency: Optimizing maintenance procedures.

c) Environmental and aesthetic considerations

i) Environmental impact: Minimizing the environmental impact of bridge maintenance activities.

ii) Aesthetics: enhancement of the aesthetic appeal of the bridge.

d) Risk management

i) Risk identification: All potential risks are identified and listed.

ii) Risk assessment: Analysis and costing of all the potential risks are done.

iii) Risk mitigation: Effectiveness of mitigation strategies and lessons learnt compiled.

10 CAPACITY BUILDING AND KNOWLEDGE MANAGEMENT

10.1 OVERVIEW

Effective bridge management relies heavily on the technical competence and institutional capacity of the agencies and other stakeholders involved in inspection, maintenance, and rehabilitation of bridges. Capacity building provides continuous training and development of personnel in areas such as structural health monitoring, inspection techniques, data analysis, asset management systems, and the application of modern maintenance technologies. Structured training programs, workshops, and certification courses should be developed to ensure that staff are updated on evolving standards, materials, and methodologies.

10.2 CAPACITY BUILDING

Capacity building in bridge maintenance management is highly recommended to sustain consistency in practice and compliance with knowledge acquisition strategies among all stakeholders involved in the bridge maintenance management. In this regard, KIHBT shall develop, technically review and roll out a training plan for all stakeholder categories.

10.2.1 Training Content

The content of training should aim to strengthen bridge maintenance management from planning and budgeting, bridge inspection and diagnosis, execution of bridge repair activities, cost estimation, tendering bridge contracts and overall management of bridge repair contracts.

10.2.2 Frequency of Training

It is recommended that the frequency of trainings shall be structured after every two months unless a specific demand arises within an agency, division or county government. KIHBT should develop training of trainers programs targeting trainers for bridge maintenance management. This shall also be in line with the overall calendar of training programs at the Institute.

Upon training, a person shall be required to practice bridge maintenance activities for a period of three (3) years after which there will be a refresher course to update on emerging issues and new findings during implementation of bridge maintenance projects. The entry behaviour of participants for refresher course shall be evaluated by KIHBT and a recommendation of various topics covered within the syllabus to be provided for training.

10.2.3 Trainers' Capacity Enhancement

All bridge maintenance trainers shall also constantly update their knowledge, skills and attitude through participation in mandatory annual refresher courses, benchmarking forums, exchange programs and stakeholder engagement forums with industries including but not limited to the Kenya Roads Board, Road Agencies, Counties, Divisions/Directorate in the Ministry of Roads and Transport, Counties and Private Sectors.

10.2.4 Professional Development

KIHBT should provide training in bridge maintenance management through structured memorandum of partnerships with Engineers Board of Kenya (EBK), Kenya Engineering Technology Registration Board (KETRB) and NCA. The professional and regulatory bodies will determine and award Professional Development Units (PDUs) to all course participants including trainees and trainers. All certifications awarded for new and refresher trainings shall be in custody of the management of KIHBT.

10.3 KNOWLEDGE MANAGEMENT

This ensures that valuable technical data, field experience, and institutional knowledge are systematically captured, organized, and shared. It includes the documentation of inspection records, maintenance histories, performance assessments, and lessons learned from past projects. Developing centralized digital knowledge repositories such as BMS, enables informed decision-making and enhances institutional memory, particularly in the face of staff turnover or organizational restructuring.

Integrating capacity building and knowledge management into bridge maintenance management frameworks strengthens resilience and sustainability of bridges, ensuring safe and cost-effective service throughout its life.

10.4 LESSONS LEARNT AND BEST PRACTICES REPOSITORY

Lessons learnt are the insights gained from the implementation of a project, process intervention including what worked (successes), what did not work (failures), why it did not work (challenges) and what can be done differently (solutions and recommendations)

10.4.1 Objectives of Repository

The objectives of repository are to:

a) Improve future performance by learning from past experiences,

b) Encourage institutional memory,

c) Support decision making and training,

d) Promote accountability and transparency.

10.4.2 Record of Experiences

The lessons learnt and established best practises in the activities involved in bridge maintenance management should be recorded clearly, shared and stored for future reference. This will ensure continuous improvement of bridge maintenance management and guide future planning of bridge maintenance activities and prevent repeat of failures.

The information required can be collected through the following means:

a) Standard reporting templates,

b) Project and progress reports,

c) Inspection and repair reports,

d) Feedback forms and interviews,

e) Focus groups,

f) Research papers,

g) Audit reports.

The key features of the repository in Table 11.1.

Table 11.1 Key features of the repository

Feature	Description
Recording Framework	Develop a template for capturing lessons learnt after each intervention or major activity.
Categorization	Classify each lesson under themes: Financial/Budgeting, Process, Operational, Technical, Safety.
Documentation Level	Document all interventions with significant technical, financial, or operational implications.
Storage	Store all entries in a centralized best practices database (digital and secure).
Dissemination	Share via: digital knowledge portal (best practices database), reports, training modules, knowledge-sharing forums, regular newsletters, workshops and webinars.

Recommendations of the lessons learnt and best practises repository are:

a) Develop a unified template for capturing lessons learnt and success stories.

b) Integrate the documentation process into routine project closure and post-implementation reviews.

c) Establish a digital repository for storing and retrieving best practices.

d) Ensure regular updates to the repository after every major intervention.

e) Link the repository to capacity building through knowledge-sharing platforms and training sessions.

A sample of lesson-learnt form is given in Table 11.2.

Table 11.2 A sample of lesson-learnt form

Category	Challenges	Solutions Applied	Impact	Recommendations	Status
Case Study / Process	Delay in procurement processes	Streamlined contractor pre-qualification	Reduced lead time by 3 weeks	Automate procurement workflow	Implemented/Ongoing
Technical	Inadequate bridge inspection tools	Procured drone-assisted inspection tools	Improved inspection coverage	Expand use to all regions	In progress
Financial	Budget overruns on maintenance projects	Introduced quarterly budget tracking	Reduced budget variance	Regular financial review meetings	Implemented
Safety	Poor site signage during repair works	Introduced temporary signage kits	Decreased near-miss incidents	Make signage mandatory in maintenance standard operating procedures (SOPs)	Implemented
Operational	Inconsistent inspection documentation	Standardized forms and checklists	Improved report quality	Mandatory training on inspection procedures	Ongoing

10.4.3 Integration into Guidelines

For long term impact, the lessons learnt will be used in the review of developed manuals on bridge inspection, repair manual and the standard specifications. This can be integrated also in the training materials by the use of training aids to present the lessons in a user-friendly manner. The content of the training materials must be updated regularly to reflect the best practises and technologies in order to be in line with current standards.

11 SUSTAINABILITY AND INNOVATION

11.1 OVERVIEW

Sustainability and innovation are integral to modern bridge management and maintenance, ensuring that bridge infrastructure remains safe, resilient, cost-effective, environmentally and socially responsive throughout its lifecycle. This section outlines the principles, strategies, and technologies that support sustainability and innovation in bridge maintenance management in line with Sustainable Development Goals (SDG) 9 and 11.

11.2 SUSTAINABLE BRIDGE MANAGEMENT PRACTICES

To enhance long-term performance while reducing environmental impact, bridge managers should incorporate the following sustainable practices:

a) Life-Cycle Assessment (LCA): Evaluate environmental impacts from design through demolition to guide material and maintenance choices that minimize emissions and waste.

b) Use of sustainable materials: Prioritize low-carbon, recycled, and locally sourced materials in bridge repair and retrofit projects.

c) Preventive maintenance: Adopt optimized, proactive and profitable inspection and maintenance regimes to extend asset life and reduce the frequency and intensity of major interventions.

d) Energy efficiency: Implement energy-saving practices during construction and maintenance operations, including low-emission equipment and optimized logistics.

e) Resilience and adaptation: Design and maintain bridges to withstand extreme weather and climate change impacts using adaptable design features and robust drainage solutions.

f) Human-centred: Develop and maintain bridges that connect people to one another and that facilitate the safety of road users.

11.3 INNOVATION IN BRIDGE MANAGEMENT

Innovation plays a key role in improving the efficiency, accuracy, and safety of bridge maintenance management. Human-centred emerging technologies and methodologies include:

a) Digital Twin Technology: Create real-time digital models of bridge assets to simulate, monitor, and predict performance and maintenance needs.

b) Structural Health Monitoring (SHM): Deploy sensors and smart systems to continuously monitor bridge conditions and detect early signs of deterioration.

c) Artificial Intelligence (AI) and Machine Learning (ML): Use AI to process inspection data, optimize maintenance schedules, and predict structural behaviour.

d) Unmanned Aerial Vehicles (UAVs)/Drones: Apply drones for visual inspections, data collection, and hard-to-reach area assessments, reducing inspection costs and risks.

e) 3D Printing and Advanced Fabrication: Explore new fabrication methods for rapid prototyping of replacement components or even structural elements.

f) Sustainable Deconstruction: Plan for end-of-life asset management using recyclable components and minimal environmental disruption.

11.4 POLICY AND GOVERNANCE SUPPORT

a) Encourage integration of sustainability and innovation goals in bridge asset management policies, regulations and funding criteria.

b) Promote partnerships with research institutions, technology providers, and the construction industry to accelerate the adoption of innovative practices.

c) Establish performance indicators and reporting requirements for sustainability outcomes in bridge maintenance management projects.

d) This guideline should be reviewed after every five years by the ministry responsible for roads and the reviews should target sustainability and innovative considerations.

12 RISK MANAGEMENT IN BRIDGE MAINTENANCE

12.1 OVERVIEW

Risk management is a structured approach that helps in identifying, assessing and mitigating potential uncertainties that could compromise the safety, structural integrity and service life of bridges. Through effective risk management, comprehensive understanding, strategic decision making, operational excellence, proactive approach, stakeholder confidence can be harnessed to navigate uncertainties reinforcing trust and credibility in bridge maintenance management. Stakeholders can make informed decisions on potential threats, select and prioritise appropriate mitigation measures, improve allocation of limited maintenance resources, and improve overall performance of bridges.

12.2 RISK MANAGEMENT FRAMEWORKS

ISO 31000 provides structured guidance for integrating risk management into all aspects of bridge maintenance. It comprises the following primary components:

12.2.1 The Framework

The framework ensures that risk management is embedded into bridge maintenance operations and aligns with broader infrastructure objectives. Key elements include:

a) Policy and Governance: Establishing clear risk management policies and leadership commitment.

b) Program Design: Developing a sustainable and practical approach tailored to the agency capacity and bridge portfolio

c) Implementation: Deploying the risk management program, including training, roles and responsibilities

d) Monitoring and Review: Continuously assessing the effectiveness of risk management activities

e) Continual Improvement: Adapting and refining the program based on lessons learnt and evolving risk environments.

This framework reflects the Plan-Do-Check-Act (PDCA) cycle to support continuous improvement and long-term sustainability of risk-based maintenance strategies.

12.2.2 The Process

The risk management process is iterative and includes the key steps shown in Figure 12.1.

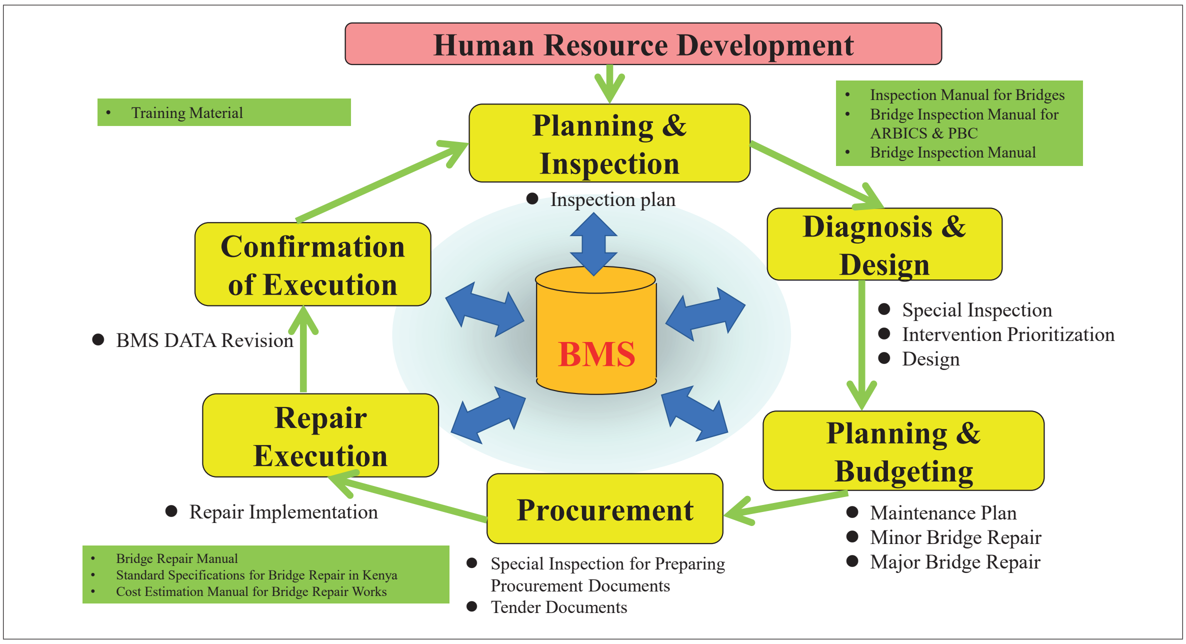

Figure 12.1 Risk management framework process component

12.2.2.1 Establishing the Risk Contexts

It defines the scope environment and objectives of the risk management in bridge maintenance. The risks being evaluated should be limited to risks in the bridge maintenance management cycle.

12.2.2.2 Risk Identification

Risk identification entails identifying vulnerabilities, uncertainties or threats that may compromise structural performance, safety and functionality of the bridge.

In order to develop targeted mitigation strategies, classification can be done for the risks including:

i. Structural degradation,

ii. Environmental impact (flood damage, sapping, scouring),

iii. Overloading,

iv. Maintenance delays- possibly due to funding delays or lack of a maintenance system,

v. Human error, terrorist activity and vandalism,

vi. Natural disasters (earthquakes, hurricanes, blizzard, rainstorm),

vii. Geologic conditions (crossing the fault belt, stratigraphic rock fragmentation).

12.2.2.3 Risk Analysis and Evaluation

Once identified, the likelihood and impact of risks should be properly assessed as given in Table 12.1 to prioritize them for treatment.

Table 12.1 Likelihood and impact scoring

Risks Category	**Likelihood scoring**					**Impact scoring**				
	Rare (1)	Unlikely (2)	Possible (4)	Likely (4)	Almost certain (5)	Insignifi-cant (1)	Minor (2)	Moderate (3)	Major (4)	Critical (5)
Structural degradation										
Environmental impact										
Overloading										
Maintenance delays										
Human error, terrorist activity and vandalism										
Seismic vulnerability										

12.2.2.4 Risk Mitigation

These are measures that are used to reduce the probability and manage the impact of identified risks.

a) Design-based Mitigation

Design-based mitigation strategies in bridge maintenance focus on incorporating the following features that reduce the likelihood and impact of future deterioration:

i. The use of corrosion-resistant materials such as stainless steel and Fiber-Reinforced Polymers (FRP), which enhance durability and reduce maintenance frequency.

ii. Incorporating redundancy in the design of critical structural elements to ensure that the bridge remains functional even if one component fails.

iii. Integration of scour-resistant designs for substructures.

iv. Providing adequate maintenance access such as catwalks and inspection hatches to facilitate regular inspections and timely repairs.

v. Using modular components to allow for easier and quicker replacement of damaged parts, minimizing service disruptions and repair costs.

b) Operational Controls

The following operational controls ensure that maintenance is timely, data-driven, and systematic:

i. Preventive maintenance plans based on risk categories.

ii. Bridge inspection regimes (Routine: 1-2 years; Principal: 5 years; Special: As needed).

iii. Bridge management system for decision support and asset prioritization.

iv. Installation of monitoring sensors.

v. Use of contractor performance tracking tools.

vi. Timely updating of maintenance logs and bridge condition ratings.

c) Financial Risk Management

Financial risk management contributes to building financial resilience by enabling preparation for mitigation of potential losses in bridge maintenance management. The following are the strategies for financial risk management:

i. Establishment of annual emergency maintenance funds and contingency reserves for unforeseen risks.

ii. Use of framework contracts for rapid mobilization during failures.

iii. Introduction of multi-year maintenance budgets.

iv. Cost control trends against performance indicators.

d) Risk Register Management

Once risks are identified and assessed, a risk register should be developed and appropriate mitigation strategies recorded, deployed, assigned responsibilities, and follow-up timelines issued to the responsible parties to reduce their probability and impact.

Risk scoring can be done using a likelihood, impact computation and risk levels assigned with these ranges: 15 to 25 (High), 6 to 14 (Medium) and 1 to 5 (Low). The risk register should be reviewed quarterly, after major inspections and after major catastrophic events.

A sample risk register is as shown in Appendix I.

12.2.2.5 Communication and Consultation

Ensures that all stakeholders are informed and involved in the risk management process.

12.2.2.6 Monitoring and Review

It involves tracking the performance of treatments and updating the risk assessment subject to changing conditions and new information.

12.2.3 Emergency Preparedness and Response Planning

When critical failures occur, the ability to respond quickly is key to protecting public safety and restoring service. It involves:

12.2.3.1 Contingency Planning

a) Creation of Bridge Emergency Response Plans (BERPs).

b) Mapping of alternative routes for traffic diversion.

c) Pre-identification of standby contractors.

d) Preparation of standard assessment templates for damage reports.

12.2.3.2 Resource Mobilization

a) Formation of Rapid Response Teams (RRTs) within bridge units.

b) Stockpiling of essential materials (e.g., joints, bearings).

c) Activation of on-call framework contracts.

d) Allocation of machinery and vehicles for emergency deployment.

12.2.3.3 Emergency Drills and Training

a) Regular simulation exercises of bridge failure scenarios.

b) Training for engineers, contractors, and first stakeholders.

c) Defined communication protocols with disaster agencies.

d) Setup of real-time reporting and escalation mechanisms.

12.2.3.4 Rapid Response Team

To ensure a timely and effective response to emergency situations affecting bridges, a dedicated Rapid Response Team (RRT) should be established as part of the bridge maintenance emergency preparedness framework. The RRT should conduct regular patrols to assess the condition of the bridges, make a recording and handle immediate works. They should be equipped with communication tools such as walkie-talkies, Closed-circuit Television (CCTV) cameras, and internet access to enable real-time communication and coordination.

The surrounding community should be informed about the existence and role of the team so that, in their absence, residents can report urgent issues. Additionally, toll-free emergency contact numbers should be clearly displayed on bridge piers and girders to encourage road users to report accidents and incidents, thereby enhancing community participation in maintaining bridge safety.

a) Composition of the RRT

The following is the proposed composition of the RRT:

i. Structural Engineer who is responsible for rapid assessment and structural integrity evaluation.

ii. Skilled Laborers and Equipment Operators who will perform emergency stabilization, repairs, and on-site support.

iii. Health and Safety Officer to ensure compliance with safety procedures and hazard mitigation during operations and provide first aid on emergency cases and contact the medical personnel.

iv. Communications Lead to coordinate internal and external communication, including stakeholder and public updates.

b) Key Attributes of the RRT

i. Regionally Deployed Teams: Strategically located across regions for faster access to critical sites.

ii. Fully Equipped: Teams should have access to essential tools, Personal Protective Equipment (PPE), and emergency repair materials.

iii. Pre-Trained and Assessed: Members must undergo periodic training and simulation drills to maintain operational readiness.

c) Deployment Warrants

The Rapid Response Team is activated under the following circumstances:

i. Structural incidents threatening public safety such as visible damage, collapse risk, or structural instability.

ii. Traffic disruptions with no alternate routes.

iii. Following events such as earthquakes, floods, or landslides to assess and respond to damage.

13 COMPLIANCE AND GOVERNANCE

13.1 OVERVIEW

Compliance and governance are central pillars of a sustainable bridge maintenance management system. By aligning practices with laws, conducting regular audits, upholding ethical standards and preventing corruption, road sub-sector stakeholders can safeguard public resources, prevent bridge failures, and promote a culture of accountability. This not only protects lives but also ensures that bridges remain safe and functional through their design life.

13.2 ADHERENCE TO NATIONAL LAWS, REGULATIONS AND STANDARDS

Maintaining bridges in a compliant manner involves not only physical repairs but also entails strict conformity to the legal, standards, and regulatory environment.

13.2.1 Laws and Regulatory Framework

Bridge maintenance must be aligned to the established national laws relating to the road sub-sector. These frameworks define who is responsible, how decisions are made, and what practices are permissible. For instance, national legislation such as the Public Roads Act, Kenya Roads Board Act, Public Procurement and Disposal Act, Anti-Corruption and Economic Crimes Act, Engineers Act, and Environmental Management and Coordination Act guide how bridge maintenance activities are to be undertaken in Kenya (Kenya Law Reports, 2021).

13.2.2 Standards

Bridge maintenance management practices should be aligned to the existing and relevant standards and there should be no relaxations or departures from the stipulations of these standards. Where exceptions to the relaxations or departures are to be considered written justifications should be provided. The following are some of the standards:

i. Road Design Manuals,
ii. British Standards,
iii. Relevant Kenya Standards (KS),
iv. AASHTO LRFD Bridge Design Specifications (AASHTO, 2020),
v. Standard Specification for Road and Bridge Construction,
vi. Eurocodes for Structural Design (EN 1990–1999),
vii. Japan Road Association (JRA) Bridge Specifications.

13.2.3 Bridge Inspection

All routine, principal, and special inspections must be conducted by qualified bridge inspectors, with clear documentation of findings. Once inspections are completed, the inspection report validates the bridge’s continued serviceability or, where necessary, flags it for remedial action or load restriction.

13.2.4 Legal Liabilities

Negligence in bridge maintenance, whether due to oversight, failure to inspect, or non-compliance with technical specifications, can result in severe legal consequences. Responsible parties, including engineers, supervisors, and contractors, may face administrative penalties, civil claims, or even criminal prosecution in cases of gross negligence leading to structural failure or public harm (World Bank, 2019). Comprehensive documentation of inspections, approvals, and remedial works provides a vital audit trail to support legal compliance and protect professionals from liability.

13.3 AUDIT AND OVERSIGHT MECHANISMS

Oversight mechanisms ensure that bridge maintenance is executed transparently, efficiently, and accountably. These mechanisms serve to uncover gaps, promote good governance, and guide improvements.

13.3.1 Internal Audits

Internal audits are typically carried out by designated audit units within the MDAs. They assess compliance with policies, evaluate how funds are used, and ensure that technical standards are observed. These audits have the potential to uncover inefficiencies, poor record-keeping, or deviations from maintenance plans and recommend timely corrective actions.

13.3.2 External Oversight Agencies

In accordance with Article 229 of the Constitution of Kenya, the Office of the Auditor-General has the mandate to audit all public entities, including infrastructure maintenance programs, to ensure prudent use of public funds and adherence to procurement and financial regulations.

a) Oversight is also supported by the Public Procurement Regulatory Authority (PPRA), which monitors contract implementation to ensure fairness, transparency, and compliance with the Public Procurement and Asset Disposal Act.

b) The Engineers Board of Kenya (EBK) plays a critical role in ensuring that bridge maintenance activities are carried out by qualified professionals, in line with the Engineers Act (2011).

c) Additional oversight may be provided by agencies such as the Ethics and Anti-Corruption Commission (EACC), particularly where integrity, procurement irregularities, or unethical conduct are in question.

d) Regular technical audits, financial reviews, and compliance inspections should be carried out by these bodies. Findings must be officially documented, and recommendations implemented within specified timelines.

e) External oversight reports shall be shared with relevant parliamentary committees, the National Treasury, and other stakeholders to enhance public accountability.

13.3.3 Findings and Corrective Measures

Audit findings should be highlighted systematically and non-complying elements are corrected through a Corrective Action Plan. Such plans identify responsible parties, set deadlines for remedy and track remedial measures. Persistent non-compliance or repeated findings may trigger further investigation, budget restrictions, or disciplinary action when the next audit is undertaken.

13.4 ETHICS AND INTEGRITY IN MAINTENANCE OPERATIONS

To uphold public trust and ensure responsible use of resources, bridge maintenance operations must be grounded in strong ethical principles. As guided by Chapter Six of the Constitution of Kenya, the Public Officer Ethics Act, and International Federation of Consulting Engineers (FIDIC) best practices, all stakeholders must demonstrate integrity, transparency, and accountability. This includes mandatory adherence to a formal Code of Conduct, zero tolerance for corruption, and regular ethics training. These measures are essential to safeguarding public safety, ensuring value for money, and fostering long-term sustainability in infrastructure management.

13.4.1 Code of Conduct

All public servants and contracted staff involved in bridge maintenance must adhere to an established Code of Conduct. This code outlines expected behaviours such as honesty, impartiality, responsible resource use, and respect for the law. Violations of the code should attract disciplinary measures including suspension, termination, or legal action.

13.4.2 Corruption Prevention Strategies

Systematic efforts should be put in place in all cycles of bridge maintenance management to prevent proactively respond and reduce corruption.

13.4.3 Conflict of Interest Management

Cases and situations where personal interests may interfere with official duties must be proactively disclosed and appropriately managed to maintain integrity in bridge maintenance operations. All parties involved including clients, contractors, consultants, and supervisory personnel should be required to submit an annual Conflict of Interest Declaration. This declaration should outline any financial, familial, or other affiliations that could potentially influence objective decision-making.

13.4.4 Whistleblower Protection

To support accountability, institutions must establish secure and confidential mechanisms for reporting unethical or illegal behaviour. Whistleblower protection laws and policies should shield individuals from retaliation and provide avenues for investigation and resolution (UNODC, 2021). Establishing trust in these systems encourages early detection of fraud or malpractice.

13.4.5 Training on Ethics

KIHBT and other institutions that train Engineers should develop, mount and sustain continuous training programs that target ethical conduct in bridge maintenance management.

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APPENDICES

APPENDIX I: BRIDGE MAINTENANCE PRIORITIZATION CRITERIA

BRIDGE MAINTENANCE PRIORITIZATION CRITERIA

Using the data collected, bridges are prioritised for repairs based on various criteria such as:

i. Safety Concerns: Bridges with structural issues that pose immediate safety risks shall be prioritised.

ii. Strategic Importance: Bridges that play a critical role in the transportation network—such as those located on major highways or key arterial routes—shall be given higher priority.

iii. Condition and Deterioration Rate: Bridges that are in poor condition or deteriorating rapidly are prioritised to prevent further degradation.

iv. Cost-Benefit Analysis: Evaluating the costs of repairs against the benefits in terms of extended lifespan and improved safety.

v. Potential for Service Disruption: Bridges whose failure could lead to significant disruption in traffic and economic activity shall be prioritised.

vi. Bridges with reoccurring maintenance costs within ten years shall be scheduled for replacement.

vii. Bridges with low deck geometry rating shall be prioritized.

viii. Bridges with insufficient clearance may be prone to accidents and structural damage and thus should be given prioritization.

ix. Bridges with high volumes of traffic shall be prioritized as well.

Bridge maintenance performance criteria and the respective performance measures

No.	Performance Criteria	Performance Measures	Element Level Weighting	Total Weighting
1.	Structure Integrity and Condition	Condition rating	35	35
2.	Safety and Crash Risk	Crash frequency	10	25
		Crash severity	10	
		Vertical clearance rating	5	
3.	Traffic and Operational Impact	ADT	15	20
		Road classification	5	
4.	Detour and Accessibility	Availability & Length	10	15
		Condition	5	

No.	Performance Criteria	Performance Measures	Element Level Weighting	Total Weighting
5.	Environmental Factors	Natural disasters	2.5	5
		Salt Spray	2.5	

1. STRUCTURE INTEGRITY AND CONDITION

This is the general condition of the bridge and will be subject to the Bridge Condition Rating (BCR) provided in the BMS. The weight for this parameter will be determined as follows;

Weight (W_{SIC}) = (100-BCR) x 35%

2. SAFETY AND CRASH RISK

Crash Frequency per year

Crash/year	Reduction Factor (R.F)	Remarks
$C < 2$	0.15	Very Low
$2 \leq C < 5$	0.30	Low
$5 \leq C < 10$	0.80	High
$C \geq 10$	1.00	Very high
Null	**0.50**	**If not provided**

Crash Severity

Parameter	Reduction Factor (R.F)	Remarks
Normal	0.50	Minor Injuries
Serious	0.80	Major injuries
Fatal	1.00	Death
Null	**0.50**	**If not provided**

Vertical Clearance Rating

Parameter	Reduction Factor (R.F)	Remarks
Sub-standard	1.00	$V.C < 4.7m$
Standard	0.75	$4.7m \leq V.C < 5.5m$
Adequate	0.15	$V.C \geq 5.5m$
Null	**0.50**	**If not provided**

3. TRAFFIC AND OPERATIONAL IMPACT

Average Daily Traffic (Veh. /Day)

ADT	Reduction Factor (R.F)	Remarks
ADT < 500	0.15	Very Low
500 ≤ ADT < 1,000	0.30	Low
1,000 ≤ ADT < 5,000	0.50	Medium
5,000 ≤ ADT < 10,000	0.75	High
ADT ≥ 10,000	1.00	Very High
Null	**0.50**	**If not provided**

Road Classification

Traffic Volume	Reduction Factor (R.F)	Remarks
Other Categories	0.15	County and KWS Roads
Class C	0.30	Rural Roads
Class B	0.50	National Trunk Roads
Class A	0.80	International Trunk Roads
Class S	1.00	Superhighway

4. DETOUR AND ACCESSIBILITY

Availability and Length

Parameter	Reduction Factor (R.F)	Remarks
Short detour	0.15	D < 10Km
Medium detour	0.30	10Km ≤ D < 30Km
Long Detour	0.80	D ≥ 30Km
No detour	1.50	No alternative route
Null	**0.50**	**If not provided**

Detour condition

Condition	Reduction Factor (R.F)	Remarks
Excellent	0.15	IRI < 2mm/m
Good	0.30	2mm/m ≤ IRI < 8mm/m
Fair	0.50	8mm/m ≤ IRI < 12mm/m
Poor	0.80	IRI ≥ 12mm/m
Null	**0.50**	**If not provided**

N/B: IRI – International Roughness Index; to be obtained from the ARICS data.

5. ENVIRONMENTAL FACTORS

Natural disaster

High Flood Level	Reduction Factor (R.F)	Remarks
¼ of pier height	0.15	Very Low
¾ of pier height	0.30	Low
Beam soffit	0.80	High
Overtopping	1.00	Very high
Null	0.50	If not provided

Salt Spray

Proximity from the Coastal Area	Reduction Factor (R.F)	Remarks
> 300km away	0.15	Very Low
101 – 300km away	0.30	Low
100km away	0.80	High
At the coast	1.00	Very high
Null	**0.50**	**If not provided**

APPENDIX II: PRELIMINARY COST ESTIMATION METHODOLOGY FOR TOTAL BRIDGE MAINTENANCE COST (TBMC) USING BMS DATA

1. GENERAL

1.1 Purpose

The objective of Preliminary Cost Estimation Methodology for Total Bridge Maintenance Cost (TBMC) using BMS data is to establish a guideline for annual budget estimation process by establishing data sets that can inform the creation of bridge work plans.

The process of establishing the TBMC methodology involves site surveys, data analysis from various maintenance operations and cost computations using Annual Road Work Plans (ARWP) approach.

Site surveys sought to establish actual costs that are employed in bridge maintenance and the data from BMS and Cost Estimation Manual were used in the analysis to arrive at appropriate proportion of the road maintenance budget for bridge maintenance.

The damage ratings are based on observed defects during inspection of bridges. The study was limited to bridges with damage ratings N, O and D and SD 1 however, it was assumed that category SD 2 is beyond maintenance and falls under reconstruction which is outside the scope of maintenance works. The damage ratings of the bridges were ranked into five categories; N – No damage, O – Observe, D – Damage, SD 1 – Severe Damage level I and SD 2 – Severe Damage level II.

The importance of bridge maintenance is to ensure proactive management of bridges is implemented so that interventions are done before progression to SD category.

1.2 Site Surveys

Using the available information from the BMS, the bridges with ranks N, O, D and SD 1 were selected for inspection. The JICA BMS Project Team visited the selected bridges as is shown in Table B1.

Table B1 Inspected bridges

No.	Bridges	Region/Corridor	Rank
1.	Three Span Bridge near Blue Post	Corridor C	N
2.	Chania River Bridge	Corridor C	N
3.	Juja Underpass	Corridor C	N
4.	Bridge near the Bantu	Corridor C	N
5.	Sabaki Bridge	Coast	O

No.	Bridges	Region/Corridor	Rank
6.	Kilifi Bridge	Coast	O
7.	Nyali Bridge	Coast	O
8.	Maji ya Chumvi Bridge	Corridor A	D
9.	Kavaini Bridge	Corridor C	D
10.	Kavenge Bridge	Corridor C	D
11.	Nguutani Bridge	Corridor C	D
12.	Kamulu Bridge	Lower Eastern	D
13.	Kithyoko Bridge	Corridor C	D
14.	Ruiru Flyover Bridge	Corridor C	D
15.	Njiru Bridge	Nairobi	D
16.	Chania River Bridge	Corridor C	D
17.	Mlolongo Footbridge	Corridor A	D
18.	Oltokai River Bridge	Corridor A	D
19.	Mtito Andei	Corridor A	D
20.	Railways Club Bridge	Corridor A	D
21.	Mbagathi RHS	Corridor A	D
22.	Kilimbini Seasonal River	Corridor A	D
23.	Iagarama Seasonal River	Corridor A	D
24.	Enkokedongoi Seasonal River	Corridor A	D
25.	Mutomo Seasonal River	Corridor A	D
26.	Kwa Rama Seasonal River	Corridor A	D
27.	Avati Seasonal River	Corridor A	D
28.	ISL Steel ltd.	Corridor A	D
29.	Salvelberg	Corridor A	D
30.	Mukobero Seasonal River	Corridor A	D
31.	Nasarian	Corridor A	D
32.	Oloika Seasonal River 2	Corridor A	D
33.	Olnkosoyo River Bridge	Nyanza	SD 1
34.	Obanda pri. box culvert	Nyanza	SD 1
35.	Unknown river Bridge at Kong’ou	Nyanza	SD 1
36.	Unknown Seasonal River at Kobala	Nyanza	SD 1
37.	Gucha River Bridge	Nyanza	SD 1

1.3 Data used for analysis

From the site surveys conducted, an estimate cost per unit area was determined based on the defects observed. The quantity of repair was multiplied by the rates provided in the Cost Estimation Manuals to come up with the total cost of repair of each structure then the total cost was divided by the total surface area of the structure to come up with the estimated cost of the unit area for each category.

A unit cost of repair was obtained for rating categories N, O, D and SD 1 as given in Tables B2 to B6.

Table B2 Average cost of repair for N bridges

S/N	Bridge Name	Area (m^2)	Cost for repair	Cost per unit area	Rank
1.	Three Span Bridge near Blue Post	325.5	1,103,948.51	3,391.50	N
2.	Chania River Bridge	216.0	336,355.31	1,557.20	N
3.	Juja Underpass	394.4	1,710,665.63	4,337.40	N
	Average cost of repair			**3,095.40**	

Table B3 Average cost of repair for O bridges

S/N	Bridge Name	Area (m^2)	Cost for repair (KSH)	Cost per unit area (KSHs)	Rank
	Sabaki Bridge	1,980.0	15,693,396.40	7,926.00	O
	Kilifi Bridge	5,418.0	23,509,223.52	4,339.10	O
	Nyali Bridge	9,650.0	36,938,014.56	3,827.80	O
	Average cost of repair			**5,364.30**	

Table B4 Average cost of repair for D bridges

S/N	Bridge Name	Area (m^2)	Cost for repair (KSH)	Cost per unit area (KSHs)	Rank
1.	Maji ya Chumvi Bridge	425.0	316,998,731.71	745,879.40	D
2.	Kavaini Bridge	170.9	46,124,377.04	269,970.00	D
3.	Kavenge Bridge	297.5	65,620,836.63	220,574.20	D
4.	Nguutani Bridge	178.5	39,329,220.00	220,331.80	D
5.	Kamulu Bridge	576.0	103,518,407.73	179,719.50	D
6.	Kithyoko Bridge	603.1	93,609,221.22	155,208.30	D
7.	Ruiru Flyover Bridge	1,037.4	56,298,697.60	54,269.00	D

S/N	Bridge Name	Area (m^2)	Cost for repair (KSH)	Cost per unit area (KSHs)	Rank
7.	Njiru Bridge	128.0	5,590,272.00	43,674.00	D
8.	Chania River Bridge	84.0	3,214,882.00	38,272.40	D
9.	Mlolongo Footbridge	104.0	2,948,800.02	28,353.80	D
10.	Oltokai River Bridge	468.0	2,132,821.30	4,557.30	D
11.	Mtito Andei	168.8	504,841.28	2,991.70	D
12.	Railways Club Bridge	515.2	1,288,753.04	2,501.50	D
13.	Mbagathi RHS	1,078.0	958,740.00	889.40	D
	Average cost of repair			**140,513.70**	

Table B5 Average cost of repair for SD 1 bridges

S/N	Bridge Name	Area (m^2)	Cost for repair (KSH)	Cost per unit area (KSHs)	Rank
1.	Olnkosoyo River Bridge	171.6	445,000,000.00	2,593,240.10	SD 1
	Average cost of repair			**2,593,240.10**	

Table B6 Average cost of repair for D box culverts

S/N	Bridge Name	Area (m^2)	Cost for repair (KSH)	Cost per unit area (KSHs)	Rank
1.	Kilimbini Seasonal River	35.0	612,480.00	17,499.40	D
2.	Iagarama Seasonal River	48.0	671,482.24	13,989.20	D
3.	Enkokedongoi Seasonal River	134.4	1,605,145.36	11,943.00	D
4.	Mutomo Seasonal River	96.0	1,091,825.87	11,373.20	D
5.	Kwa Rama Seasonal River	47.5	537,634.48	11,318.60	D
6.	Avati Seasonal River	234.6	2,428,854.40	10,353.20	D
7.	ISL Steel ltd.	112.0	549,840.00	4,909.30	D
8.	Salvelberg	30.0	139,884.40	4,662.80	D
9.	Mukobero Seasonal River	80.0	349,914.00	4,373.90	D
10.	Nasarian	60.0	242,834.40	4,047.20	D
11.	Oloika Seasonal River 2	70.2	203,675.82	2,901.40	D
	Average cost of repair			**8,851.90**	

1.4 Analysis of the data

From the above unit cost per unit area, the number of structures falling in the respective categories were obtained from the BMS for each of the regions and corridors. The estimated maintenance cost was thus computed from number of structures by different categories which is expressed in the Tables B7 to B9.

Table B7 Total repair cost for all bridges (KShs)

	Cost (Ksh/m²)	**3,095**	**5,364**	**140,513.7**	**2,593,240**	**for bridges**
	Bridge Condition Rank	N Blue	O Green	D Yellow	SD1 Orange	Total
1.	Central	975,818	71,521,828	737,778,999	0	810,276,646
2.	Coast	27,314,856	205,813,425	122,606,660	0	355,734,941
3.	Corridor A	43,736,767	128,085,304	578,792,211	409,602,273	1,160,216,554
4.	Corridor B	20,704,202	136,746,184	756,135,291	149,681,818	1,063,267,496
5.	Corridor C	28,518,955	284,666,534	567,038,631	0	880,224,120
6.	Lower	16,228,759	113,229,322	746,346,121	0	875,804,203
7.	Nairobi	1,442,199	78,710,012	156,400,212	578,500,000	815,052,422
8.	North E	5,802,596	8,479,847	56,627,033	0	70,909,476
9.	North R	81,834,392	68,981,187	94,094,035	0	244,909,614
10.	Nyanza	14,596,225	79,436,015	1,288,650,429	72,818,182	1,455,500,852
11.	South R	0	23,785,414	163,761,726	0	187,547,140
12.	Upper E	2,830,436	17,113,740	93,896,754	0	113,840,930
13.	Western	2,361,480	41,033,814	178,565,128	809,225,758	1,031,186,179
	Total Bridge Maintenance cost (KSH)	**246,346,684**	**1,257,602,627**	**5,540,693,231**	**2,019,828,030**	**9,064,470,573**

Table B8 Total repair cost for all box culverts (Kshs)

	Cost (Ksh/m²)	**173.1**	**1,269**	**8,851.9**	**104,167**	**for box culvert**
	Bridge Condition Rank	N	O	D	SD1	
		Blue	Green	Yellow	Orange	Total
1.	Central	63,867.6	17,682,289	49,145,699	15,708,338	82,600,194
2.	Coast	334,978	39,135,281	33,906,898	8,233,336	81,610,494
3.	Corridor A	490,686	32,998,265	12,561,605	0	46,050,557
4.	Corridor B	703,761	20,587,323	74,079,755	0	95,370,839
5.	Corridor C	2,658,342	103,850,915	22,824,239	0	129,333,496
6.	Lower	858,537	13,257,072	38,744,543	0	52,860,152
7.	Nairobi	71,865	11,629,637	10,702,647	0	22,404,149
8.	North E	473,426	3,243,999	13,516,729	0	17,234,154
9.	North R	3,168,634	46,184,540	129,556,688	31,277,198	210,187,060
10.	Nyanza	1,577,031	27,801,285	115,684,722	57,200,018	202,263,056
11.	South R	189,388	7,766,859	19,713,757	0	27,670,005
12.	Upper E	93,310	8,106,047	24,198,697	9,254,378	41,652,432
13.	Western	332,627	8,182,238	19,263,928	0	27,778,793
Total Bridge Maintenance cost (KSH)		**11,016,452**	**340,425,751**	**563,899,909**	**121,673,268**	**1,037,015,380**

Table B9 Average repair cost per bridge

	Bridge	**Box Culvert**	**Total**
Number of bridge/box culvert	726	2,756	3,482
Total cost (KSh)	9,064,470,573	1,037,015,380	10,101,485,953
Average cost per bridge (KSh)	12,485,497	376,276	6,430,886

1.5 Samples used for this study

This study used the data from KeNHA BMS which was developed by INES/Centunion—through the support of the African Development Bank (AfDB). Table B10 shows sample data items that can be generated from the BMS.

Table B10 Sample items generated from the BMS

Code	Total length (m)
Name	Overall width (m)
Region	Total surface (m^2)
Township	Road category
Road	Main material
General typology	Principal inspection score
Structure typology	Rank

Table B11 shows the classification of bridges and box culverts under structure typology and general typography.

Table B11 General typology

General typology
Viaduct (Bridge length≧50m or free height≧25m)
Major bridge (10m≦Bridge length<50m)
Minor bridge (5m≦Bridge length<10m)
Culvert/Box Culvert (Bridge length <5m)
Footbridge

2 STUDY APPROACH

Repair unit rate (KSh/m^2) from sample data using BMS

Using the available information from the BMS, the bridges with ranks N, O, D and SD 1 were selected for inspection. The JICA BMS Project Team visited the selected bridges, inspected them and calculated the cost estimates required for the repair of the bridges. The summary of the information collected is shown in Table B12.

The required cost estimates were assumed to be a good representation of the costs of repair for similar ranked bridges.

Table B12 Cost of repair for each condition rating

Condition Rating	Bridge Repair Unit Price (Kshs/m^2)	Box Culvert Repair Unit Price (Kshs/m^2)
N	3,095.40	173.10
O	5,364.30	1,268.85
D	140,513.70	8,851.90
SD 1	2,593,240.10	104,166.70

It is important that the unit prices be updated regularly.

The results of the repair cost per bridge and box culvert from the BMS samples calculated using the above method are shown in Figures B1 and B2.

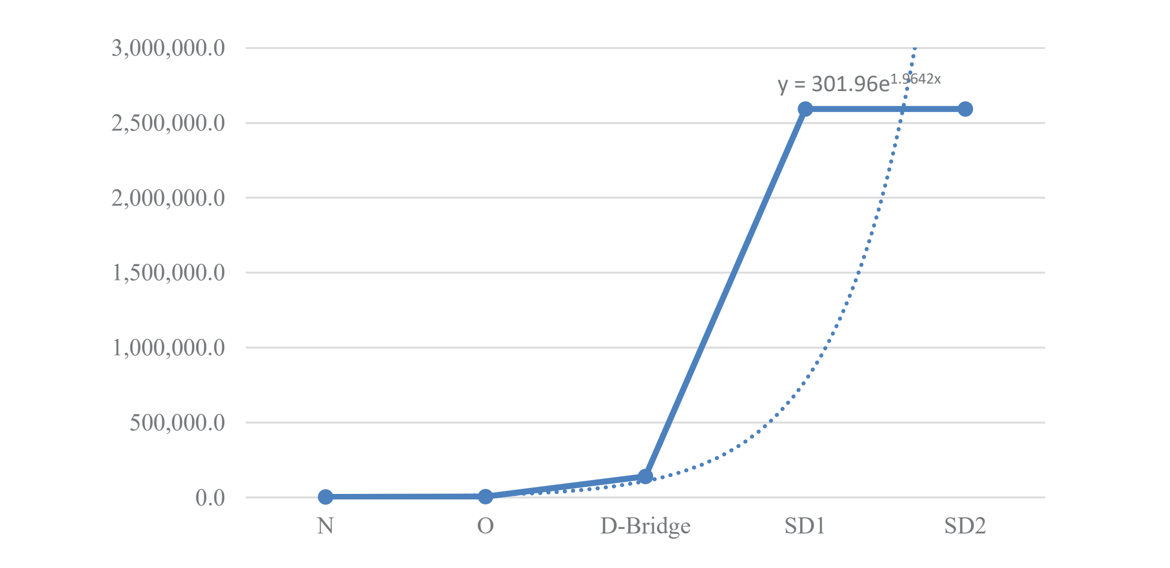

Figure B1 Bridge repair costs

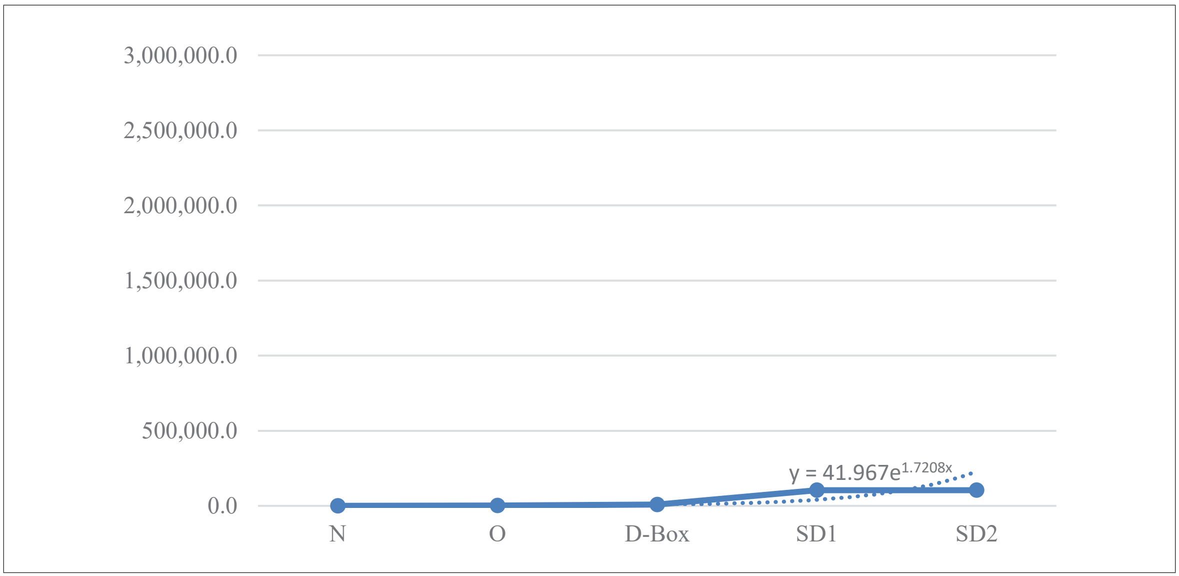

Figure B2 Box culvert repair costs

Computation formula of required repair cost for each bridge

The required cost of repair per bridge was calculated as follows.

Total repair cost per bridge (KSh) = Repair work unit rate (KSh/m^2) × Surface area (m^2) × Reserve fund (1.3)

A 30% reserve fund has been added to the repair cost per bridge to cater for indirect costs, overhead and profit costs.

3 FUTURE PROJECTIONS

3.1 Introduction of projections

Projections serve as essential tools for guiding bridge managers in making informed decisions about resource allocation, long-term planning, and prioritization of interventions.

The projections aim to:

i. **Guide policymakers:** By forecasting potential future scenarios, these projections help decision-makers understand the long-term implications of various maintenance strategies. This enables them to adopt proactive approaches rather than reactive ones, leading to more efficient use of resources and better preservation of infrastructure assets.

ii. **Align with existing budget caps:** A key aspect of projection planning is to ensure that future repair and maintenance needs can be reasonably accommodated within established or expected budgetary limits. This alignment helps avoid unexpected costs or funding shortfalls by providing a forward-looking estimate of financial requirements.

Projections are based on current data, trends in deterioration, and expected intervention strategies. They offer a structured approach to anticipating future repair needs and associated costs, ultimately contributing to more sustainable asset management.

3.2 Projection performance

To undertake the projection, three cases have been considered. In the first case, the present cost of repair is computed according to the inspected defect. In the second case, an assumed deterioration rate is projected for a ten-year period in which the observed defect with no or minimal action done to them have now increased and the structure condition has been moved from the observed condition to the next condition.

In case three, a longer period 10 to 30 years is projected and more defects observed and higher cost assumed for the structure repair.

Table B13 Simulation Settings

Case	Assumption
Case 1: Present	Calculate the cost of repair for all bridges and box culverts using BMS ranks (score)
Case 2: Total costs of repair after approximately 10 years (if no repairs are addressed)	Calculate cost of repair for 20% of all bridges and box culverts, assuming a one rank increase from the current rank. Ex: D (present) to SD1 (assuming approx. 10 years from now)
Case 3: Total costs of repair after approximately 20-30 years (if no repairs are addressed)	Calculate costs of repair for 35% of all bridges and box culverts, assuming a one rank increase from the current rank. Ex: D (present) to SD2 (assuming approx. 20-30 years from now)

3.3 Observations from the projections

The following were noted from the projections:

- Current cleaning methodologies can suffice.

Simulations were performed in three cases based on the inspection results described in this document. The simulations were based on the score as per the bridge inspection results obtained from January 2021 to July 2022. The total cost of repair was calculated for all the bridges in N, O, D and SD 1 condition. The settings and the projected changes in repair costs and amounts are shown in Table B14 and Table B15 and in Figure B3. The results show that if all bridges and box culverts are cleaned and repaired at the current stage, the total cost shall be KSh 10.1 billion, but if nothing is done, the cost shall increase by 3.7 times to KSh 37.0 billion after 10 years and by 10.9 times to KSh 109.9 billion after 20 to 30 years, respectively.

Note 1: It should be noted that the deterioration of more bridges to SD 2 rank, the cost of reconstruction will also increase.

Note 2: In Case 2 and Case 3, tentatively 20% and 35% respectively, has been set for all bridges and box culverts that would be deteriorated. However, there is a possibility that these percentages will increase, so appropriate repairs are important.

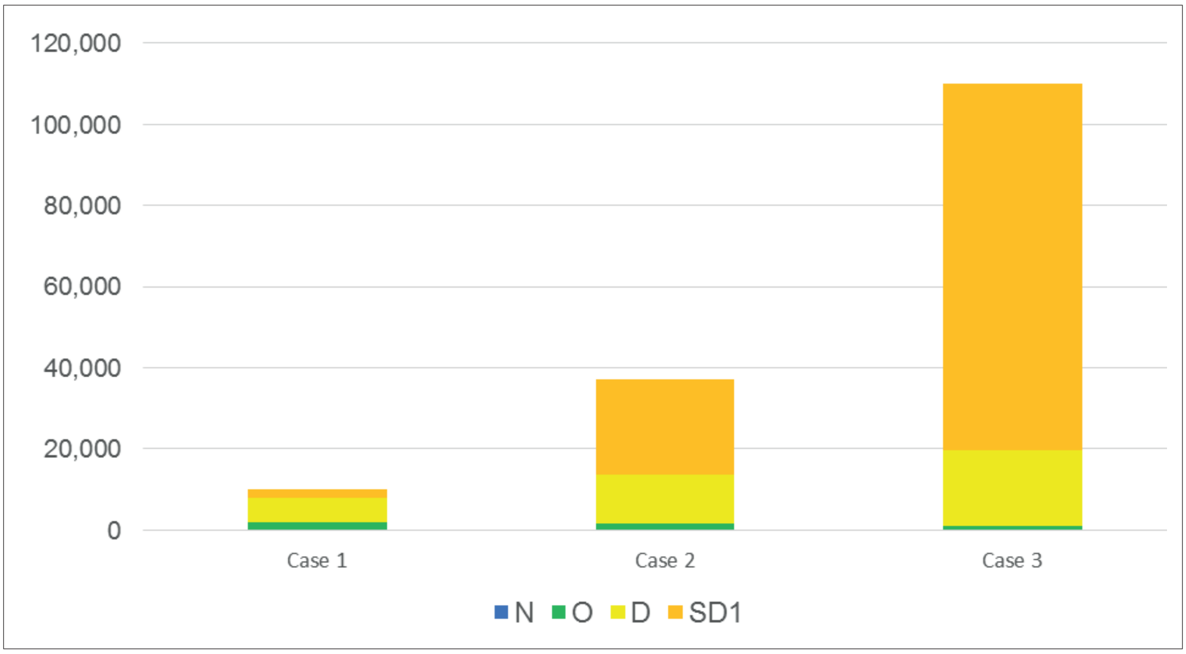

Figure B3 Simulation results

Table B14 Simulation results by rank

Unit: Million Kshs

Bridge + Box	N	O	D	SD1	Total
Case 1	257	1,598	6,105	2,142	10,101
Case 2	206	1,380	11,947	23,492	37,024
Case 3	134	1,039	18,477	90,273	109,922

4. RECOMMENDATIONS FOR POLICY ADVANCEMENT

4.1 Policy

It is important that policy guides implementation.

The following are policy advancement recommendations are made to help include bridge maintenance in to the budgeting process:

i. A prioritization criterion be developed that guides structure prioritization among competing defective structures (1) SD 1 rank, and (2) D rank.

ii. Budgeting should be related to actual repair costs and observed defects.

iii. In instances of budget cuts, a prioritization criterion be adopted. ((1) Structure integrity and condition, (2) Safety and crash risk, (3) Traffic and Operational Impact, (4) Detour and Accessibility and, (5) Environmental factors).

iv. Annual Road and Bridge Inventory and Condition Survey (ARBICS) to be included in operation procedures and inform the budget.

4.2 Budget

The current practice is that structure maintenance is provided for but not in a deliberate structure form with targeted structure maintenance. In the example analysed, based on 23/24 APRP, the budget amount allocated for structure is 4.77% against TBMC. Evaluating this with a maintenance cycle of five years, 7.06% of ARWP will be allocated translating to 20.0% of TBMC. Similarly, taking a return period of 10 years, 3.53% of ARWP will be allocated translating to 10.0% of TBMC.

Table B15 Draft KeNHA's budget

Source: APRP Data (KRB)

	KSH	% by Total ARWP	% against TBMC	Remarks
Total ARWP	28,635,834,103	100.00%	283.48%	APRP (23/24)
Structure Budget	482,111,092	1.68%	4.77%	APRP (23/24)
ARICS	23,500,000	0.08%	0.23%	APRP (23/24)
Structure Maintenance	10,000,000	0.03%	0.10%	APRP (23/24)
Case study				
Total necessary repair amount	10,101,485,953	35.28%	100.00%	
7.06% ARWP	2,020,297,191	7.06%	20.00%	
Years to cover TBMC				
3.53% ARWP	1,010,148,595	3.53%	10.00%	
Years to cover TBMC			10	

4.3 Annual bridge repair work plan

For sustainable maintenance to occur, a short, intermediate and long-term bridge maintenance management plan should be developed. This will ensure adequacy of interventions and appropriate budgeting.

4.4 Mid and long-term maintenance plan

In developing a medium-term maintenance management plan, adjusting the timing of repairs according to the budget amount and equalizing the budget will lead to sustainable maintenance management (see image in Figure B4).

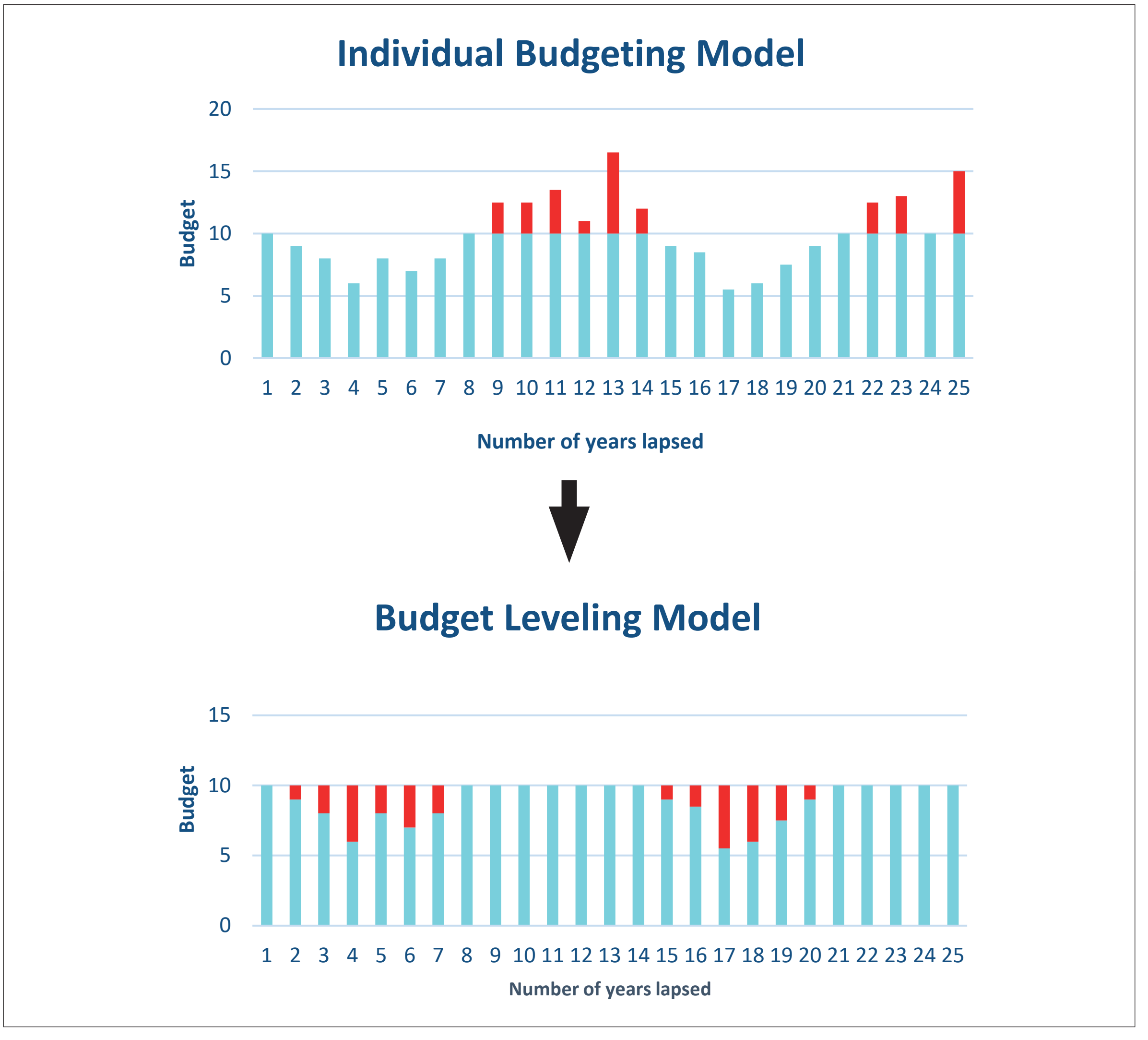

Figure B4 Maintenance budget leveling image

5. REMARK

The above estimation is based on simplified approach using condition rating from the BMS. Further comparison and justification may require:

1) Comparison of actual maintenance work cost/m2 from actual works done.
2) Comparison of estimated cost from KeNHA BMS maintenance planning module.

APPENDIX III: RISK REGISTER SAMPLE FORMAT

KeNHA Road/Bridge Project Risk Register				
Contract Name: Performance Based Contract for Maintenance of kendubay - homabay (B2) Road				
Directorate:	RA&CM			
Previous Date of Reporting:	None	Current Reporting Date:	9th December,2020	
Previous % Progress:		Current % Progress weighted on payment:	50%	
Contract Number:	KeNHA/RD/RA&CM/2796/2019			
Commencement Date:	30th April, 2019	Contract Period:	36 months	

Risk No.	Risk Category	Risk Description	Risk Cause (s) / Factors / Drivers	Consequences	Last Review Date	Impact	Likelihood	Score	Heat Rating	Risk Response	Risk Owner	Response Review Date
1	Operational	Encroachment on the road reserve	1.Stone dressing on road reserves 2. Traders encroaching at the market centres.	Obstructions/ blockages of the drainage system, damage to the road pavement layers, road accidents, delay on execution of works	1st July, 2020	5 3	3 3	15 9		1. continous sensitization to the public against encroachment	1. Contractor 2. Resident Engineer	30/9/2020
2	Operational- Health and Safety	Covid 19 emergence	Global Pandemic	Delayed work progress	1st July, 2020	3	3	9		Social distance/ government health directives	1. Contractor	30/9/2020
3	Operational- Weather	Rainy season	Weather Pattern	Delayed work completion time		4	3	12		Working extra hours when there is no rain.	1. Contractor	
4	Operational/Economic	Potholes emerging at moderate rate	1. Overloading by trucks	Increased maintenance cost		3	3	9		1. Remove encroaching structures so as to free up side drains.	1. Resident Engineer	
5	Operational-Safety	Contractor's staff not using PPE's all the time	1. Contractor provides inadequate PPEs 2. Workers failing to use PPEs 3. Inadequate safety awareness by Contractor's staff	Injuries, death, delay of works, claims	1st July, 2020	5	2	10		1. Contractor to be reminded to provide adequate PPEs 2. No access to site without PPEs 3. Undertake sensitization of Contractor's workers	RE/Contractor	30/9/2020
6	Operational	Absence of road furniture	1. Vandalism of road furniture 2. Road accidents 3. Road Maintenance works	1. Road accidents 2. Poor guidance to road users 3. Increased cost due to replacements		5	5	25		1. Engage local administration to be vigilant 2. Replacement of damaged/vandalised furniture 3. Care to be taken by contractor during execution of works	1. Regional Director 2. Contractor	

KeNHA Risk Assessment Criteria-Impact

1	No likely impact on the project even if crystallize
2	Could result into a limited negative impact on the project
3	Could result into a moderate negative impact on the project
4	Could result into asevere negative impact on the project
5	Could result into a sustained negative impact on the project

KeNHA Risk Assessment Criteria-Likelihood

1	Almost impossible
2	Extremly unlikely
3	Possible
4	Isolated incidents
5	Repeated incidents