ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

COMPUTER PROGRAM FOR RAILWAY BRIDGE MANAGEMENT

A Thesis in Railway Engineering

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled **Computer Program for Railway Bridge Management** presented by **Abdurehman Muleta**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled Computer Program for Railway Bridge Management is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Abdurehman Muleta

ABSTRACT

A railway route contains a number of bridge structures along its path. Consequently during operation, these bridges go through different type of load and stresses; as a result the bridges get damaged. The severity of the damage is mainly dependent on the volume of traffic, tonnage of the rolling stock, service year of the bridge, maneuver of users, etc. But in order to determine whether a bridge needs to be maintained or reconstructed, there must be an investigation, either thorough or timely scheduled investigation.

Asset management is a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates, and replaces assets to manage their performance, risks, and costs over their lifecycle to provide safe, cost-effective, and reliable service to current and future customers.

For an organization to have a proficient bridge asset management, incorporating BMS in the system is very important. BMS is a formal procedure for collecting, processing, and updating data, predicting deterioration, identifying alternative actions and predicting their costs, and identifying optimal preservation policies.

For an effective bridge management, computer aided management system is a very valuable choice that would serve the need of the authorized legal entity management personnel those responsible for monitoring of Railway Bridges, and managing bridge maintenance, rehabilitation, and reconstruction.

This research study is focused to develop and introduce a computer program that could assist specially bridge asset management decision making. Transportation accesses are critical to the well being of the nation. And one of the biggest factors to influence transportation is railway transport service. It supports everyday social, political and economic activities by linking communities and connecting people with services. Hence, keeping the railway infrastructures in good condition is keeping the railway transport service efficiently.

The computer program graphical interface is designed using Visual Basic Programming tool which is user friendly and easy to slot in all necessary information in to the computer. The data encoded in to the software are stored for fast and reliable accessibility using SQL (Server Query Language) Server, which allows all authorized computers on the network to access the information on their desk.

The computer program does bridge registration and inventory, inspection data processing, priority ranking, maintenance cost estimation and maintenance plan generation.

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Contents

LIST OF TABLES

LIST OF FIGURE

LIST OF ABBREVIATION

AALRT ....Addis Ababa Light Rail Transit

AF ....Age Factor

AHP ....Analytical Hierarchy Process

BaTMan ....Bridge and Tunnel Management System

BCI ....Bridge Condition Index

BCS ....Bridge Condition Score

BEADS ....Bridge Expert Analysis and Decision Support system

BMIS..................Bridge Management Information System

BMS ....Bridge Management System

BRIDGEIT.........Bridge Information Technology

BRIDGEMAN ...BRIDGE Management System

BSCI...................Bridge Index condition Score

CI ....Condition Index

CIF ....Client Impact Factor

CMS ....Culvert Management System

COSMOS ....Computerized System for the Management of Structures

CWL...................Current Water Level

DANBRO...........Danish Bridges and Roads

DBA ....Data Base Administrators

DOT ....Department of Transportation

ECF ....Environmental Change Factor

ECI ....Element Condition Index

ERA....................Ethiopian Roads Authority

ESCI....................Element Structural Condition Index

F ....Condition of Bridge in a Fair state

FHWA ....Federal Highway Authority

FinnRABMS ......Finnish National Roads Administration Bridge Management System

FO ....Functional Obsolescence

G ....Condition of Bridge in a Good state

GUI ....Graphical User Interface

HF ....Historical Factor

HiSMIS ....Highway Structures Management Information System

HWL ....High Water Level

IR ....Inspector's Recommendation

JE ....Junior Engineer

JICA ....Japan International Cooperation Agency

MAUT................Multi Attribute utility Theory

Mi ....Material Vulnerability Factor

MICHI................Ministry of Construction Highway Information Database

MTO...................Ministry of Transportation of Ontario

NBIS ....National Bridge Investigation System

NRA ....National Roads Authority

OBMS ....Ontario Bridge Management System

P ....Condition of Bridge in a Poor state

PENBMS............Pennsylvania Bridge Management System

PONTIS..............Preservation, Optimization, and Network Information System

QC ....Quality Control

RSDP..................Road Sector Development Plan

RTA ....Roads and Traffic Authority

SAMOA ....Surveillance, Auscultation and Maintenance of Structures

SD ....Structural Deficiency

SDF ....Structural Deficiency Factor

SI ....Structural Importance

Si ....Structural Significance Factor

SMART..............Simple Multi Attribute Rating Technique

SPF ....Serviceability Potential Factor

SQL....................Server Query Language

SR ....Sufficiency Rating

STEG..................Structures Register

TMIS..................Transport Management Information System

USA....................United States of America

VG ....Condition of Bridge in a Very Good state

VP ....Condition of Bridge in a Very Poor state

1. Introduction

1.1. Background

Bridges are critical and valuable components in any road and rail transportation network. As time goes by Railroad Bridges and other Infrastructures that are currently in good condition will deteriorate and become structurally deficient due to the actions of weather, traffic and other various causes, just like any physical asset. These deficient structures potentially endanger the safety and economical use of the railway transportation system. To keep on top of the deterioration of our asset, investment must be made continually for maintenance.

Bridge remedy has always been a top priority for asset managers and engineers, but identifying the nature of true defect deterioration and associated repair treatments remains a complex task.

If the bridge inspections are not carried out for all bridges, total collapse of bridges would occur frequently across the county and invites social and political troubles without doubt. One bridge collapse can cause casualties and require considerable amount of money and time to reconstruct the new bridge.

Bridge consists of several members and elements that have different durability due to the difference of materials, locations, and sensitivities against weather and loads. This indicates that to keep the appropriate functions of bridges expected in their design life, appropriate maintenance is essential in response to the actual deteriorations.

It is obvious that where there is no enough capacity and enough money to maintain every road that needs work in a single year is unavailable, then one has to make the best use of the resources we have to get the best investment results for road users.

How one invest is critical to achieving the best outcome for the users. Where there is a budget and resources shortage, it is very important to make good analogy on whether a bridge should wait until it reach its maximum capacity and replace it with new one, or maintain it regularly and extend the life time.

The adoption of Asset Management Principles can deliver a systematic approach to this by planning well into the future and making informed decisions based on sound engineering.

Asset management has been widely accepted as a means to deliver a more efficient and effective approach to management of railway infrastructure assets through longer term planning, ensuring that standards are defined and achievable for available budgets. It also supports making the case for funding and better communication with stakeholders, facilitating a greater understanding of the contribution railway infrastructure assets, and makes its contribution to economic growth and the needs of local communities.

Railway Transportation sector is a newly emerging division that started its contribution to Ethiopian transportation. Addis Ababa Light Rail Transit (AALRT) is now fully functional, giving service in both North – South Direction from St. George square to Kality station and East – West Direction from Torhailoch to Ayat. In addition, the National railway is expected to start its service soon. All these railway lines have bridges and other different infrastructures that need maintenance to give extended time of service.

As time goes by Railroad Bridges and other Infrastructures that are currently in good condition will deteriorate and become structurally deficient due to the actions of weather, traffic and other various causes, just like any physical asset. These deficient structures potentially endanger the safety and economical use of the railway transportation system. To keep on top of the deterioration of our asset, we must invest continually in maintenance.

If the bridge inspections are not carried out and maintenance measures are not taken timely, bridges would collapse frequently across the county and would invite social and political troubles without doubt. One bridge collapse can cause casualties and require considerable amount of money and time to reconstruct the new bridge.

Thus during the time of the operation, the maintenance work shall be done timely and effectively. To do these the following problems shall be solved first:

- Difficulty to manage all constructed bridges.
- Difficulty to gain information on any bridge if it is manual.
- Some information on hard copy may be lost or damaged.
- It takes much space to store the files
- No of person that gain the information is limited

- Engineers on other offices, if they want any information about the bridge condition either they have to come or wait information to be sent from the head quarter.
- It is difficult to give information when peoples come for research purpose or to check whether the bridge is capable or not for the overload import materials.

1.2. Objective and Scope of the Study

1.2.1. Objective of the Study

Any organization responsible for asset management especially bridge administration is expected to monitor potentially ruthless hazards due to any structural failure or natural disaster. Nowadays Decision Support Systems are widely used to assist decision makers across an extensive spectrum of unstructured decision environments. The main objective of this research is to create a very efficient, reliable and comfortable bridge asset management environment by developing a Railway Bridge Management Software program based on requirements-driven methodology for bridge monitoring and maintenance which has the ability to process the bridge condition inspections and find the best remedial treatment with the aim of maintaining a bridge within acceptable limits of safety, serviceability and sustainability.

In addition the software is anticipated to introduce Computer aided bridge management system and facilitate Bridge Management and speed up the working and communication time, provide safe and reliable information, guaranteed and efficient storage of file and documents. Thus furthermore the software is used:

- To minimize the duration of data analysis of any inspection
- To minimize the amount of paper work required
- To provide a searchable database of all past inspections
- To provide an automated channel for the public to request information
- To increase the efficiency of bridge management work.

1.2.2. Scope of the Study

The study will create excellent understanding on the applicability of Computer aided bridge management system for better and efficient administration of bridge in operation.

The software developed during this study can be used in practical bridge management system by the Ethiopian Railway Corporation and other authorized bodies.

Due to wideness of activities in asset management, this study is limited to asset management of bridge structures only. It doesn’t include railway line asset management and culvert structures management.

1.3. Organization of the Thesis

The Presentation of the study is organized in to five chapters.

Chapter One: deals with a brief introduction where background, objective, scope of the study and organization of the thesis briefed.

Chapter Two: contains surveys of different literatures related to asset management, different countries asset management practices, inventory and inspection, bridge damage types, bridge condition assessment, prioritization technique and decision making technique.

Chapter Three: describes components of the computer program and methods of analysis used in the program. Here, flow chart diagram and its description are included in addition with description of modules in the program and analysis approach of the program.

Chapter Four: discusses about the application of the program, Input data samples, and the output in addition of briefing on methods to change or update data.

Chapter Five: discusses on the results achieved during the study are included with their conclusion, in addition to recommendation appropriate for potential users and areas of future study.

2. Literature Review

2.1. Asset Management

One of the biggest factors to influence railway transport services is the condition of the railway infrastructures. This is not surprising as transport infrastructure is critical to the well being of the nation. It supports everyday social and business activities by linking communities and connecting people with services.

Asset management is a well established discipline, implemented for the management of physical assets. Many asset owning organizations have adopted the principles of asset management and as a result, can demonstrate benefits in terms of financial efficiencies, improved accountability and stewardship of the asset, better value for money and improved customer service.

Asset management is a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates, and replaces assets to manage their performance, risks, and costs over their lifecycle to provide safe, cost-effective, and reliable service to current and future customers [5].

A Bridge Management System (BMS), like any other asset management, is a formal procedure for collecting, processing, and updating data, predicting deterioration, identifying alternative actions and predicting their costs, and identifying optimal preservation policies.

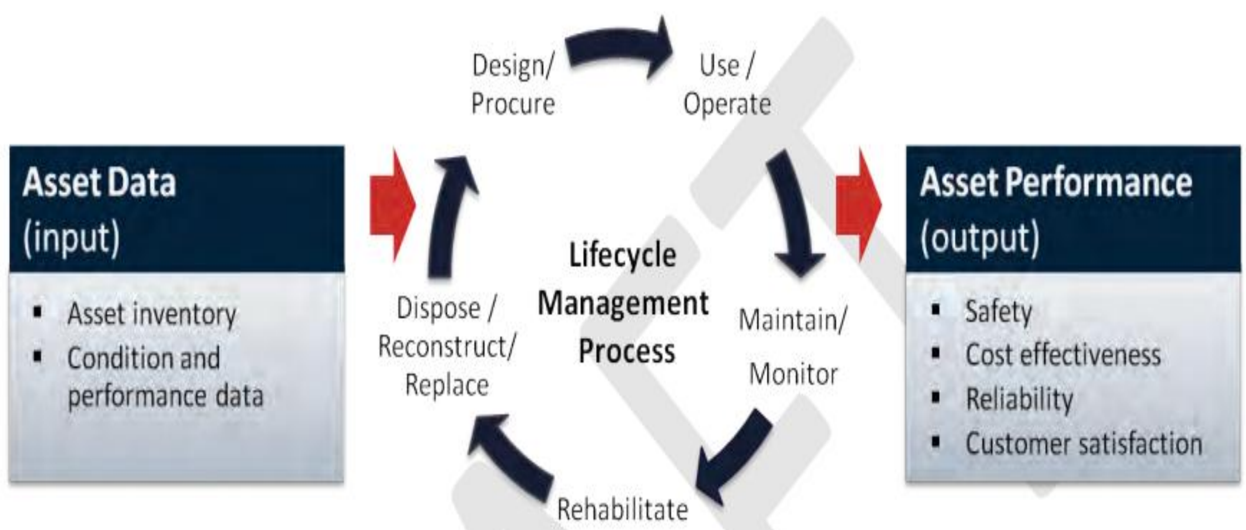

Figure 2-1: Lifecycle Management Process [4]

2.2. Bridge Asset Management for Decision Making

Bridge Asset management is about making sound financial decisions. It is very valuable in using available finance to maximize the usable lifetime and serviceability of bridge assets. This means decisions need to be made that balance short term needs with the longer term objectives.

Bridge asset management is about making the best use of the money we have. The core of asset management is understanding and minimizing the total cost of ownership of an asset while still maximizing its performance. Asset management integrates activities across departments and offices in the agency to optimize resource allocation by providing quality information and well-defined business objectives to support decision-making within and between classes of assets [5].

Bridge asset management is about doing the right thing at the right time, to maximize the serviceable life of assets. Decisions can be made about making timely interventions to reduce the cost of maintaining bridge assets through the duration of their life. If the right thing is done at the right time the serviceable life of assets can be maximized.

Bridge asset management is most effective when clear objectives are identified for the short, medium and long term objectives. Asset inventory and current condition data can then be used to calculate the required investment to achieve these objectives and highlight some of the likely effects of under investing.

2.3. Bridge Management System Practices

2.3.1. Other Countries Practice on Bridge Management

A) United States of America

Bridge management in the United States has advanced considerably in the past 40 years, with significant accomplishments at the federal and state levels. The National Bridge Inspection Standards (NBIS) which were implemented in the 1970s established a single, unified method of collecting data on the nation's public highway bridges. The NBIS enabled the FHWA and state departments of transportation (DOTs) to monitor bridge condition and performance nationally on a consistent basis, identify bridge needs, define criteria of project eligibility for federal bridge funding, and thereby promote the public safety through better stewardship of bridge assets. Bridge structural deficiency (SD) and functional obsolescence (FO), two ratings that the NBIS defined, became key performance measures that agencies continue to monitor today. Similarly, the bridge sufficiency rating (SR) is embodied in the eligibility formula for federal bridge funding. While some revisions to NBIS have occurred, the definition and application of these bridge ratings have remained essentially unchanged for more than 30 years.

In USA bridge management system a minimum of 6 meter is set as a requirement to classify bridge and culvert structures [2]. Different states of the country use different types of bridge management software. Currently there are three major computer programs that have acceptance in many states of the country, namely:

- PONTIS
- BRIDGIT
- PENBMS

B) CANADA

Canada has different bridge management system for different states. Even though this difference creates lack of unified specifications for the inspection, maintenance, and rehabilitation because each province has its own specifications, it shows the degree of their attention towards asset management [2].

Among all BMSs in Canada, the Bridge Expert Analysis and Decision Support system (BEADS) of Alberta has different architecture from other BMSs, such as Ontario BMS or Quebec BMS. Alberta Transportation is an authorized government department, which is responsible for more than 4100 bridges in provincial highways and 9800 bridges on the municipal road system throughout the province.

The BEADS system consists of a series of individual modules, which are Substructure, Superstructure, Paint, Strength, Bridge Width, Bridge Rail, Vertical Clearance, Replacement and Culvert modules. The Superstructure and Paint Modules are related to the condition state of bridges. The Strength, Bridge Width, Bridge Rail, and Vertical Clearance Modules are related to functionality states of bridges. They produce the improvement needs based on inventory and performance data, and predict the future timing of a functional need. Also, a cost estimate, the timing for each action and road user costs will be determined.

Other than Alberta State the following states are also using their own asset management software

1. **British Columbia**: is responsible for most of the management of the province's bridges using the Bridge Management Information System (BMIS), which has been developed over the last 20 years.
2. **Nova Scotia**: is responsible for the safety and management of approximately 4000 bridges on the provincial highway system, of which about 60% are timber, 20% are concrete, and 20% are steel bridges. In 1998, the NSTPW launched a project named the Transportation Management Information System (TMIS) to help the Department achieve its mandate of safe highways, cost-effective highway infrastructure management, public satisfaction and support for economic development.
3. **Ontario**: is one of the earliest provinces to develop a BMS. The Ministry of Transportation of Ontario (MTO) is responsible for the management of more than 16,500 kilometers of highway networks in addition to approximately 3000 bridges. In order to manage these old bridges effectively, the MTO decided to develop a brand-new system called Ontario Bridge Management System (OBMS).

C) SWEDEN

Transport and communication network in Sweden consists of 13,642 km railway and 98,400 km roadway. When terrain is not suitable for roadway and railway, bridges have been built to enable to communication and transport [17].

In Sweden a bridge must have a span of at least 3 meters to be called a bridge. This definition applied until 1998. Many pipe bridges, built of steel, were not categorized as a bridge according to this definition since most of them have a span of less that this limit. Therefore, they were not maintained and inspected according to bridge standards. In 1998 the definition of the bridge was changed and the new bridge definition specified a span of 2 meter [17].

Sweden has a long tradition in bridge management. Since 1944, information about the condition of the national road network has been documented and stored in different archives. The Swedish Transport Administration (Trafikverket) is the largest bridge manager in Sweden. Over the years, Trafikverket has developed an information technology based bridge and tunnel management system that is widely used by Trafikverket and other owners of transport infrastructure. The latest update of Trafikverket's BMS is called a Bridge and Tunnel Management system (BaTMan), which was introduced in 2004. BaTMan is a computerized Internet based system, which means that users can always have access to updated information about the actual bridges online (https://batman.vv.se/). Furthermore, the system consists of a separate navigation tool (WebHybris) that can access the BaTMan's database and answer any related question for any research or management purposes. BaTMan is recognized as the best known software-based digital BMS in Europe [18].

The system is a tool for operational, tactical and strategic management where the complete system encompasses systems and tools for collecting, storing, processing, analyzing and presenting administrative, technical and inspection data. The system includes codes and manuals to provide guidance for carrying out bridge management activities as properly and as uniformly as possible. The inspection manual gives information on bridge types and their structural members and types of damage and their causes [17]. Along with the inspection manual there is a measurement and condition assessment manual, which includes methods and codes for measuring and assessing the physical and functional condition of bridges [18].

D) United Kingdom

The proposal of 'worst first' approach balanced with a parallel program of preventative maintenance forms a basis for Infrastructure and Asset Management Plan to increase the life span of roads and reduce the percentage of roads in need of repair [2].

During 2015 it is introduced and implemented an extended indicative Five Year Capital Maintenance Program, with a view to further extending that program as one start to develop a more comprehensive and refined picture of asset condition. A process known as 'Deterioration Modeling' to predict the relative condition of the highway network over the coming years and this will help to decide where one should be channeling resources at the optimum time to treat our roads in the most cost-effective way, providing the greatest benefit.

Currently, there are about four computer programs that are given recognition by different parts of the country, namely

- STEG
- HiSMIS

- BRIDGEMAN
- COSMOS

E) Other Countries

There are other countries that use different software developed according to their management practice. Here under some of the famous BMS programs developed by different countries summarized and presented in Table 2.1, below [2].

Table 2-1: Computer programs by other countries

Name of Program	Country
DANBRO	Denmark
FinnRABMS	Finland
DISC	Netherland
COWI	
SAMOA	Italy
MICHI	Japan
BMS.NRA	South Africa
SIHA	

2.3.2. Ethiopia's Practice on Bridge Management

A) Ethiopian Roads Authority

Implementation of the Bridge Management System (BMS) is a new practice in Ethiopian Roads authority and since 2004, ERA aggressively moving towards realizing this system by establishing Bridge Management Branch Office, upgrading the existing ERA-BMS and developing ERA-CMS (culvert Management System) software, launching nationwide bridge inventory and inspection projects, conducting capacity building focused trainings to ERA and Regional Road Authority engineers as well as by formulating bridge rehabilitation projects for the selected bridges that need immediate intervention [4].

Lack of information about the existing bridges in Ethiopia, since long time ago, was one of the major problems to contemplate bridge rehabilitation or replacement issues. During formulation of RSDP projects, in 1997, absence of bridge database prevailed itself as vital issue.

Following this, in 2000 “Bridge Management System” is introduced in Ethiopia, which is widely used in developed countries since the past two decades. In 2004, ERA-BMS software is officially launched with assistance of cooperation by JICA.

ERA sets a minimum span length of 4 meter as a requirement to classify cross drainage as bridge and culvert structures for those less than 4m. As of 2008, following the Regional Roads Bridge Inventory and Inspection, over 4407 bridges and 40567 culverts have been registered with their detail information in ERA BMS [4].

2.4. Bridge Types and Components

2.4.1. Bridge Types

1. **Reinforced Concrete Bridge:** is a type of bridge in which most of the elements of the bridge are composed of composite material of reinforcement bars and concrete. . Modern reinforced concrete can contain varied reinforcing materials made of steel, polymers or alternate composite material in conjunction with rebar or not.
2. **Pre-cast Concrete Bridge:** is a type of reinforced concrete bridge in which most of the elements of the bridge, especially the girder is casted in controlled environment out of the bridge site and transported and placed in place after curing process is completed.
3. **Pre-stressed Concrete Bridge:** is a special type of reinforced concrete bridge in which most of the elements of the bridge, especially the girder is permanently stressed (in compression), so as to improve the behavior of the final structure under working loads. The most common methods of doing this are known as pre-tensioning and post-tensioning.
4. **Steel Bridge:** is a type of bridge in which main elements of the bridge are composed of steel structures.

2.4.2. Railway Bridge Components

1. **Track Structure:** is the track on a railway or railroad, also known as the railway track or permanent way, is the structure consisting of the rails, fasteners, sleepers and ballast (or slab track), plus the underlying sub grade. It enables trains to move by providing a dependable surface for their wheels to roll.
2. **Super Structure:** is the entire portion of a bridge structure which primarily receives and supports loads and, in turn, transfer the reactions resulting to the bridge substructure.

Superstructures generally vary by support type (simply supported or continuous), design type (slab-on-stringer, arch, rigid frame, etc.), and material types (steel, concrete, timber, etc.). The major types of superstructures and their principal advantages and disadvantages are which affect their design, construction, and maintenance.

3. **Sub Structure:** is the foundation portion of the bridge that supports the superstructure and transfers the loads to the earth.
4. **Foundation:** is provided to transmit the load from the piers or abutments and wings or returns to and evenly distribute the load on to the soil strata. This is to be provided sufficiently deep so that it is not affected by the scour caused by the flow in the river and does not get undermined.
5. **Ancillaries:** are non structural bridge components which are functionally essential and aesthetically important in the design of bridges and other road related structures. Usually these components constitute a disproportionately small percentage of the cost of a bridge compared with their importance to the performance, utility and safety of the structure but are difficult and costly to replace in the event of damage or malfunction.

2.4.3. Railway Bridge Elements

Bridges serving for railway route contain the followed elements.

1. Track Structure
2. Deck Slab
3. Expansion Joint
4. Guard Rail/ Parapet
5. Girder
6. Bearing
7. Pier
8. Abutment and Wing wall
9. Foundation
10. Embankment
11. Drainage
12. River Channel

2.5. Inventory and Inspection

2.5.1. Bridge Inventory

Bridge inventory is a procedure where data and general information about a bridge is gathered which is essentially not subjected to change unless a mistake exist in the first data entry. As a minimum the following information are recorded for each bridge [5].

When a bridge is significantly altered by widening lengthening, or by some other manner which extensively modifies the structure, the bridge inventory data should be updated to reflect the change made to be bridge. The bridge inventory data should also be updated to reflect change in track structure, railings and others similar items [3].

2.5.2. Bridge Inspection

Bridge inspection is an action to assess correctly the bridge conditions in a standardized manner and is the most important element in the Bridge Management Cycle that is the systematic maintenance process of inspection, assessment, selection of measures, prioritization and repair to keep bridges in satisfactory levels [5].

The purpose of bridge inspection is not simply to collect the latest information about the present bridge conditions but, more importantly, it should be understood that the inspection is to provide essential information for Bridge Management Cycle. The railroad administration sometimes must take the critical decisions such as closure and reconstruction of the bridge based on the inspection results.

Bridges cannot keep good conditions forever. Bridges start deteriorating soon after their completion because of the actions of weather, traffic and other various causes [5]. If the bridge inspections are not carried out at all lots of bridges would collapse frequently across the county and would invite social and political troubles without doubt. One bridge collapse can cause casualties and require considerable amount of money and time to reconstruct the new bridge. It is important to understand that a bridge consists of lots of members and elements that have different durability in nature due to the difference of materials, locations, and sensitivities against weather and loads. This indicates that in order to keep the appropriate functions of bridges expected in design, appropriate maintenance is essential in response to the actual deteriorations. Service life of a bridge is usually expected as long as fifty years and longer.

Therefore, bridge inspections should be conducted correctly by qualified inspectors who have good knowledge about bridge design, construction and maintenance.

Bridge inspections are classified into four types in terms of purposes and frequencies.

- Initial Inspection
- Regular Inspection
- Major Inspection
- Emergency Inspection

A) **Initial Inspection:** Initial inspection is a onetime inspection conducted during the first three months starting from the opening of the bridge to the traffic.

B) **Regular Inspection:** The regular inspection is a planned, periodic, and superficial inspection to confirm the structural safety and safe traffic condition as frequently as possible [5]. It consists of broad general visual inspection by Assistant Inspector once a year [7]. It is also expected that the regular inspections can detect the major/serious defects and damages as soon as possible.

Inspectors must develop the annual plan for the regular inspection work to cover all the bridges in the Routes to meet the frequency requirement of once a year [5].

C) **Major Inspection:** The major inspection is a planned, periodic inspection to be conducted once in every three years by close visual inspection method. The results of the major inspections are core information of the Bridge Management System and bridge inspectors of the District must conduct the major inspections [5].

It is also known as technical inspection during which thorough examination of each and every component of the Bridge is carried out with the help of equipment covering all points against a prepared checklist. This inspection is done by Junior Bridge Engineer once in five years [7].

D) **Emergency Inspection:** This inspection is done for specified bridge which needs an inspection due to some extraordinary reasons i.e. distressed and early steel bridges, bridge damaged due to accidents or natural calamities, bridge to be undergone heavy repairs etc., bridge showing built-in-imperfections or heavy deterioration etc. this inspection may be carried out by specified authority/ person [7].

The emergency inspection shall be conducted when needed. After natural disasters and severe traffic accidents the emergency inspection may be needed. The purpose of this inspection is to provide information on structural safety and safe traffic condition. If needed, bridge inspectors must do the emergency inspection without delay so as to judge necessity of emergency measures [5].

Table 2-2: Types of Inspection [5]

Classification	Type	Purpose	Frequency	Method	Inspector
Initial Inspection	One time Detail	Assessing traffic safety and structural safety. Finding major defects.	Once after opening to traffic	Visual inspection from ground level. Report on check list	Railway Track inspector, Bridge Inspector
Regular Inspection	Periodic Superficial	Assessing traffic safety and structural safety. Finding major defects.	Once a year	Visual inspection from ground level. Report on check list	Railway Track inspector, Bridge Inspector
Major Inspection	Periodic Detail	Assesing conditions of all the structural components	Once in a five years	Close Visual equipment. Detailed report with damage ratings.	Bridge Inspector, Bridge Engineer
Emergency	Nor-Periodic	Assessing traffic safety and structural safety.	When needed	Visual	Bridge Inspector, Bridge Engineer.

2.5.3. Schedule of Inspection

The schedule of inspection for various officials is prescribed in Indian Railways Bridge Manual. As per manual all the bridges are to be inspected by JE(Tracj) / JE(WKS) once a year before monsoon and by AENs once a year after monsoon and structures are inspected by JE (Bridges) once in a five years and selected bridges by Bridge Engineers. DyCE(Bridges) as and when found necessary side by side track on the bridge should also be inspected thoroughly. The bridges that have been referred to by AEN/ DEN/ Sr.DEN for inspection by a higher authority should also be inspected by higher authority which are over stressed should be inspected more frequently and inspection reports should be filled properly in bridge registers [7].

2.6. Common Damage to Bridge Elements

1. Damage to Concrete Elements

Defects of concrete structures can occur in different stage of bridge life span due to internal or external reasons. Any type of defect occurrence is undesirable that leads to minor or major problem shortly to deterioration.

Deterioration is the process that adversely affects the performance of a structure over time due to defects and damages occurred by naturally occurring chemical, physical or biological actions, repeated actions such as those causing fatigues, normal or severe environmental influences, and wear due to use, abuse, and others.

Here, the initial defect basically should be repaired at construction stage. The instantaneous damage does not change much in their degree with time after they arise. Therefore, in general, they may be treated promptly as emergency treatment. On the other hand, since the rate of performance degradation of structure due to deterioration would change apparently with time, the deterioration mechanism should be identified as much as possible and appropriate actions concerning the prediction of deterioration and evaluation/judgment of performance degradations should be carried out. Therefore, the deterioration should be mainly dealt with as the target for the maintenance activities

The followings are some of the typical defects/ damages frequently observed on Reinforced Concrete Elements [3].

A. **Cracking**: Concrete is by nature a brittle material, so reinforced concrete structures are destined to suffer cracking. Cracking cannot be prevented completely with present techniques. Not all types of concrete cracking, however, pose problems; some are detrimental to structures but others are not. Damaging cracking includes those types that cause water leakage due to cracking throughout the member, excessive deflection, aesthetic concerns and defect to the durability of structure.

   Cracks in concrete may described in a variety of ways. Some of the more common ways are in terms of surface appearance, depth of cracking, width of cracking, current state of activity, and structural nature of the crack. Cracking can be an important indicator of deterioration taking place in concrete and possible corrosion of reinforcement steel depending on the size, extent and location of the cracks.

   Cracks of concrete are classified as structural or non-structural cracks.

i. **Flexural Crack**: are vertical structural cracks which start in the maximum tension zone and proceed toward the compression zone. These types of cracks are originated from insufficiency of the section to withstand the flexural, settlement and other stresses developed in that section due to dead and live loads applied upon it. Poor design is also another cause of this type of crack. Flexural cracks will usually be substantial in width, and **the** opening may tend to increase as a result of continuous loading and creep of the concrete.

ii. **Shear Crack**: are structural cracks found near the bearing area. It begins at the bottom of the member and extends diagonally upward. These types of cracks are originated from insufficiency of the section to withstand the shear, and other stresses developed in that section due to dead and live loads applied upon it. Poor design is also another cause of this type of crack. Shear cracks will usually be substantial in width, and the opening may tend to increase as a result of continuous loading and creep of the concrete.

iii. **Non-structural cracks**:-Can be referred as cracks caused by temperature, shrinkage, workmanship Problems and mass concrete cracks. These cracks are relatively minor and generally do not affect the load carrying capacity of the member. They can, however, provide openings for water and contaminants, which can lead to serious problem.

B. **Spalling and Delamination**: is gradual or sudden loss of larger pieces of intact concrete from the surface due to insufficient cover or excessive loading. There are two types of disintegration, scaling and dusting. Scaling is the gradual and continuing loss of surface mortar and aggregate over an area. Dusting is the development of a powdered material at the surface of hardened concrete. Dusting will usually be noted on horizontal concrete surfaces that receive a great deal of traffic.

Delamination occurs when layers of concrete separate at the level of outermost layer of reinforcing bars. Delaminated areas give a hollow sound when tapped with a hammer.

C. **Rebar Exposure**: occurs when there is insufficient cover or concrete deterioration is started due to rebar corrosion. Rebar exposure to the surface leads to the corrosion of the rebar as a result of different interaction with chemical in the atmosphere.

The corrosion of reinforcement may caused by carbonation and chloride attack. Carbonation or chloride attack involves the contamination (ineffectively) of protective alkaline environment provided by good quality concrete.

The presence of excessive amounts of chloride ions, originating from the use of the admixture calcium chloride, will also destroy the passive layer, which prevents corrosion

D. **Material Deterioration**: due to poor construction or environmental effects most bridge element materials deteriorate through time.

E. **Honey Comb**: refers to voids in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles. This may be due to leakage of mortar through formwork joints which is not well prepared. It usually becomes apparent when the formwork is stripped (exposed), revealing a rough and, 'stony 'concrete surface with air voids between the coarse aggregate. Sometimes, however, a surface skin of mortar masks the extent of the defect.

Honeycombing may extend some depth into the member. Honeycombing is always an aesthetic problem, and depending on the depth and extent may reduce both the durability performance and the structural strength of the member.

Honeycomb preferably shall be repaired at the construction time, before handing over the original work, with supervision Poor Construction

F. **Water Leakage**: is the ingress of water through the surface of the concrete structure. Water leakage mostly occurs when the surface is exposed to structural or non structural cracking. The cause of cracking might be excessive loading, poor design, poor construction, shrinkage cracks, voids, concrete porosity, and absence of impermeable wearing course, defect to joint sealants, or blockage of drains and any other minor errors.

An extended water leakage largely contributes to the deterioration of the bridge part prone to this specific defect. The repair technique dealt therefore enables to protect the concrete section from being continuously degraded.

2. Damage to Steel Elements

The followings are some of the typical defects/ damages frequently observed on Steel Elements.

A. Undulation:
B. Break Failure:
C. Excessive Loading, Collision

D. Deformation: Collision
E. Crack: Fatigue, Excessive Loading
F. Bolt Missing:
G. Corrosion:
H. Wearing:
I. Paint Peel Off:

3. Damage to Foundation Elements

The followings are some of the typical defects/ damages frequently observed on Foundation Elements in contact with the ground.

A. **Settlement**: Cumulative loads of a bridge or a retaining wall are supported by the foundation substructure in direct contact with soil. The soil underneath the substructure becomes compressed and deformed during its interaction with the substructure. This deformation is the settlement that may be permanent due to dead loads or may be elastic due to transition live loads. The amount of settlement depends on many factors, such as the type of soil, the load intensity, the ground water conditions, and the depth of substructure below the ground level.

   If the soil bearing capacity is different under different isolated substructures or footings of the same bridge a differential settlement will occur. Due to uneven settlement of supports the structural system becomes over stressed.

   Poor Design and Poor Construction are major cause of excessive settlement which might lead to additional bending and torsional moments in excess of the resisting capacity of the members, which could lead to excessive cracking and failures.

B. **Scouring**: refers to a localized loss of soil, often around a foundation element. Scour occurs when floodwater passes around obstructions in the water column. As the water flows around an object, it must change direction and accelerate. Soil can be loosened and suspended by this process or by waves striking the object, and be carried away. Pilings, pile caps, columns, walls, footings, slabs, and other objects found under bridges can lead to localized scour. Scour effects increase with increasing flow velocity and turbulence, and with increasing soil erodeability.

Poor design and channel constriction are the main factor causing scouring to the foundation elements. Horizontal or vertical channel constructions create a high velocity, flooding, protruding abutments, debris, and river bends.

C. **Sedimentation**: refers to a localized accumulation of soil and any other material, often around opening of the bridge. Sedimentation takes place when river water transports and dumps soil and other derbies around the bridge opening. Sedimentation cause the opening of the river to be narrow to convey the water and cause overtopping. The major cause of sedimentation is lack of proper maintenance.

4. Damage to Other Elements

The followings are some of the typical defects/ damages frequently observed on Foundation Elements in contact with the ground.

A. Functional Failure:
D. Dislocation:
E. Deformation:
F. Abnormal Restraint:
G. Abrasion:
H. Distortion:

2.7. Bridge Condition Assessment

Bridge condition assessment based on field inspections is a fundamental step for providing the appropriate inputs for any condition rating system. The reliability of decisions to find a remediation strategy or fund allocation is highly dependent upon the thoroughness of the condition assessment and diagnosis process.

In order to assess the condition of the bridge, bridge scoring system is proposed which takes into account the conditions of bridge elements, the degree of their contribution to bridge integrity and the contribution of bridges to the overall bridge stock condition.

Scoring methods may be used to classify bridge elements according to their importance and condition. It is then input into an algorithm that can derive the overall bridge condition. By building up a standardized system, the condition of the bridge stock can be assessed and reviewed by the bridge manager.

Table 2-3: Condition State of Bridge Element [14]

Condition State	Description of Defect
1	The element is as new condition and shows no deterioration or the defect has no significant effect on the element on strength and/ or serviceability (visually or functionally).
2	Early signs of deterioration, minor defect/damage, no reduction in functionality of element. Minor cracks and spalls may be present but there is no evidence of corrosion of non-prestressed reinforcement or deterioration of the prestress system.
3	Moderate defect/damage, minor defect/damage, no reduction in functionality of element. Some delaminations and/or spalls may be present. No evidence of deterioration of the prestress system. Corrosion of non- prestressed reinforcement may be present but loss of section is minor and does not significantly affect the strength and/or functionality of either the element or the bridge.
4	Sever defect/damage, significant loss of functionality and/or element is close to failure/collapse. Delaminations, spalls and corrosion of non- prestressed reinforcement are prevalent. There may also be exposure and deterioration of the prestress system (manifested by loss of bond, broken strands or wire, failed anchorages, etc). There is sufficient concern to warrant an analysis to ascertain the impact on the strength and/or functionality of either the element or the bridge.
5	The element is non-functional / Failed

Railway Bridge Defect Ratings

Defects identified during inspection are rated 1 to 5 according to their severity of damage. Here in table below common damages occur in Railway Bridges, their condition state and description about the condition is briefly discussed.

Table 2-4: Railway Bridge Defects Rating [19]

Railway Bridge Defects	Condition	Description
Cracking (RC Bridge)	1	None to Single crack width of less than 0.25mm & Spacing of cracks > 3m or multiple hairline crack
	2	Single crack width of between 0.25mm-1.00mm & Spacing of cracks 2m-3m or multiple crack width of less than 0.25mm with no water leakage
	3	Single crack width of between 1mm-3mm & Spacing of cracks 1m-2m or multiple cracks width of less than 1 mm, together with slight water leakage which causes reduction in durability
	4	Single crack width of between 3mm-5mm & Spacing of cracks 1m-0.5m or multiple cracks width of less than 3 mm, together with water leakage, free lime or salt which causes reduction in loading capacity
	5	Single crack width of greater than 5mm & Spacing of cracks < 0.5m or multiple cracks width of less than 5 mm, together with water leakage, free lime or salt which causes the bridge elements not to support & transfer the load
Cracking (Prestress Bridge)	1	None to Hairline Cracks
	2	Single crack width of less than 0.1mm & Spacing of cracks 2m-3m or multiple Hairline crack with no water leakage
	3	Single crack width of between 0.1mm - 0.23mm & Spacing of cracks 1m-2m or multiple cracks width of less than 0.1mm, together with slight water leakage which causes reduction in durability
	4	Single crack width of between 0.23mm - 0.76mm & Spacing of cracks 1m-0.5m or multiple cracks width of less than 0.23mm, together with water leakage, free lime or salt which causes reduction in loading capacity
	5	Single crack width of greater than 0.76mm & Spacing of cracks < 0.5m or multiple cracks width of less than 0.76mm, together with water leakage, free lime or salt which causes the bridge elements not to support & transfer the load
Peel Off	1	Very small peel off less than 25cm²
	2	Small range of peel off between 25cm²-200cm² due to external forces
	3	Wide range of peel off between 200cm²-760cm² due to rebar corrosion which causes reduction in durability
	4	Serious peel off between 760cm²-1000cm² which causes reduction in loading capacity
	5	Serious peel off greater than 2200cm² which couses concrete falling down
Rebar Exposure	1	If there is no rebar exposure
	2	Partial rebar exposure between 0cm²-400cm² without corrosion
	3	Partial rebar exposure between 400cm²-1000cm² with corrosion which causes reduction in durability
	4	Serious and wide range of rebar exposure between 1000cm²-1700cm² together with corrosion which causes a reduction in loading capacity
	5	Serious and wide range of rebar exposure greater than 1700cm² together with corrosion which causes a concrete falling down

Honeycomb	1	Very small Honeycomb less than 100cm²
	2	Honeycomb between 100cm²-400cm² Which affects the durability
	3	Honeycomb between 400cm²-1000cm² With Seriously corroded rebar
	4	Honeycomb between 1000cm²-1700cm² With seriously corroded rebar, which causes a reduction in loading capacity
	5	Honeycomb greater than 1700cm² with very serious damage to the rebar, which causes the closure of the bridge
Void	1	Very small Void less than 33cm³
	2	Wide range of voids between 33cm³-600cm³ without water leakage
	3	Voids between 600cm³-800cm³ with serious water leakage
	4	Voids between 800cm³-1150cm³ With serious and continuous water leakage
	5	Voids greater then 1150cm³ With serious and continuous water leakage, multiple voids volume, which causes the closure of the bridge
Water Leakage	1	Very small Water Leakage less than 100cm²
	2	Localized or partial water leakage between 100cm²-400cm²
	3	Serious and wide range of water leakage through cracks or voids between 400cm²-1000cm²
	4	Serious and wide range of water leakage between 1000cm²-2130cm² through cracks or voids which may progress
	5	Serious and wide range of water leakage greater than 2130cm² through cracks or voids which may progress and cause a reduction in loading capacity, together with leaching free lime or salt
End Block Damage (Prestressed Concrete Bridge)	1	None to Hairline Cracks
	2	Spot cracking width of less than 0.1mm
	3	Partial cracking width of between 0.1mm - 0.23mm which causes reduction in anchorage
	4	Serious and wide range of cracking between 0.23mm - 0.76mm which causes reduction in anchorage
	5	Outstanding cracking greater than 0.76mm on the main end block member, which causes loss of anchoring functions
End Bearing Plate Damage (Prestressed Concrete Bridge)	1	If there is no broken or corrosion
	2	Partial corrosion between 0cm²-50cm²
	3	End bearing plates are partially broken or corroded which causes reduction in anchorage, between 50cm²-100cm²
	4	Serious and wide range of broken or corroded End bearing plates which causes reduction in anchorage between, 100cm²-200cm²
	5	End bearing plates are broken in wide range greater than 200cm² which causes loses of anchoring functions

Drainage Pipe-Damage	1	If there is no Pipe-Damage
	2	Locally damaged pipe between 0%-7.5% of the whole pipe, which causes negative effects to other bridge elements
	3	reduces durability of other bridge elements (results in corrosion of metal components or rebar, between 7.5%-20% of the whole pipe
	4	causes heavy problem to others by falling down, between 20%-50% of the whole pipe
	5	the drainage pipes are no more functional, greater than 50% of the whole pipe
Drainage Pipe Blocked	1	If there is no Blocked
	2	Slight blockage between 0%-7.5% of the whole pipe
	3	Causes standing water during rainfall, effecting on traffic, between 7.5%-20% of the whole pipe
	4	causes serious hindrance in safety to daily traffic and traffic interruption during and after rain, between 20%-50% of the whole pipe
	5	the drainage pipes are no more functional, greater than 50% of the whole pipe
Drainage Pipe Inlet-Damage	1	If there is no Inlet-Damage
	2	Slight damage between 0%-7.5% of the whole pipe
	3	Reduces drainage function, between 7.5%-20% of the whole pipe
	4	Causes a hindrance to traffic, between 20%-50% of the whole pipe
	5	the drainage pipes are no more functional, greater than 50% of the whole pipe
Pier, Abutment, Wing wall and Foundation Displacement	1	Very small displacement less than 3.3mm which causes no negative effect
	2	Slight displacement between 3.3mm 13.75mm which Causes no negative effect
	3	Displacement between 13.75mm 31.25mm Causes reduces stability
	4	Displacement between 31.25mm-50mm which may progress and cause reduce stability
	5	Displacement greater than 50mm which may progress and cause Pier, Abutment, Wing wall and Foundation failure
Scour	1	If there is no scour
	2	Minor scouring to element in river is suspected
	3	Foundation is exposed up to the top of footing or caisson, which may progress and cause a reduction in stability
	4	Foundation is exposed in depth from the top of footing, caisson or design datum level for pile bent, which may progress and cause a serious reduction in stability of foundation
	5	Foundation is exposed in depth from the top of footing, caisson or design datum level for pile bent, which may progress and cause bridge failure

Embankment Depression	1	If there is no embankment depression
	2	Slight depression with mean difference is less than 13.75 mm in elevation.
	3	Serious depression with mean difference is between 13.75mm-31.25mm in elevation, which may progress and cause a hazard to the bridge and track structure
	4	Outstanding crack or depression with mean difference is between 31.25mm-50mm in elevation, which may progress and cause a hazard to the bridge and track structure
	5	Outstanding crack or depression with mean difference is greater than 50 mm in elevation, which may progress and cause a hazard to the bridge and track structure
Main - Damage for Bearing	1	If there is no Main - Damage
	2	Spot cracking, corrosion or swelling of main element, less than 5% of the whole bearing
	3	Partial cracking, corrosion or swelling of main element, between 5%-10% of the whole bearing
	4	Outstanding damage, such as cracking on the main bearing member, which affects the loading capacity on metal bearing, between 10%-20% of the whole bearing
	5	Outstanding damage, such as cracking on the main bearing member, which affects the load transfer system, greater than 20% of whole bearing
Parts Missing for Bearing	1	If there is no Parts Missing
	2	Slight damage, less than 5% of the whole bearing
	3	Partial cracking, incline or swelling on the secondary elements, between 5%-10% of the whole bearing
	4	Secondary elements, such as stopper, anti- lift devices, are broken which reduces bearing function on metal bearing, between 10%-20% of the whole bearing
	5	Secondary elements, such as stopper, anti- lift devices, are broken which causes failure of bearing function on metal bearing, greater than 20% of whole bearing
Anchor Damage for Bearing	1	If there is no Anchor Damage
	2	Partial corrosion, less than 5% of the whole bearing
	3	Anchor blots are partially broken or corroded on metal bearing, between 5%-10% of the whole bearing
	4	Anchor bolts are broken in wide range, between 10%-20% of the whole bearing
	5	Anchor bolts are broken in wide range which loses anchoring functions on metal bearing, greater than 20% of whole bearing

Bed-Damage for Bearing	1	If there is no Bed-Damage
	2	Partial cracking or spalling, excessive accumulation of dirt and debris on bearing beds, less than 5% of the whole bearing
	3	Wide range cracking or spalling, between 5%-10% of the whole bearing
	4	Major splitting of bearing block, which loses bearing function on high block type bed, between 10%-20% of the whole bearing
	5	Major splitting of bearing block, which loses bearing function on high block type bed and fail to transfer load, greater than 20% of whole bearing
Unusual Movement for Bearing	1	If there is no Unusual Movement
	2	Slight unusual clearance, less than 5% of the whole bearing
	3	Unusual clearance, which reduces rotating of sliding function, between 5%-10% of the whole bearing
	4	Excessive and unusual clearance from the original place, between 10%-20% of the whole bearing
	5	Excessive and unusual clearance from the original place which causes a hazard for the track structure, greater than 20% of whole bearing
Water Leakage for Expansion Joint	1	If there is no Water Leakage
	2	Slight water leakage
	3	Slight water leakage, which causes leakage trace on slab, beam or piers
	4	Water leakage, which accumulates debris dirt on pier caps, affects seriously and causes a reduction in durability to other bridge components.
	5	Excessive leakage, which causes hindrance to other bridge components.
Deformation for Expansion Joint	1	If there is no Deformation
	2	Slight Hollow or swelling
	3	Slight Hollow or swelling which has an effect on smooth driving
	4	Hollow or swelling which has an effect on safe driving
	5	Deformation or cracking to joint elements, which causes a hindrance to traffic on metal joints
Peel Off for Expansion Joint	1	If there is no Peel Off
	2	Seal material is partially taken away
	3	Seal material is partially taken away which causes negative effect on smooth riding
	4	Sealing material is taken away, which has an effect on water leakage and smooth driving
	5	Serious peel off of joint elements which causes a hindrance to safe traffic

Missing for Expansion Joint	1	If there is no Missing
	2	Minor Joint components partially missing
	3	Minor Joint components partially missing which causes negative effect on smooth riding
	4	Joint components missing which has an effect on smooth driving
	5	Major components missing to joints, which may progress and causes a hindrance to safe train traffic
Defect Rating for Steel Girder		
Deformation / Deflection	1	If there is no Deformation / Deflection
	2	Partial deformation less than 1mm on secondary members
	3	Partial deformation between 1mm-2mm on primary members
	4	Outstanding deformation between 2mm-5mm, which affects the loading capacity due to buckling or partial yielding
	5	Outstanding deformation greater than 5mm, which affects the loading capacity due to buckling or partial yielding
Cracking	1	If there is no Cracking
	2	Spot cracking less than 1mm on secondary members
	3	Spot cracking between 1mm-2mm on primary bridge components
	4	Cracking between 2mm-5mm on primary members, especially in welded parts
	5	Outstanding cracking greater than 5mm on primary members, especially in welded parts
Corrosion	1	If there is no Corrosion
	2	Partial corrosion less than 400cm² on secondary members
	3	Partial corrosion between 400cm²-1000cm² on primary member
	4	Major corrosion between 1000cm²-3000cm², which affects the loading capacity by reducing cross sectional area on primary member
	5	Major corrosion greater than 3000cm², which affects the loading capacity by reducing cross sectional area on primary member
Wearing	1	If there is no Wearing
	2	Partial wearing less than 400cm² which affects the durability of secondary members
	3	Partial wearing between 400cm²-1000cm² which affects the durability of primary members
	4	Major wearing between1000cm²-3000cm² in almost all range on bridge components, which affects the durability of primary and secondary members
	5	Major wearing greater than 3000cm² in almost all range on bridge components, which affects the durability of primary and secondary members

Bolt Missing	1	If there is no Bolt Missing
	2	Missing or loosening of 1 bolt on joints
	3	Missing bolt 1-3 on a secondary member joints
	4	Missing bolt 3-6 on a primary member joints
	5	Missing bolt greater than 6 on a primary member joints
Paint Peel off	1	If there is no Paint Peel off
	2	Paint Peel less than 400cm² off which affects the steel durability, but without corrosion
	3	Paint Peel off between 400cm²-1500cm² which affects the steel durability, together with corrosion
	4	Peel off of paint almost all of area, which affects the steel durability, together with serious corrosion
	5	Peel off of paint almost all of area, which affects the steel durability, together with serious corrosion
Defect Rating for Track Structure		
Gauge, Mm	1	If it is 0
	2	Less than 6 or -2
	3	Between 6-7 or Between -2-(-4)
	4	Between 6-9 or Between -2-(-4)
	5	Greater than 9 or Less than -4
Level, Mm	1	If it is 0
	2	Less than 4
	3	Between 4-6
	4	Between 6-10
	5	Greater than 10
High-low, Mm	1	If it is 0
	2	Less than 4
	3	Between 4-6
	4	Between 6-10
	5	Greater than 10

Direction, Mm	1	If it is 0
	2	Less than 4
	3	Between 4-6
	4	Between 6-10
	5	Greater than 10
Twist of track (Easement curve), Mm	1	If it is 0
	2	Less than 4
	3	Between 4-5
	4	Between 5-7
	5	Greater than 7
Twist of track (Straight & Circular curve), Mm	1	If it is 0
	2	Less than 4
	3	Between 4-6
	4	Between 6-9
	5	Greater than 9

2.7.1. Bridge Condition Index

To describe the overall condition the bridge, condition status of structural elements shall be identified first. The Element Structural Condition Index (ESCI) is the common parameter used to identify the condition of structural elements. ESCI is introduced as [11]:

$$ESCI = \frac{\sum(Qi \; x \; Ci)}{\sum Qi} \qquad (2.1)$$

Where, Q_i: Quantity of Elements Reported in Condition Index

C_i: Condition of Sub-element, given as Condition State (1, 2, 3, 4, 5)

As can be seen in the ESCI estimation process, deterministic values are used as an approximation for the element value at each of the five condition states. This approximation may not be quite reliable, since data collected through inspection process is usually associated with subjectivity and uncertainty [17].

It should be clearly understood that some elements require more attention than the others in terms of material vulnerability and/or structural significance. For example, a defective main beam will require more urgent attention than the bridge drainage outlets. However the determination of structural/material vulnerability of various bridge elements is a difficult task. Sometimes doing additional structural analysis such as non-destructive testing is unavoidable.

Alternatively, bridge experts and inspectors can rely on their own experience and knowledge to determine these factors. Generally, the prevailing condition (rating) of the particular element may cause some inaccuracies in the overall structural assessment. For example, a minor component with severe deterioration may unreasonably raise the rating value of that element under which the component is grouped. This problem can be dealt with the introduction of element structural significance factor which is not dependent on the prevailing condition of components.

The evaluation incorporates many parameters and human judgments that may cause the procedure to be slightly uncertain and imprecise. Efforts have been made to employ a systematic approach to quantify the structural importance of various bridge elements [17, 7, 15]. Tee et al. [17] defined the structural significance as the role of an element in comparison to the other components and quantified this factor for different elements at different condition rating based on survey results from 46 inspectors and bridge experts. Dabous and Alkass [15] described the structural importance of a bridge component as the level the component contributes to the overall structural safety and integrity of the bridge and proposed the Analytical Hierarchy Process (AHP) to estimate the value of that parameter.

The Structural Significance Factor (Si) and Material Vulnerability Factor (Mi) are expressed by Maria Rashidi and Brett Lemass [11] according to their research conducting questionnaires to Engineers and Inspectors.

The Structural significance factor considers the contribution of bridge elements to the overall bridge stability. Commonly bridge is divided about ten to twelve elements. These elements are given structural significance factor according to their degree of importance in the total bridge.

Table 2-5 : Structural Significance Factor

Element	**Structural Significance Factor , Si**
Barrier, Footways, Curbs, Joints	1
Foundation, Abutment, Wing wall	2
Deck and Bearing	3
Track Structure, Beams, Headstocks, Piers	4

Table 2-6: Material Vulnerability Factor

Material of the Element	**Material Vulnerability Factor , Mi**
Steel	1
Reinforced Concrete	2
Pre-cast Concrete	3
Other Materials	3
Pre-stressed Concrete	4

As can be seen in the tables, The higher Si represents the superior structural importance and the greater Mi reflects the higher material vulnerability. The overall structural importance of concrete bridges can be estimated through the following equation [11].

$$S.I = \frac{(Si\ x\ Mi\ x\ ESCIi)}{16} \qquad (2.2)$$

Where, S.I: Overall Structural Importance

Si: Element Structural Significance Factor

Mi: Material Vulnerability Factor

ESCIi: Element Structural Condition Index

Table 2-7: Element Condition Index

Element Condition Index	Rating
0 < S.I ≤ 1	1
1 < S.I ≤ 2	2
2 < S.I ≤ 3	3
3 < S.I ≤ 4	4
4< S.I ≤ 5	5

The SI is computed based on taking into account the contribution of each bridge element, weighted accordingly depending on their importance. Hence, key bridge elements contribute to a larger degree than element with lower SI with the same condition state.

Thus the condition of the bridge will be obtain by

There are two types of BCI's, namely BCI (average) and BCI (critical). The first is involved with all the bridge elements that contribute to the overall score, while the latter considers the bridge elements that are of very important to the bridge's ability to provide safety and durability. The two types of BCI's are computed as follows, with 'critical' or 'average' used in the subscripts accordingly [11]:

$$BCIave = \frac{\sum(ECI\ )}{n} \qquad (2.3)$$

$$BCIcritical = max\{ECI\ of\ elements \qquad (2.4)$$

Where, BCI_{ave} = average Bridge Condition Index

$BCI_{critical}$ = critical Bridge Condition Index

ECI = Element Condition Index

n = number of elements

In order to better represent the bridge condition, the Bridge Condition Score (BCS) is used, defined on a scale of 0 (worst) to 100 (best). The determined BCI is converted into a BCS with ‘critical’ or ‘average’ used in the subscripts accordingly. The relationship between BCI and BCS is as follows [8]:

$$BCSave = 100 - 2\{(BCIave)\ 2 + (6.5 \times BCIave) - 7.5)\} \qquad (2.5)$$

$$BCScri = 100 - 2\{(BCIcri)\ 2 + (6.5 \times BCIcri) - 7.5)\} \qquad (2.6)$$

Where, BCS_{ave} = average Bridge Condition Score

BCS_{cri} = critical Bridge Condition Score

BCI_{ave} = average Bridge Condition Index

$BCI_{critical}$ = critical Bridge Condition Index

2.7.2. Bridge Stock Condition Index

In addition to considering the condition of structures on a bridge level, a broader perspective needs to be achieved for effective bridge management. The Bridge Stock Condition Index (BSCI) suitably fulfils this need. To correctly reflect the contribution of each bridge, the size of each bridge should be considered. Hence the deck areas are used to weight each bridge’s contribution. The BSCI s are computed on a scale of 0 (worst) to 100 (best) and its method is as follows [11]:

$$BSCI = \frac{\sum(BCI\ x\ Deck\ Area)}{\sum Deck\ Area} \qquad (2.7)$$

Where BSCI = Bridge Stock Condition Index

BCI = Bridge Condition Index

Deck Area = Area of the deck (total length x total width)

2.8. Prioritization

Many bridge agencies commonly use only structural condition. Parameters such as functionality and criticality may not be specifically addressed in existing practices. The developing condition rating method described herein is an important step in adding more holism and objectivity to the current approaches. The main factors which should be addressed are described in the following sections.

2.8.1. Factors Affecting Prioritization

There are numerous factors which need special consideration during bridge condition assessment. Amongst many factors used to rate the bridge condition, the following factors are considered to be important.

i. Physical Condition of the bridge
ii. Functional Classification of Railway line
iii. Serviceability of the Route
iv. Environmental Factor
v. Client Interest
vi. Historical Factor

i. Physical Condition of the Bridge

Bridge Condition Index (BCI) is used to express the physical condition of the bridge. This indicates the degree of deterioration or decay of constituent bridge material (e.g. cracking, corrosion and delamination, failure of joints and bearing) [14]. The ratings to be considered in characterizing this factor are already discussed in the topic above on Bridge Condition Assessment.

ii. Age Factor (AF):

The life expectancy of existing bridges is dependent on their age, and major concrete bridges are designed for a service life of 100 years. Since bridges are designed to withstand fatigue loading which increases with time, age is an important parameter involved in structural condition assessment. Durability measures should be adopted for 100 years. When service life is raised further than 50 years, the study of major bridges requires that safety be reconsidered to incorporate coherence into the design. Generally, bridges in the last quarter of their design life (typically 100 years) require more serious remedial actions than in previous quarters [12]. The service life of a bridge will be ended when one of the key components fails to function as designed. The Rating of age factor on the Bridge Condition is described on the table below

Table 2-8: Age Factor Rating

Age Factor (AF)	Rating
Recently Built	1
New	2
Medium	3
Old	4
Very Old	5

iii. Functional Classification of Railway Line

Most travel occurs through a network of interdependent railway lines, with each railway segment moving locomotives through the system towards destinations. The concept of functional classification defines the role that a particular railway line plays in serving this flow of locomotives through the network , properties, volume of passenger traffic, goods traffic volume, maximum allowable axle load, design speed, etc. Railway lines are assigned to one of several possible functional classifications within a hierarchy according to the character of travel service each railway line provides.

Basses for railway classification include

- axle load of rolling stock,
- maximum running speed,
- designed speed, and
- Significance of railway construction.

Table 2-9: Functional classification of railway line

Functional Class (FC)	Rating
Class III	1
Class II	3
Class I	5

iv. *Serviceability Potential Factor (SPF):*

The bridge functional efficiency is dependent on volume of passenger and goods traffic that it can withstand, which is mainly related to the existing number of lanes or the width of the deck. This parameter indicates the potential level of service and operation efficiency of a bridge. Load carrying capacity is a critical aspect of serviceability. Bridge width, overhead clearance and provision for pedestrians and cyclists are also determining issues. A poor SPF may trigger substantial remediation, bridge modifications or even bridge replacement.

Table 2-10: Serviceability Potential Factor Rating

Serviceability Potential Factor (SPF)	Rating
Excellent	1
Good	2
Fair	3
Poor	4
Failed	5

v. *Strategic Importance Factor (SF):*

This factor is based on usage and importance of the bridge to the network addressing the economic and political importance of the route and span length of the bridge.

Table 2-11: Strategic Importance Factor

SEF	Strategic Importance Factor , Mi
Very Low	1
Low	2
Medium	3
High	4
Very High	5

vi. *Environmental Change Factor (ECF):*

This parameter considers post-design changes in climatic conditions, introduced aggressive factors such as chlorides, sulphates, carbon dioxide and other pollutants; substantial increases in traffic flow; increases of the bridge dead load due to repeated repaving; closing of joints; potential abutment rotation due to differential and/or excessive backfill material expansion; and non-anticipated alkali silica reaction [14]. Measuring the level of risk introduced by environmental change is often based on a bridge inspector's experience or laboratory tests which are conducted within the detailed inspection phase.

Table 2-12: Environmental Change Factor Rating

Environmental Change Factor	Rating
Very Low	1
Low	2
Medium	3
High	4
Very High	5

vii. *Client Impact Factor (CIF):*

The nature of a bridge site and the extent of the bridge remediation treatment may cause decision makers to close bridge or create alternative routes or bypasses to control the traffic flow. This factor helps build the social implications of remediation into the risk assessment process. It is a vast improvement on the 'do nothing' course of action, as this factor can be systematically weighted and considered along with the other condition rating factors. Alternatively, it can be ignored by assigning it a weight of zero during decision making.

Table 2-13: Client Impact Factor Rating

Client Impact Factor (CIF)	**Rating**
Very Low	1
Low	2
Medium	3
High	4
Very High	5

viii. Historical Factor (HF):

Some bridges have historical value and some are also heritage-listed. Generally, heritage-listed bridges are rarely used by the public, but some bridges with noted historical significance may need to remain in service.

Table 2-14: Historical Factor Rating

Historical Factor (HF)	**Rating**
Very Low	1
Low	2
Medium	3
High	4
Very High	5

ix. Inspector's Recommendation (IR):

Inspector's recommendation is a very important input to consider while decision making.

Table 2-15: Inspectors Recommendation

Inspectors Recommendation (IR)	Rating
Inspection	2
Maintenance	3
Rehabilitation	4
Replacement	5

2.8.2. Priority Rank Computation

Since the importance of the above-mentioned factors is not the same, summing up all the values is not a rational way for finding the priority rank order (P_r). Therefore some weight factors should be assigned by the decision makers and maintenance experts that reflect the importance of each condition index factor. A weighting of zero means that a specific priority factor is judged to have no bearing on the decision making environment, whilst a rating of five means that the factor is extremely important. If all of the nine condition rating factors are assigned weights greater than zero, the relevant weighted condition index equation is as follows, [11]:

$$P_r = \frac{\sum(Wi\ x\ Fi)}{45} \qquad (2.8)$$

Where, P_r = Priority Rank

W_i: Weight of the i^{th} factor [0 - 5]

F_i: assigned value of i^{th} factor [1-5]

The priority rank then will be ordered with the highest with rank-1 to the lowest in decreasing order.

2.9. Maintenance Strategy

2.9.1. Risk Assessment

Dominant Constraint Bridge risk evaluation often serves as the basis for bridge remediation priority ranking, and is conducted periodically for the purpose of safety and functionality. The user is therefore required to assign a weighting for each constraint for individual bridges within their jurisdiction. Major risks and client constraints for bridge maintenance are categorized in table below.

Table 2-16: Major Risks and Client Constraints for Bridge Remedy

Criterion	Risks	Constraints
Safety	Potential Injury / Fatality	Minimal Damage / Maximum Safety of the Public
	Damage to Property	
Functionality	Low Level of Service	Maximum Service life / Load Bearing Capacity
	Closure of a strategic / Regional Route	Minimal Traffic Disruption
Sustainability	Excessive Remediation Cost	Minimal Cost
	Excessive Work Implication	Minimal work Implication
Environment	Environmental Damage	Minimal Environmental Damage
	Not Aesthetically Pleasing	Maximum Aestheticism
Legal / Political	Major Changes in Standards	Minimum Vulnerability to Political Pressures
	Major Changes in Governance	

2.9.2. Decision Tree

Major Strategies most real-world decisions are not limited to singular, unique solutions. The decisions are usually less than optimal and are drawn from a set of feasible solutions that have been termed as 'satisfying' solutions [9]. To define and categories all the possible alternatives, a comprehensive classification should be defined. A decision tree is an appropriate decision analysis tool for this purpose. Figure 2.3 represents a decision tree which includes all the major courses of action for bridge remediation (Level 1 and 2) and some specific treatment options for concrete bridges (Level 3).

Multi Attribute Utility Theory (MAUT) ranking method is used as decision analysis tool to choose the best remediation alternative. Judgments using MAUT are made explicitly, the value information can be used in many ways to help simplify a decision process, and a decision maker typically learns a great deal through these joint efforts to construct their views on their priorities.

However the determination of the maximum and minimum ranges of the attributes and deriving work from the utility functions are perceived limitations [15]. MAUT is more practical method used for ranking purpose. Through the MAUT process, firstly, the problem under consideration is broken down into a hierarchy as shown in figure below.

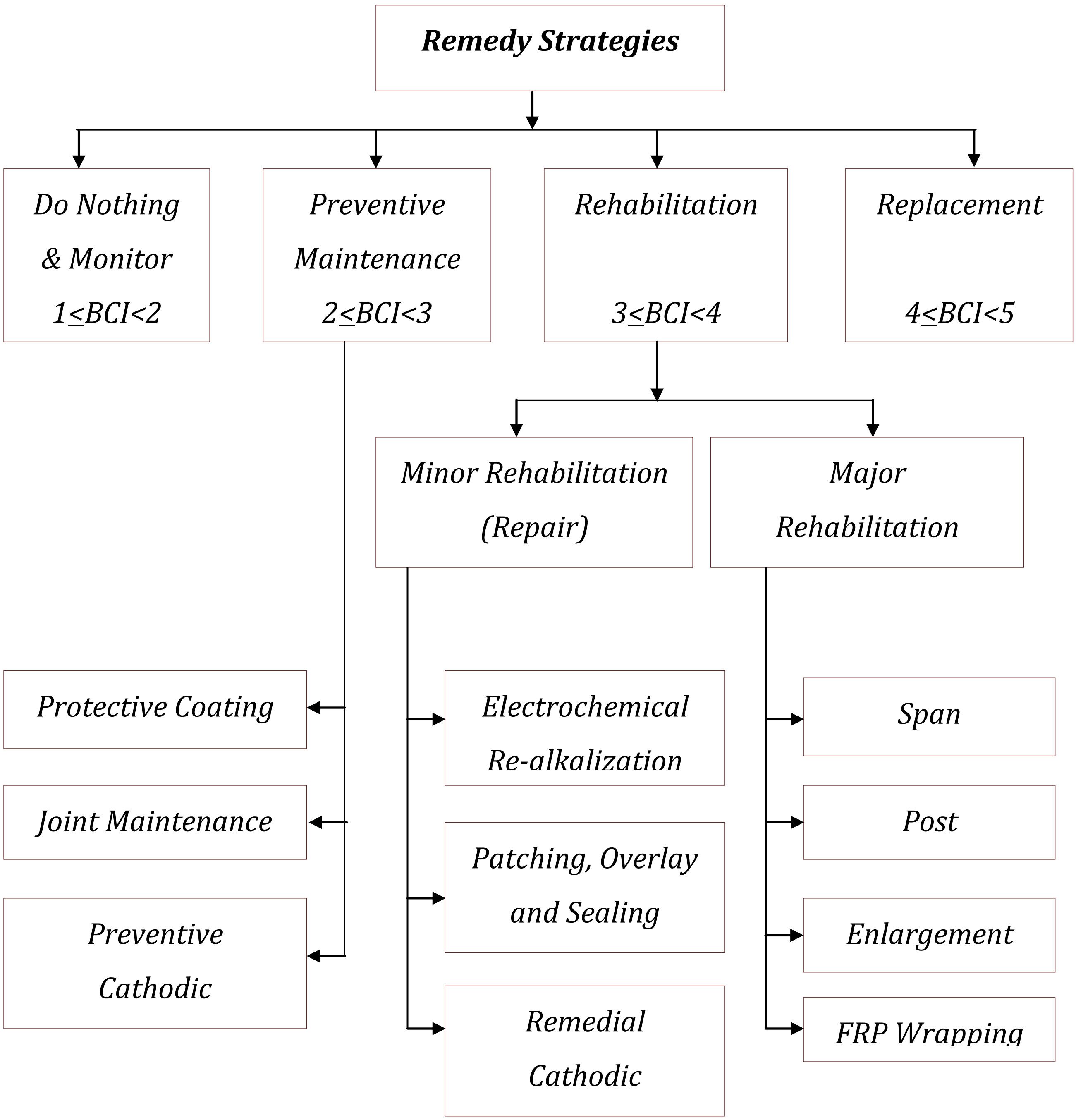

Figure 2-2: A typical hierarchy structure for bridge remediation

Decision criteria are adopted from previous literatures that are collected during interviews with bridge engineers and asset managers. All the elements (goal, objectives and constraints) are organized into a four- level hierarchy structure, which consider all the main aspects of the problem. This approach deals with identifying the overall goal and proceeding downward until the measure of value is included.

The first level of the structure is the overall goal of the ranking. The second level contains the objectives (criteria) defined to achieve the main goal. The third level holds the constraints (sub criteria) to be employed for assessing the objectives. The last level is added for the remediation treatment alternatives. Each criterion has a weight indicating its importance which is defined by the decision maker [15].

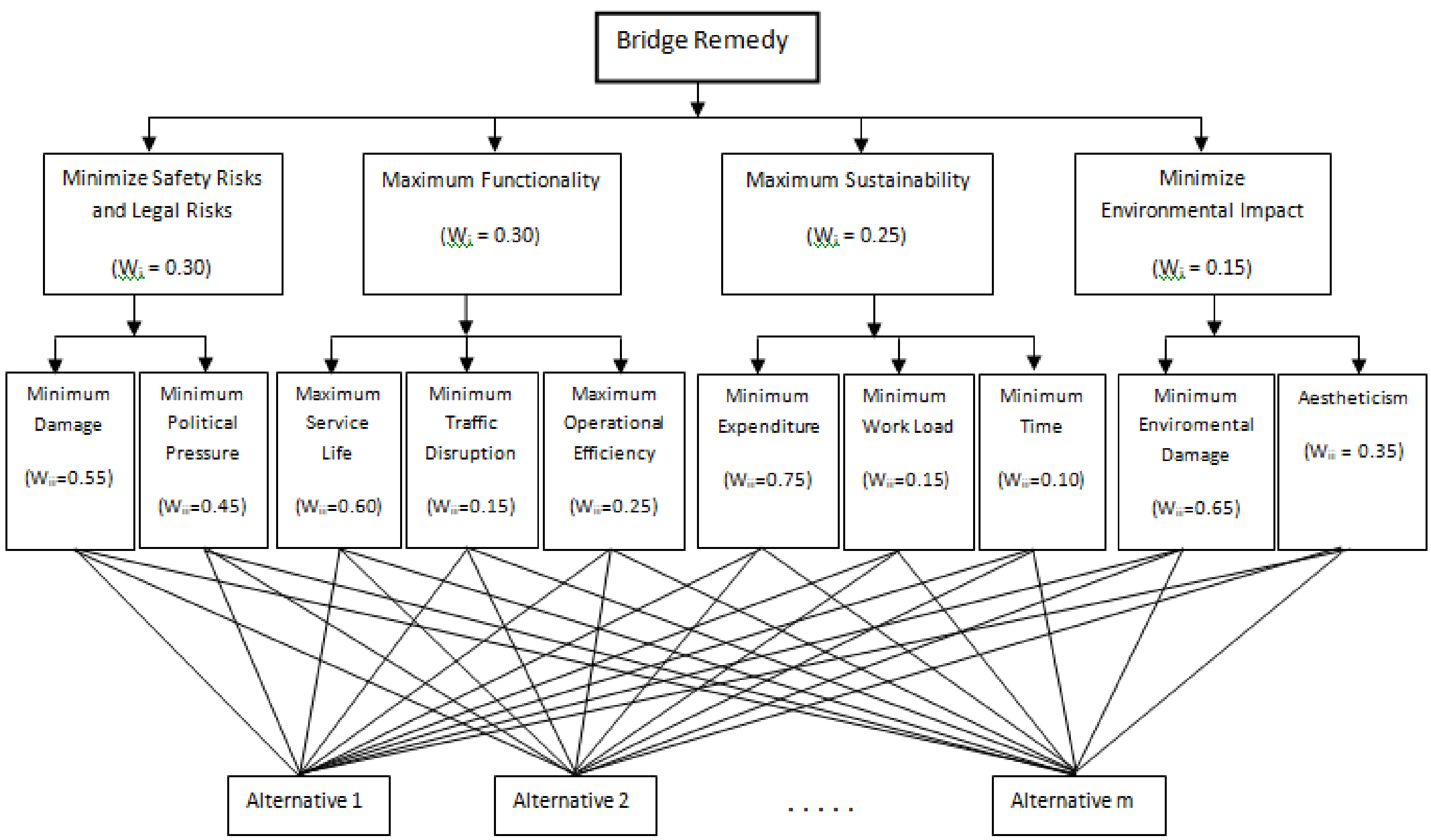

Figure 2-3: Decision tree for possible bridge remediation courses of action

In the majority of cases based on the MAUT, the weights associated with the criteria can clearly reflect the relative importance of the criteria if the scores a_{ij} are from a dimensionless scale. The basic step of MAUT is the application of utility functions to transform the raw performance values of the alternatives against the constraints, both objective and subjective to a common dimensionless scale so that a more favored option gains a higher utility value [8].

Weights of the criteria and sub criteria are usually defined based on the expert's judgments (which should reflect organizational policy) extracted during the problem solving. Final weights are obtained through normalizing the sum of the scores to one [15].

Simple Multi Attribute Rating Technique (SMART) is a form of MAUT. In order to simplify the process, the utility function can be replaced by some scores which indicate the relative importance level of each treatment alternative with respect to the decision criteria.

The overall ranking value of each alternative Xj is expressed as follows:

$$X_j = \sum_{i=1}^{m} (W_k \ x \ W_{ki} \ x \ W_{ij}) \quad j = 1.2.3 \ldots m \qquad (2.9)$$

Where, Xj = Overall Ranking Value

W_k and W_{ki} are the weights of criteria and sub criteria

a_{ij} is the importance level of jth alternative in respect to the ith sub criterion and kth criterion.

The chosen alternative is normally the option with the highest overall score.

3. Computer Program

3.1. Introduction

This study is intended to develop a computer program for railway bridge asset management. In life cycle of any civil work after the asset is constructed and commenced the operation, its management is a very exhaustive and complicated activity to handle.

Like any other assets, bridge assets also require a careful follow up of their condition during service in order to achieve a desired design life time.

Bridge asset management adds a value to the bridge by keeping the bridge in desirable condition with minimum operation cost for long time. Thus, supporting these management system with computer aided software will provide a faster & efficient system with low storage area and reliable data.

Currently in Ethiopian many railway bridges are constructed and also many are under constuction in both Light Railway and National Railway Cases. But yet there is not as such organized asset management activities with in the sector.

Thus considering bridge asset management in its earliest stage would be very important and supporting the management system with computer program is very wise.

The computer program provides an easier and efficient way of bridge asset management system. To enhance its use the software is devided in to four modules. i.e setting module, data entry (input) module , analysis module, and information (output) modules. Thus the software provides several processes in order to achieve better decision-making. The processes include; inventory creation, monitoring, maintenance data analysis, priority setting, and budgeting and funding allocation.

The Bridge Management System is a series of engineering and management function which provide the action necessary to implement a bridge maintenance and replacement program.

The system contains

- a set of data that describe the physical and operating condition of the bridge at any given time.

- Criteria for developing a range of options of feasible improvements considering the bridge geometry, location, type, functional class, volume, etc.
- A procedure for estimating the cost of feasible improvement actions, including the associated user costs
- Establishment of priority lists of rehabilitation, replacement and improvement options and corresponding cost estimates.

In order to achieve the development of a computer program for railway bridge asset management two softwares are used as a developing tool. The first one is Visual Basic 2010 (VB.net) as a developing tool for Graphical User Interface (GUI) which makes it easy to interact with the user, and the second is Server Query Language (SQL server 2008) as a database to store information needed and to acces when ever necessary.

Visual Basic is an object-oriented programming language. Hence, it is no longer procedural as other programming language instead it is event-driven model. Meaning users or programmers do not follow a sequential logic to take control and determine the sequence of execution. Instead, the user can press keys and click various buttons and boxes in a window. Each user action can cause an event to occur, which triggers a Basic procedure that a user has written. This makes it very user friendly and easy to work with.

Microsoft SQL Server 2008 R2, which is used as a database server, is the most advanced, trusted, and scalable data platform released todate. Building on the success of the original SQL Server 2008 release, SQL Server 2008 R2 has made an impact on organizations worldwide with its groundbreaking capabilities, empowering end users through self-service business intelligence (BI), bolstering efficiency and collaboration between database administrators (DBAs) and application developers, and scaling to accommodate the most demanding data workloads .

3.2. Description of Flow Chart

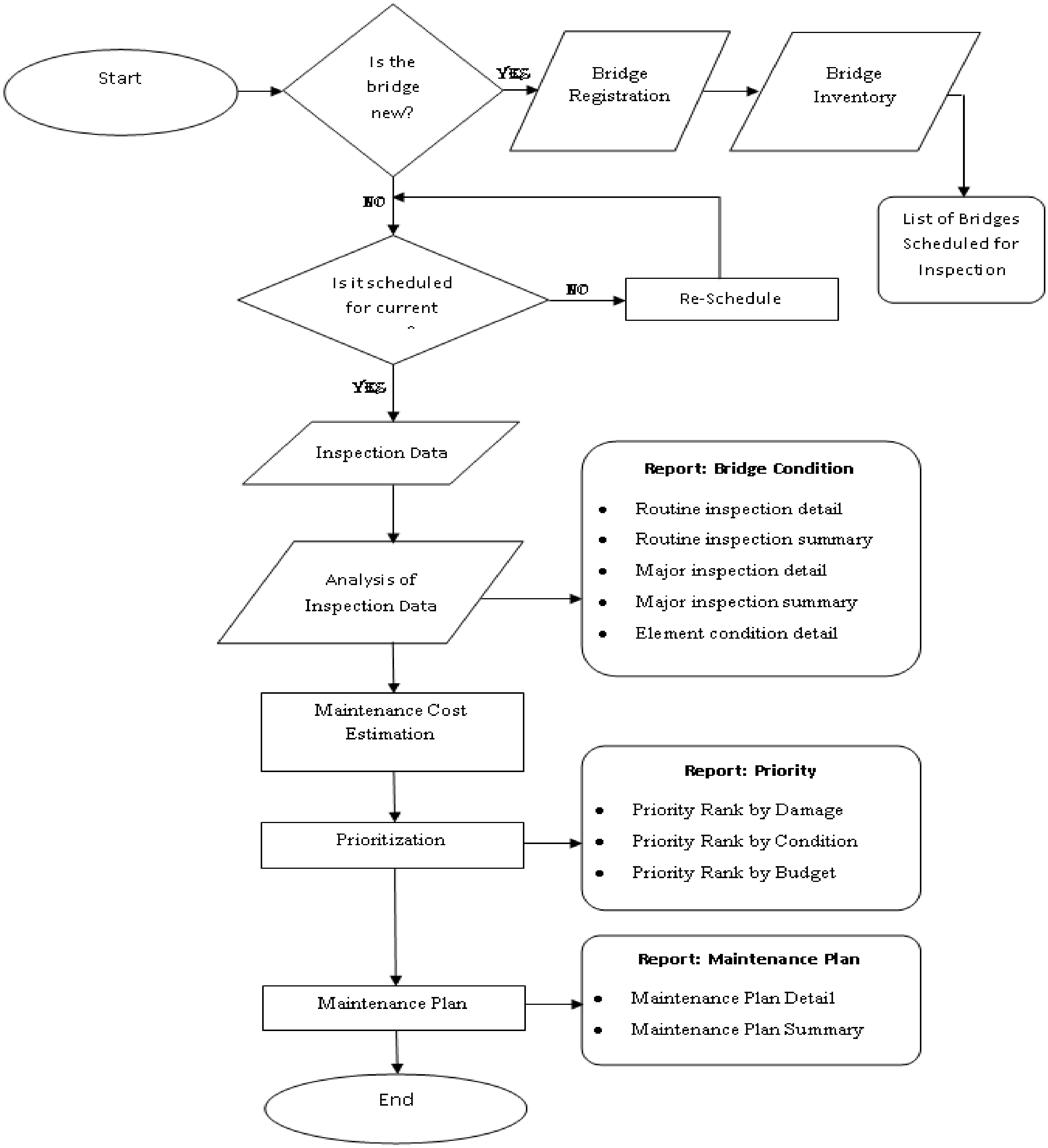

Figure 3-1: Computer Program Flow Chart

3.3. Description of Software Module

3.3.1. Setting Module

Setting Module is a section where we adjust permanent information that do not change frequently. In this module information about the route, sub route, bridge components, maintenance and repair costs, damage weight, etc can be adjusted.

A. Route Setting

Route setting is used to adjust information about the routes. Newly introduced routes will be registered, if there is any information change about the route it can be updated here and obsolete routes that are excluded from the network can also be deleted from here.

B. Sub Route Setting

Sub Route setting is used to adjust information about the sub routes. Sub routes found in newly introduced routes will be registered, if there is any information change about the sub route through time it can be updated here and obsolete sub routes that are excluded from the network can also be deleted from here.

C. Bridge Component Setting

Every bridge component is registered here before first use of these bridge components in the software. This setting helps us to use uniformity on bridge components names used in the software.

D. Maintenance and Repair Cost Setting

During scheduling one damaged bridge for maintenance or repair, it is very important to estimate how much money shall be allocated for this maintenance or repair. Maintenance and repair cost setting will solve our question by allowing us to set appropriate maintenance or repair cost for each damage type.

E. Damage weight setting

Elements of a bridge have different contribution to the overall bridge structure. Hence damage to these structures has different weight according to their importance in the overall bridge structure. Therefore damage weight of each elements will be introduced to the software is using this setting.

3.3.2. Data Entry Module

Data entry module is one section of the software which contains essential access points in order to feed all necessary information about the bridge. Within the data entry module bridge registration, bridge inventory, inspection data entries are included.

A. Bridge Registration

It is a process where a newly constructed Bridges or Bridges previously not incorporated in the System will be registered. In this process general information about the Bridge will be introduced.

B. Bridge Inventory

Once the Bridge is registered, the inventory process will take the greatest share in introducing detailed information of the bridge to the system.

Bridge Inventory is a repository of information about bridge assets. It is intended to provide accessible, consistent, and comprehensive information about the bridge. It is also intended to provide consistent information to support enterprise-level business processes, including capital programming and maintenance budgeting.

Inventory process is an approach in which asset detail information is registered. Bridge inventory is the first step in organizing and managing information of the asset. It is important to have this process to determine what should constitute the asset inventory, how the inventory should be organized, and the critical information that is needed to manage the items in the asset inventory over their lifecycle [2].

C. Inspection Schedule

Every bridge registered in the Bridge Management System will be scheduled for different types of inspections (i.e. Routine & Major).

Once the bridge is scheduled for inspection, Inspection Checker will check and list out bridges which have been scheduled for the current year.

D. Inspection

Bridges scheduled for current year inspection will be inspected by eligible Engineers. The Engineers will fill the necessary information about the bridge condition, site condition and any other information in the format prepare for Bridge Inspection.

The inspector measures and records the quantities of the bridge element in each condition state independently. The total quantity must be measured in the correct units for the elements. The units of measurement are square meters (deck, pier, and pile), linear meters (joints and railings) or each item (bearing pad, waterway, etc).

Inspection results will be collected and filled to the computer for further analysis. According to the evaluation criteria on Bridge Inspection Manual, the bridge will be rated and checked for severity of damage.

Each bridge will be inspected in accordance with its own requirements for condition inspection and monitoring that depend on its performance characteristics, the risks, and impacts of failure. Gathering condition and performance data can be costly, so having strategic approaches to gather the data that is most cost-effectively acquired and valuable is very important. This information is used to improve reliability through an agency's ability to predict failure and address the root causes and proactively plan for the investments required to maintain good performance on the most critical assets. It also is used to manage risk and determine needs to be addressed in asset management plans.

To do bridge inspection in the standardized manner can provide [2]:

- Basic information to assess the safety of bridges
- Data and information to all the activities of Bridge Management Cycle
- Information on any potential trouble spots
- Information on a consistent maintenance strategy
- Information on the effect of any changes in traffic loads
- Information on the behavior of repair and new strengthening techniques
- Hard facts on the results of new constructions and measures

3.3.3. Analysis Module

Data provided using data entry module will be processed according to stored procedures or users viewing preference of the information using analysis module. Enormous amount of data will be processed with in a second maintaining reliable and efficient processing speed.

3.3.4. Information (Reporting) Module

Information module is an important section of the software which provides ample information to the users according to their interest. It provides vast data within short period of time with reliable and efficient processing speed. This module in Combination with Analysis module displays information processed according to the user point of interest.

A. Ranking

All bridges will be ranked and ordered in a descending order of severity of Damage.

B. Prioritization

Every Bridge will be ranked according to the severity of damage & Maintenance cost.

C. Maintenance Plan

Budget allocated for maintenance and replacement of bridges in the current year will be considered.

D. Maintenance Cost Estimation

Each damage of a bridge will be checked according to the Maintenance Strategy. Thus the maintenance cost of each damage will be summed up to give the bridge maintenance cost.

E. Implementation

After the Bridges are scheduled for replacement or maintenance according to the maintenance plan. Implementation process of replacement or maintenance of bridges will commence.

F. Documentation

Every activity of a bridge maintenance activity necessary for the bridge history will be recorded and will be composed in order to give sensible information when required.

3.4. Software's Analysis Approach

For comparison purpose manual computation of one randomly chosen bridge is conducted and the result will be checked with the software output. The analysis approach for bridge condition computation, Prioritization, remedy treatment selection is presented with example below. This data is pseudo bridge data which is generated only and only for the purpose of testing the software.

General information about the Bridge

Route: Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle

Sub Route: Addis Ababa-Modjo

Bridge No: NR01-01-002

Bridge Name: Bishoftu

Km from Addis: 42.80

Owner: ERC

Consultant: SWEROAD

Contractor: CCCC

Construction Year: 1985

Bridge Type: Reinforced Box Girder

Bridge Length: 60

Primary Purpose: Rolling Stock Crossing

Secondary Purpose: Vehicle Crossing

River Name: NA

X-Cord: 498271

Y-Cord: 967137

Altitude: 1920

Input Data: Major Inspection Data is used to compute the physical condition of the bridge.

General Inspection Information

Inspection Date: 06/29/2016

Inspection No.: MJI-16-001

Maintainer: ERC Crew

QC Engineer: Dr. Kemal

Humidity 62

Team Leader: Eng. Behailu

Team Member: Bridge Team

Weather:Rainy

Temperature: 19

Sample detail inspection data generated to test a computer.

Table 3-1: Detail Inspection Sample Data

RIALWAY BRIDGE MAJOR INSPECTION SAMPLE DATA

Route Name:	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	**Maintainer:**	ERC Crew	**Weather:**	Rainy	**Date:**	
Sub Route Name:	Addis Ababa-Modjo	**QC Engineer:**	Dr. Kemal	**Temperature:**	19	6/29/2016	
Bridge No.:	NR01-01-002	**Team Leader:**	Eng. Behailu	**Humidity:**	62		
Inspection No.:	RNI-13-001	**Team Member:**	Bridge Team				

Track Structure

	VG	G	F	P	VP
Undulation	20	10	25	5	0
Wearing	10	15	5	20	0
Corrosion	10	10	5	30	5
Break Failure	20	5	5	5	25
Cracking	10	10	25	15	40
Spalling off	10	10	20	30	30
Rebar Exposure	10	20	15	45	10
Bolt Missing	50	130	50	150	20
Functional Failure	75	125	90	200	10
Break Down	75	50	200	50	25
Scorring	0	0	0	0	0
Cloagging	1	1	3	6	1

Super Structure

Deck

	VG	G	F	P	VP
Cracking	50	70	200	350	50
Concrete Peeloff	70	75	125	200	250
Rebar Exposure	70	75	125	200	250
Honey Comb	80	90	125	125	300
Void	90	90	340	150	50
Water Leakage	70	70	80	400	100
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0
Bearing					
Total Damage	5	10	16	5	0
Parts Missing	10	20	5	1	0
Anchor Damage	10	5	20	1	0
Bed Damage	10	10	15	1	0
Movement	5	25	5	1	0

Girder

	VG	G	F	P	VP
Cracking	64	90	256	448	62
Concrete Peeloff	90	96	160	256	318
Rebar Exposure	90	96	160	256	318
Honey Comb	102	115	160	160	383
Void	115	115	435	192	63
Water Leakage	90	90	102	511	127
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0

Sub Structure

Pier

	VG	G	F	P	VP
Cracking	45	200	15	10	0
Concrete Peeloff	40	210	10	10	0
Rebar Exposure	70	200	0	0	0
Honey Comb	80	190	0	0	0
Void	80	190	0	0	0
Water Leakage	80	190	0	0	0
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0
Displacement	0	2	0	0	0
Scour	0	2	0	0	0

Abutment and Wing wall

	VG	G	F	P	VP
Cracking	10	80	10	3	0
Concrete Peeloff	100	3	0	0	0
Rebar Exposure	103	0	0	0	0
Honey Comb	103	0	0	0	0
Void	40	60	3	0	0
Water Leakage	20	20	60	3	0
Displacement	50	53	0	0	0
Bulging	50	53	0	0	0
Foundation					
Displacement	134	0	0	0	0
Scour	14	20	100	0	0

Ancillaries

Parapet

	VG	G	F	P	VP
Cracking	5	20	30	60	5
Concrete Peeloff	35	0	20	65	0
Rebar Exposure	25	25	55	15	0
Corrosion	20	80	20	0	0
Paint Peeloff	10	10	100	0	0
Deformation	0	120	0	0	0
Missing	120	0	0	0	0

Expansion Joint

	VG	G	F	P	VP
Noise	1	3	0	0	0
Water Leakage	0	0	1	3	0
Deformation	0	4	0	0	0
Peel off	0	1	3	0	0
Missing	0	4	0	0	0

River Channel

	VG	G	F	P	VP
Channel Scour	0	0	0	0	0
Embankment Errosion	0	0	0	0	0
Slope Protection	0	0	0	0	0
Water Way Adequacy	0	0	0	0	0

Sing and Post

	VG	G	F	P	VP
Missing Sign	2	5	1	0	0
Missing Bolt	2	6	0	0	0
Missing Welds	3	5	0	0	0

Note:

- Very Good : Elements found in new condition and shows no deterioration or the defect has no significant effect on the element on strength and or serviceability.
- Good : Early signs of deterioration, minor defect/damage, no reduction in functionality of element.
- Fair : Moderate defect/ damage, Some delamination and /or spalls may be present. No reduction in functionality of element.
- Poor : Severe defect/ damage, significant loss of functionality and or element is close to failure / collapse.
- Very Poor : The element is non functional / failed

Element Damage Factor

Factor considered for each element damage type is presented in table below. These factors are pseudo damage factors generated for trial purpose of the software only. Each factor can be adjusted to real value whenever needed on the software.

Table 3-2:: Element Damage Factor

ABUTMENT		FOUNDATION		DECK	
DamageType	**Factor**	**DamageType**	**Factor**	**DamageType**	**Factor**
CRACKING	0.25	SETTLEMENT	0.6	CRACKING	0.2
CONC PEELOFF	0.1	SCOURING	0.4	CONC PEELOFF	0.075
REBAR EXPOSURE	0.15			HONEY COMB	0.05
HONEY COMB	0.05			VOID	0.05
VOID	0.05			WATER LEAK	0.1
WATER LEAK	0.15			CORROSION	0.15
DISPLACMENT	0.2			PAINT PEELOFF	0.05
BULGING	0.05			DEFORMATION	0.2
				REBAR EXPOSURE	0.125
	1.00		**1.00**		**1.00**
TRACK STRUCTURE		**GIRDER**		**PIER**	
DamageType	**Factor**	**DamageType**	**Factor**	**DamageType**	**Factor**
UNDULATION	0.15	CRACKING	0.2	CRACKING	0.145
WEARING	0.04	CONC PEELOFF	0.075	CONC PEELOFF	0.12
CORROSION	0.08	REBAR EXPOSURE	0.125	REBAR EXPOSURE	0.12
BRK FAILURE	0.07	HONEY COMB	0.05	HONEY COMB	0.025
CRACKING	0.15	VOID	0.05	VOID	0.025
SPALLING OFF	0.03	WATER LEAK	0.1	WATER LEAK	0.75
REBAR EXPOSURE	0.12	CORROSION	0.15	CORROSION	0.075
FUNC FAILURE	0.12	PAINT PEELOFF	0.05	PAINT PEELOFF	0.025
BRK DOWN	0.07	DEFORMATION	0.2	DEFORMATION	0.145
SCOURING	0.03			DISPLACMENT	0.145
CLOGGING	0.02			SCOURING	0.025
BOLT MISSING	0.12				
	1.00		**1.00**		**1.00**
PARAPHET		**BEARING**		**JOINT**	
DamageType	**Factor**	**DamageType**	**Factor**	**DamageType**	**Factor**
CRACKING	0.2	TOTAL DAMAGE	0.35	NOISE	0.15
CONC PEELOFF	0.1	PARTS MISSING	0.15	WATER LEAK	0.25
REBAR EXPOSURE	0.15	ANCHOR DAMAGE	0.35	DEFORMATION	0.25
CORROSION	0.15	BED DAMAGE	0.05	PEELOFF	0.1
PAINT PEELOFF	0.05	MOVEMENT	0.1	MISSING	0.25
DEFORMATION	0.2		**1.00**		**1.00**
MISSING	0.15	**RIVER**			
	1.00	**DamageType**	**Factor**		
SIGN		CHANNEL SCOUR	0.25		
DamageType	**Factor**	EMBANK EROSION	0.25		
SIGN MISSING	0.4	SLOPE PROTECT	0.25		
BOLT MISSING	0.3	WATER WAY	0.25		
LOOSE WELDING	0.3				
	1.00		**1.00**		

3.4.1. Bridge Condition Computation

Inspection data are presented in table below. Each table contains different damage types of an element with a measured value of damages under the corresponding severity of damage.

Table 3-3: Measured damage value of bridge elements

TRACK STRUCTURE	VG	G	F	P	VP
Undulation	20	10	25	5	0
Wearing	10	15	5	20	0
Corrosion	10	10	5	30	5
Break Failure	20	5	5	5	25
Cracking	10	10	25	15	40
Spalling off	10	10	20	30	30
Rebar Exposure	10	20	15	45	10
Bolt Missing	50	130	50	150	20
Functional Failure	75	125	90	200	10
Break Down	75	50	200	50	25
Scorring	0	0	0	0	0
Cloagging	1	1	3	6	1

DECK	VG	G	F	P	V
Cracking	50	70	200	350	50
Concrete Peeloff	70	75	125	200	250
Rebar Exposure	70	75	125	200	250
Honey Comb	80	90	125	125	300
Void	90	90	340	150	50
Water Leakage	70	70	80	400	100
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0

GIRDER	VG	G	F	P	VP
Cracking	64	90	256	448	62
Concrete Peeloff	90	96	160	256	318
Rebar Exposure	90	96	160	256	318
Honey Comb	102	115	160	160	383
Void	115	115	435	192	63
Water Leakage	90	90	102	511	127
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0

BEARING	VG	G	F	P	VP
Total Damage	5	10	16	5	0
Parts Missing	10	20	5	1	0
Anchor Damage	10	5	20	1	0
Bed Damage	10	10	15	1	0
Movement	5	25	5	1	0

PIER	VG	G	F	P	VP
Cracking	45	200	15	10	0
Concrete Peeloff	40	210	10	10	0
Rebar Exposure	70	200	0	0	0
Honey Comb	80	190	0	0	0
Void	80	190	0	0	0
Water Leakage	80	190	0	0	0
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0
Displacement	0	2	0	0	0
Scour	0	2	0	0	0

FOUNDATION	VG	G	F	P	VP
Displacement	134	0	0	0	0
Scour	14	20	100	0	0

ABUTMENT & WINGWALL	VG	G	F	P	VP
Cracking	10	80	10	3	0
Concrete Peeloff	100	3	0	0	0
Rebar Exposure	103	0	0	0	0
Honey Comb	103	0	0	0	0
Void	40	60	3	0	0
Water Leakage	20	20	60	3	0
Displacement	50	53	0	0	0
Bulging	50	53	0	0	0

PARAPET	VG	G	F	P	VP
Cracking	5	20	30	60	5
Concrete Peeloff	35	0	20	65	0
Rebar Exposure	25	25	55	15	0
Corrosion	20	80	20	0	0
Paint Peeloff	10	10	100	0	0
Deformation	0	120	0	0	0
Missing	120	0	0	0	0

EXPANSION JOINT	VG	G	F	P	VP
Noise	1	3	0	0	0
Water Leakage	0	0	1	3	0
Deformation	0	4	0	0	0
Peel off	0	1	3	0	0
Missing	0	4	0	0	0

SIGN & POSTS	VG	G	F	P	VP
Missing Sign	2	5	1	0	0
Missing Bolt	2	6	0	0	0
Missing Welds	3	5	0	0	0

RIVER CHANNERL	VG	G	F	P	VP
Channel Scour	0	0	0	0	0
Embankment Errosion	0	0	0	0	0
Slope Protection	0	0	0	0	0
Water Way Adequacy	0	0	0	0	0

Severity of damage represented by VG, G, F, P & VP, have the following values.

- VG, quantity of bridge found in a very good condition, = 1
- G, quantity of bridge found in a good condition, = 2
- F, quantity of bridge found in a fair condition, = 3
- P, quantity of bridge found in a poor condition, = 4
- VP, quantity of bridge found in a very poor condition, =5

Here under, one sample of each computation is done. The result of the rest damages that have similar computation technique will be shown with value only.

Condition of damage computation

Sample from Element: Track Structure,

Damage Type: Undulation

$$CI = \frac{((1x20)+(2x10)+(3x25)+(4x5)+(5x0)}{60} = 2.25$$

Similarly, values for each of damages listed under track structure are 2.70, 3.17, 3.33, 3.65, 3.60, 3.25, 2.90, 2.89, 2.75, 0.00, and 3.42. From values of damage conditions of an element, one can compute the element condition index by multiplying each value with the corresponding damage factors,

Referring factors described in table 2-5 for structural significance factor and table2-6 for material vulnerability, Overall Structural Importance of elements can be computed. Taking track structure as an example SI is computed as follows

- Structural Significance Factor of Track Structure = 4
- Material Vulnerability Factor of Steel = 1
- Material Vulnerability Factor of Pre-stressed Concrete = 4
- Material Vulnerability Factor of Other Materials = 3

$$S.I = \frac{\begin{matrix}(4\ x\ 1\ x\ 2.25x0.15)+(4x1x2.7x0.04)+(4x1x3.17x0.08)+(4x1x3.33x0.07)+(4x4x3.65x0.15)\\ +(4x4x3.6x0.03)+(4x4x3.25x0.12)+(4x3x2.9x0.12)+(4x3x2.89x0.12)+(4x3x2.75x0.07)\\ +(4x3x0x0.03)+(4x3x3.42x0.02)\end{matrix}}{16} = 1.50$$

Referring table 2-7, For 1 <S.I $\leq$ 2, Element Condition Index, CI = 2

Similarly, the overall CI values for Deck, Girder, Pier, Bearing, Abutment & Wing wall, Foundation, Parapet, Expansion joint, River channel and Sign & post are listed as follows 2, 2, 2, 1, 1, 1, 1, 1, 1, 1 respectively.

Thus the condition of the bridge will be the average of the elements condition or the condition of the most damaged element found in critical condition.

$$BCI_{ave} = \frac{\sum(ECI)}{n} = \frac{(2+2+2+2+1+1+1+1+1+1+1)}{11} = 1.364$$

$BCI_{critical} = max\{ECI\ of\ elements = 2$, Track Structure

Computation of Bridge Condition Score

$BCS_{ave} = 100 – 2\{(BCI_{ave})^{2} + (6.5 \times BCI_{ave}) – 7.5)\}$

$= 100 – 2 \{(1.364^{2}) + (6.5\ x\ 1.364) -7.5)$

$= 93.54$

$BCS_{cri} = 100 – 2\{(BCI_{cri})^{2} + (6.5 \times BCI_{cri}) – 7.5)\}$

$= 100 – 2 \{(2^{2}) + (6.5\ x\ 2) -7.5)$

$= 81$

Score Range	Bridge Condition
100 – 95	Very Good
94 – 85	Good
84 – 65	Fair
64 – 40	Poor
39 - 0	Very Poor

Table 3-4: Bridge score and condition

Referring the table above the bridge’s average condition is in a good condition. But considering the critical element the bridge is in fair condition.

3.4.2. Priority Analysis

After knowing the bridge condition, one can prioritize bridges by damage, by condition or by budget.

By Damage

Bridges prioritized by damage can be computed by bridge’s average condition or critical condition. In each case bridges will be given a rank by their condition score.

By Condition

Priority by condition will be affected by some factors. Each factor with the pseudo values assumed for testing the software only are presented as follows:

Bridge condition = 1.364 (93.54) taking average bridge condition (bridge score)

Rail Class: Class I,   i.e. FC = 5

Environment Effect: Very Low, i.e. ECF = 1

Historical Value: Very Low, i.e. HF = 1

Client's Interest: Very Low, i.e. CIF = 1

Inspector Recommendation: Maintenance, i.e. IR = 2

Traffic Volume = 2000000 ton annual, SPF = 5

Strategic Importance, bridge length = 60, i.e. SEF = 3

Age = 31 Years, i.e. AF = 3

Table 3-5: Factors for Priority Ranking

Condition	Factor
Physical Condition	40
Inspector Recommendation	23
Age	7
Rail Class	4
Serviceability	6
Strategic Importance	8
Environmental Effect	3
Client Interest	5
Historical Factor	4

Thus, referring to the above table each condition will be multiplied with the corresponding factor and summed to give the priority rank Index.

$$P_r = \frac{\sum(Wi \ x \ Fi)}{45} \quad = \frac{(1.364x40)+(2x23)+(3x7)+(5x4)+(5x6)+(3x8)+(1x3)+(1x5)+(1x4)}{45} = 4.61$$

This priority rank value will be checked with other bridges rank and the highest will be rank 1 and goes on in a decreasing order.

3.4.3. Remedial Treatment selection

Once the priority rank is computed, remedy treatment will be selected according to the bridge condition. Referring to the figure2-2, recommended remedy action for bridge as a whole with condition index BCI = 1.364 is do nothing & monitor or routine inspection.

But considering bridge element condition part by part the recommended remedy action will be as follows:

Similarly, the overall CI values for Deck, Girder, Pier, Bearing, Abutment & Wing wall, Foundation, Parapet, Expansion joint, River channel and Sign & post are listed as follows 2, 2, 2, 1, 1, 1, 1, 1, 1, 1 respectively.

Table 3-6: Recommended Remedy Action

Bridge Element	Element Condition	Recommended Remedy Action
Track Structure	2	Maintenance
Deck	2	Maintenance
Girder	2	Maintenance
Pier	2	Maintenance
Bearing	1	Do Nothing & Monitor
Abutment & Wing Wall	1	Do Nothing & Monitor
Foundation	1	Do Nothing & Monitor
Parapet	1	Do Nothing & Monitor
Expansion Joint	1	Do Nothing & Monitor
River Channel	1	Do Nothing & Monitor
Sign & Posts	1	Do Nothing & Monitor

4. Application

Any organization responsible for asset management especially bridge administration is expected to monitor potentially ruthless hazards due to any structural failure or natural disaster. Nowadays Decision Support Systems are widely used to assist decision makers across an extensive spectrum of unstructured decision environments. Thus supporting this system with the computer aided technology will enhance the efficiency and reliability of the decision making process.

As a result this computer program is developed to be applicable on and support railway bridge asset managenent. Thus the program provides several procedures in order to achieve better decision-making. The program is based on requirements-driven methodology for bridge monitoring and maintenance which has the ability to process the bridge condition inspections and find the best remedial treatment with the aim of maintaining a bridge within acceptable limits of safety, serviceability and sustainability.

4.1. How to Apply the Software

Generally to use this computer program, one should install the application on a computer. This software works on Microsoft windows XP/7/8. Thus when finished the installation following the instruction on the installation wizard, the software can be accessed from the programs list. But installing the software only do not assure the proper function of the software, jointly the SQL server 2008 application should be installed where the software can use it as a database and access the data during operation.

Once installed and ready to use one can open the computer user interface from programs list. This action will launch the software and the Home Page of the software shown on the figure below will appear.

Figure 4-1: Home Page of Computer Program.

The Home Page is the first window the users interact with. Here users can access the software by using the seven main menus provided at the top most part of the window.

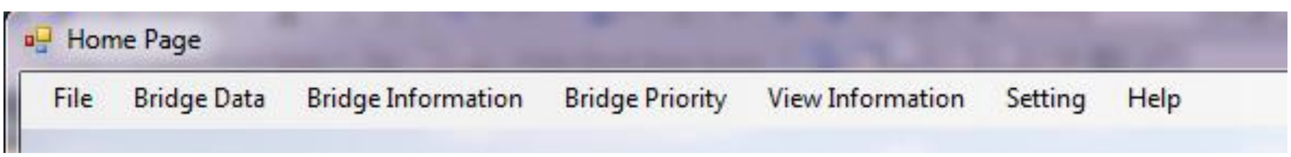

Figure 4-2: Main Menus of the Computer Program

The main menus showed above will be discussed here under according to their precedence of order of position on the menu bar.

A. File Menu

This menu helps to activate the software, create employee access grant, create and change password and finally to Exit when done working with.

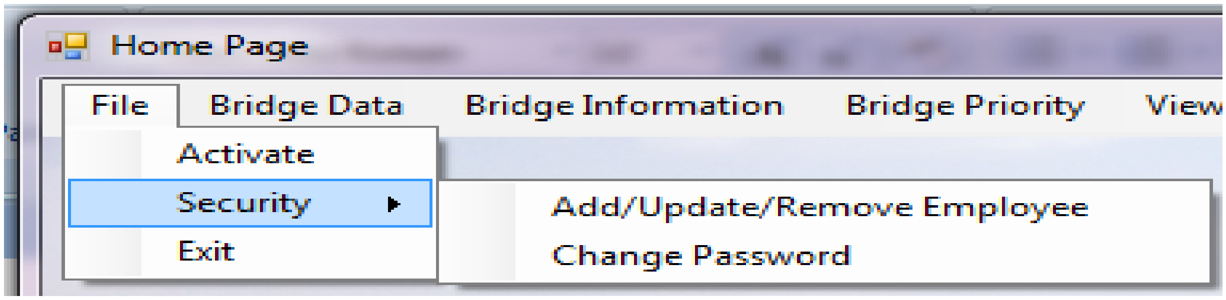

Figure 4-3: File Menu

B. Bridge Data

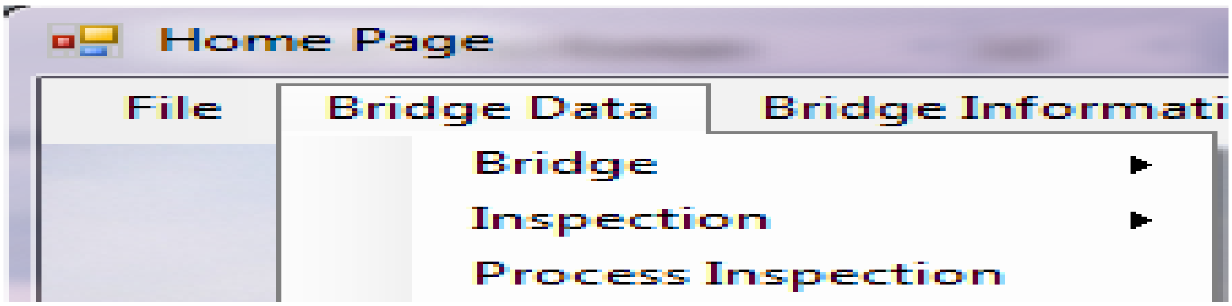

Figure 4-4: Bridge Data

Bridge data contains menus for data input and data analysis; like Bridge Registration, Bridge Inventory, Initial Inspections, Routine Inspection, Major Inspection and Process Inspection.

Bridge Registration: helps to input general information about a bridge to be introduced to the system.

Bridge Inventory: follows bridge registration. Once the bridge is introduced to the system detail information about the type of bridge and its components & physical dimensions of the bridge will be inputted.

Inspection data: after initial, routine or major inspection the collected information on the bridge physical condition will be inserted on initial inspection, routine inspection and major inspection forms respectively.

Process Inspection: once the inspection data are feed in to the program, the inspection results will be processed here. It will conduct the analysis according to the pre set analysis procedure.

C. Bridge Information

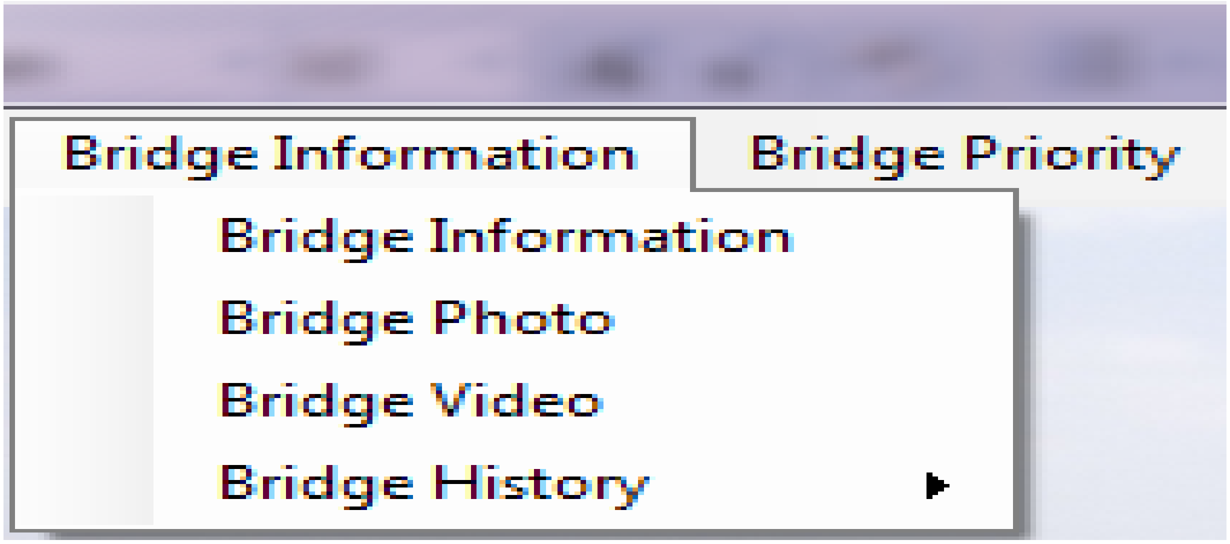

Figure 4-5: Bridge Information

Here information about bridges registered into the system is displayed.

Bridge Information: contains lists of bridge registered in the software and an access to view additional information; like photo, video or bridge history.

Bridge Photo: displays photographic information of bridges in the system.

Bridge Video: displays video of bridges in the system.

Bridge History: displays documented written information about the bridge.

D. Bridge Priority

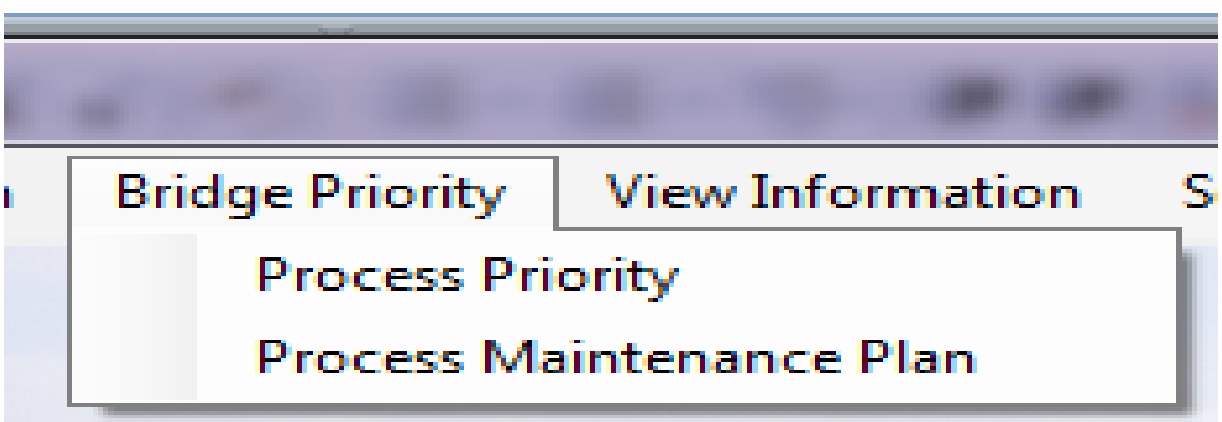

Figure 4-6: Bridge Priority

Within this menu analysis related to ranking bridge by their priority and preparation of maintenance plan according to the analyzed priority is conducted.

E. View Information

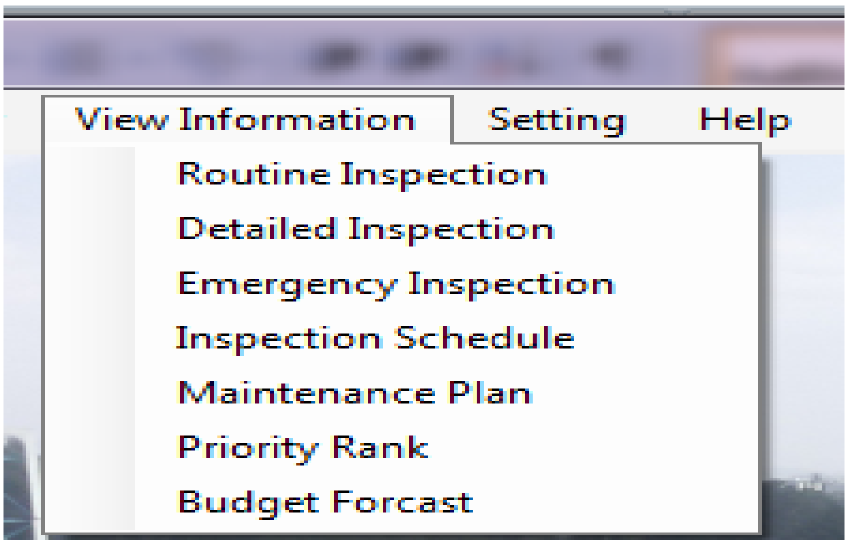

Figure 4-7: Bridge Information

Here all information about following the analysis result will be shown.

Routine Inspection: shows information about the bridge elements condition after routine inspection is conducted and analyzed.

Detailed Inspection: shows information about the bridge elements condition after major inspection is conducted and analyzed.

Emergency Inspection: shows reports on the bridge condition inspected urgently without schedule.

Inspection Schedule: shows yearly schedule of bridges for inspection

Maintenance Plan: shows the maintenance type and cost and order of bridges according to their priority.

Priority Rank: shows the priority order of bridges according to their damage, budget requirement or condition evaluation for maintenance.

Budget Forecast: shows the forecasted amount of money required to conduct maintenance or rehabilitation or replacement as per the bridge current physical condition.

F. Setting Menu

This menu has a very important role in setting different types of occasionally and frequently changing information: like setting a route, sub route, bridge component, maintenance and replacement cost and percentage/weights of damages.

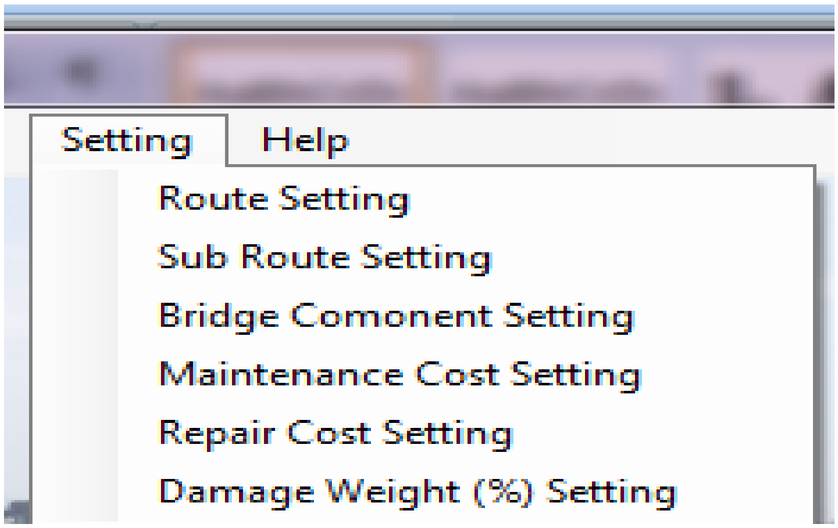

Figure 4-8: Setting Menu

Route Setting: helps to register the routes of railway line incorporated in the bridge asset management system. Thus before using the program for the first time it is mandatory to register available routes. The information in here is occasionally changing, but whenever the route information is changed one can update here.

Sub Route Setting: helps to register the routes of sub routes divided with in one route. In order to set sub route, it is mandatory to set the route first. Likewise the route information in here is also occasionally changing, but whenever there is a change in sub route information we can update here.

Bridge Component Setting: is very important in setting the different types and components of a bridge which are available in the system. i.e types of Bridge, types of bearing, types of abutment, types of deck etc.

Bridge Maintenance Cost setting and Bridge Replacement Cost Setting: are places where users allowed to set a maintenance and replacement unit rate cost for each type of damage on the elements of a bridge. These unit rate costs are very important in estimating the total damage repair or replacement cost of a bridge after condition survey.

Damage Weight Setting: helps to set different types of weighing criteria by giving appropriate percentage according to their significance. The setting includes; Age factor setting, Serviceability factor setting and Strategic Importance factor setting. Even though the information in here is occasionally changing, whenever necessary the user can update here.

G. Help

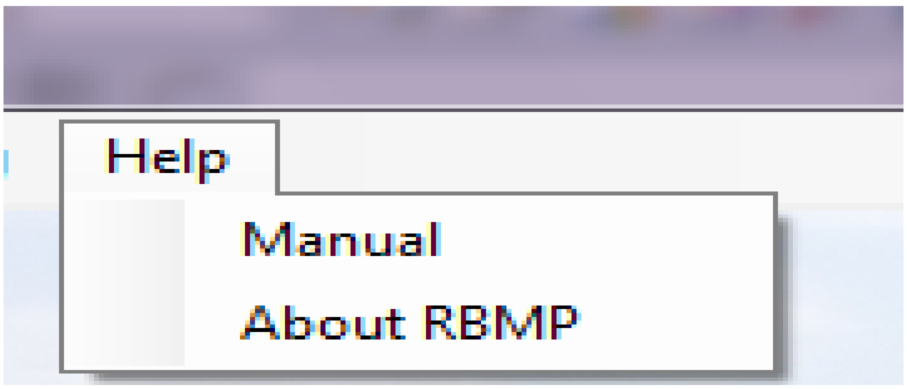

Figure 4-9: Help Menu

This menu provides assistance for the troubleshooting by giving information on how the program works and how to solve the specific error. Whenever the bridge maintenance manual is uploaded the users will access it to refer the required information without searching for the manual other place. In addition it contains information about the software version, programmed year, programmers contact address and any other information regarding the software on About RBMP.

4.2. Input Data Sample

Table 4-1: Sample Registration Data Format

RIALWAY BRIDGE REGISTRATION SAMPLE DATA

	Route	Sub Route	Bridge No	Bridge Name	Km from Addis	Owner	Consultant	Contractor	Construction Year	Bridge Type	Bridge Length	Primary Purpose	Secondary Purpose	River Name	X-Cord	Y-Cord	Altitude
1	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	Addis Ababa-Modjo	A2-11-010	Bishoftu	42.80	ERC	SWEROAD	CCCC	1985	Reinforced Box Girder	60	Rolling Stock Crossing	Vehicle Crossing	NA	498271	967137	1920
2	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	Modjo-Awash	A2-11-011	Beseka	205.90	ERC	SWEROAD	CREC	1960	Reinforced Concrete Arch	75	Rolling Stock Crossing	River Crossing	Beseka	595162	985901	947
3	Awash-Kombolcha-Mekelle-Shire	Awash-Kombolcha	A2-11-012	Ataye	268.00	ERC	Molinari Rail	YAPI MERKEZ	2010	Steel Girder	80	Rolling Stock Crossing	River Crossing	Ataye	610371	1078532	890
4	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	Addis Ababa-Modjo	A2-11-013	Legu Bridg	15.60	ERC	SWEROAD	CCCC	2005	Prestressed Box Girder	40	Rolling Stock Crossing	Vehicle Crossing	NA	470834	991085	2300
5	Modjo-Shashemene-Arbaminch-Konso-Moyale	Modjo-Shashemene	A2-11-014	Ziway	208.50	ERC	SWEROAD	CREC	2010	Prestressed Box Girder	150	Rolling Stock Crossing	River Crossing	Ziway	475702	893781	1643
6	Awash-Kombolcha-Mekelle-Shire	Kombolcha-Mekelle	A2-11-015	Weldiya	822.13	ERC	Molinari Rail	YAPI MERKEZ	1970	Steel Truss	30	Vehicle Crossing	Rolling stock Crossing	NA	564643	1310834	2112
7	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	Awash-Dire Dawa	A2-11-016	Unknown	429.00	ERC	SWEROAD	CCCC	1995	Precast Box Girder	40	Vehicle Crossing	Rolling stock Crossing	NA	635105	1002098	750
8	Modjo-Shashemene-Arbaminch-Konso-Moyale	Modjo-Shashemene	A2-11-017	Arbaminch	257.00	ERC	SWEROAD	CREC	1990	Precast Box Girder	40	Pedisterian Crossing	Rolling stock Crossing	NA	341408	673355	1285
9	Awash-Kombolcha-Mekelle-Shire	Awash-Kombolcha	A2-11-018	Unknown	325.40	ERC	Molinari Rail	YAPI MERKEZ	2005	Steel Girder	200	Rolling Stock Crossing	River Crossing	NA	586966	1201400	1424
10	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	Dire Dawa-Dewanle	A2-11-019	Genfel	620.00	ERC	SWEROAD	CCCC	2000	Prestressed Deck Girder	20	Vehicle Crossing	Rolling stock Crossing	NA	635105	1002098	1275
11	Awash-Kombolcha-Mekelle-Shire	Kombolcha-Mekelle	A2-11-020	Unknown	453.00	ERC	Molinari Rail	YAPI MERKEZ	2002	Prestressed Deck Girder	10	Pedisterian Crossing	Rolling stock Crossing	NA	559626	1424021	2540

Table 4-2: Sample Inventory Data Format

RIALWAY BRIDGE INVENTORY SAMPLE DATA

Route Name: Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle
Sub Route Name: Addis Ababa-Modjo
Bridge No.: NR01-01-002
Bridge Type: Reinforced Deck Girder

Client: ERC
Consultant: SWEROAD
Contractor: CCCC

General Information		Track Structure Informatioin		Super Structure Information		Sub Structure Information		
Construction Cost	900000.00	Track Type	Slab Track	Span Length (m)	20	Abutment Type	Masonry	Height of Pier (m)
Bridge Length (m)	60	Ballast Thickness (cm)	0	Total Span (m)	60	Abutment Height (m)	5.4	Pier Foundation Type
Bridge Width (m)	12	No of Track	2	Number of Box / Girder	3	Abutment Width (m)	12	Pier Foundation Size (mxm)
Number of span	3	Track Gauge	Standard Gauge	Depth of Box/ Girder (m)	2	Wing wall Length (m)	3.51	No. of Pier Piles
Load Capacity (ton)	70	Track c/c Spacing (m)	5	Width/ Spacing of Girder (m)	4	Soil Type		Pier Pile Depth (m)
River Width (m)	0	Track Guard Rail	Yes	Carriage way width (m)	9	Foundation Type	RC Pile	Pier Bearing Type
CWL (m)	0	Rail Type	U71Mn	Side walk width (m)	3	Foundation Size (mxm)	12 X 3.51	
HWL (m)	0	Rail Joint Fastner	Steel	Expansion Joint Type	Rubber	No of Piles	9	
Piles Depth (m)	30	Rail Expansion Gap (mm)	0.5	Guard Rail Type	RC Steel Composite	Depth of Piles (m)	30	
		Sleeper Type	PC Sleeper			Abutment Bearing Type	Bearing Plate	
		Sleeper Spacing (cm)	60			No. of Piers	2	
		Middle Joint Faster Type	Steel			Type of Pier	RC Column	

Span Composition

Span No.	Type	Length(m)	Width(m)	Depth(m)
1	Reinforced Deck Girder	20	4	2
2	Reinforced Deck Girder	20	4	2
3	Reinforced Deck Girder	20	4	2

Table 4-3: Sample Routine Inspection Data Format

RIALWAY BRIDGE ROUTINE INSPECTION SAMPLE DATA

Route Name:	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	**Maintainer:**	ERC Crew	**Weather:**	Rainy	**Date:**
Sub Route Name:	Addis Ababa-Modjo	**QC Engineer:**	Dr. Kemal	**Temperature:**	19	6/29/2016
Bridge No.:	NR01-01-002	**Team Leader:**	Eng. Behailu	**Humidity:**	62	
Inspection No.:	RNI-13-001	**Team Member:**	Bridge Team			

Track Structure		**Super Structure**				**Sub Structure**			
		Deck		**Girder**		**Pier**		**Abutment and Wing wall**	
Undulation	Fair	**Cracking**	Poor	**Cracking**	Poor	**Cracking**	Good	**Cracking**	Good
Wearing	Poor	**Concrete Peeloff**	Very Poor	**Concrete Peeloff**	Very Poor	**Concrete Peeloff**	Good	**Concrete Peeloff**	Very Good
Corrosion	Poor	**Rebar Exposure**	Poor	**Rebar Exposure**	Poor	**Rebar Exposure**	Good	**Rebar Exposure**	Very Good
Break Failure	Very Poor	**Honey Comb**	Very Poor	**Honey Comb**	Very Poor	**Honey Comb**	Good	**Honey Comb**	Very Good
Cracking	Very Poor	**Void**	Fair	**Void**	Fair	**Void**	Good	**Void**	Good
Spalling off	Very Poor	**Water Leakage**	Very Poor	**Water Leakage**	Very Poor	**Water Leakage**	Good	**Water Leakage**	Fair
Rebar Exposure	Poor	**Corrosion**	NA	**Corrosion**	NA	**Corrosion**	NA	**Displacement**	Good
Bolt Missing	Poor	**Paint Peeloff**	NA	**Paint Peeloff**	NA	**Paint Peeloff**	NA	**Bulging**	Good
Functional Failure	Poor	**Deformation**	NA	**Deformation**	NA	**Deformation**	NA	**Foundation**	
Break Down	Fair	**Bearing**				**Displacement**	Good	**Displacement**	Very Good
Scorring	NA	**Total Damage**	Fair			**Scour**	Good	**Scour**	Fair
Cloagging	Very Poor	**Parts Missing**	Good						
		Anchor Damage	Fair						
		Bed Damage	Fair						
		Movement	Good						

Ancillaries							
Parapet		**Expansion Joint**		**River Channel**		**Sing and Post**	
Cracking	Poor	**Noise**	Good	**Channel Scour**	NA	**Missing Sign**	Good
Concrete Peeloff	Poor	**Water Leakage**	Poor	**Embankment Errosion**	NA	**Missing Bolt**	Good
Rebar Exposure	Fair	**Deformation**	Good	**Slope Protection**	NA	**Missing Welds**	Good
Corrosion	Good	**Peel off**	Fair	**Water Way Adequacy**	NA		
Paint Peeloff	Fair	**Missing**	Good				
Deformation	Good						
Missing	very Good						

Note:

Very Good :	Elements found in new condition and shows no deterioration or the defect has no significant effect on the element on strength and or serviceability.
Good :	Early signs of deterioration, minor defect/damage, no reduction in functionality of element.
Fair :	Moderate defect/ damage, Some delamination and /or spalls may be present. No reduction in functionality of element.
Poor :	Severe defect/ damage, significant loss of functionality and or element is close to failure / collapse.
Very Poor :	The element is non functional / failed

Table 4-4: Sample Detail Inspection Data Format

RIALWAY BRIDGE MAJOR INSPECTION SAMPLE DATA

Route Name:	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	**Maintainer:**	ERC Crew	**Weather:**	Rainy	**Date:**	
Sub Route Name:	Addis Ababa-Modjo	**QC Engineer:**	Dr. Kemal	**Temperature:**	19	6/29/2016	
Bridge No.:	NR01-01-002	**Team Leader:**	Eng. Behailu	**Humidity:**	62		
Inspection No.:	RNI-13-001	**Team Member:**	Bridge Team				

Track Structure

	VG	G	F	P	VP
Undulation	20	10	25	5	0
Wearing	10	15	5	20	0
Corrosion	10	10	5	30	5
Break Failure	20	5	5	5	25
Cracking	10	10	25	15	40
Spalling off	10	10	20	30	30
Rebar Exposure	10	20	15	45	10
Bolt Missing	50	130	50	150	20
Functional Failure	75	125	90	200	10
Break Down	75	50	200	50	25
Scorring	0	0	0	0	0
Cloagging	1	1	3	6	1

Super Structure

Deck

	VG	G	F	P	VP
Cracking	50	70	200	350	50
Concrete Peeloff	70	75	125	200	250
Rebar Exposure	70	75	125	200	250
Honey Comb	80	90	125	125	300
Void	90	90	340	150	50
Water Leakage	70	70	80	400	100
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0

Bearing

	VG	G	F	P	VP
Total Damage	5	10	16	5	0
Parts Missing	10	20	5	1	0
Anchor Damage	10	5	20	1	0
Bed Damage	10	10	15	1	0
Movement	5	25	5	1	0

Girder

	VG	G	F	P	VP
Cracking	64	90	256	448	62
Concrete Peeloff	90	96	160	256	318
Rebar Exposure	90	96	160	256	318
Honey Comb	102	115	160	160	383
Void	115	115	435	192	63
Water Leakage	90	90	102	511	127
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0

Sub Structure

Pier

	VG	G	F	P	VP
Cracking	45	200	15	10	0
Concrete Peeloff	40	210	10	10	0
Rebar Exposure	70	200	0	0	0
Honey Comb	80	190	0	0	0
Void	80	190	0	0	0
Water Leakage	80	190	0	0	0
Corrosion	0	0	0	0	0
Paint Peeloff	0	0	0	0	0
Deformation	0	0	0	0	0
Displacement	0	2	0	0	0
Scour	0	2	0	0	0

Abutment and Wing wall

	VG	G	F	P	VP
Cracking	10	80	10	3	0
Concrete Peeloff	100	3	0	0	0
Rebar Exposure	103	0	0	0	0
Honey Comb	103	0	0	0	0
Void	40	60	3	0	0
Water Leakage	20	20	60	3	0
Displacement	50	53	0	0	0
Bulging	50	53	0	0	0

Foundation

	VG	G	F	P	VP
Displacement	134	0	0	0	0
Scour	14	20	100	0	0

Ancillaries

Parapet

	VG	G	F	P	VP
Cracking	5	20	30	60	5
Concrete Peeloff	35	0	20	65	0
Rebar Exposure	25	25	55	15	0
Corrosion	20	80	20	0	0
Paint Peeloff	10	10	100	0	0
Deformation	0	120	0	0	0
Missing	120	0	0	0	0

Expansion Joint

	VG	G	F	P	VP
Noise	1	3	0	0	0
Water Leakage	0	0	1	3	0
Deformation	0	4	0	0	0
Peel off	0	1	3	0	0
Missing	0	4	0	0	0

River Channel

	VG	G	F	P	VP
Channel Scour	0	0	0	0	0
Embankment Errosion	0	0	0	0	0
Slope Protection	0	0	0	0	0
Water Way Adequacy	0	0	0	0	0

Sing and Post

	VG	G	F	P	VP
Missing Sign	2	5	1	0	0
Missing Bolt	2	6	0	0	0
Missing Welds	3	5	0	0	0

Note:

Very Good :	Elements found in new condition and shows no deterioration or the defect has no significant effect on the element on strength and or serviceability.
Good :	Early signs of deterioration, minor defect/damage, no reduction in functionality of element.
Fair :	Moderate defect/ damage, Some delamination and /or spalls may be present. No reduction in functionality of element.
Poor :	Severe defect/ damage, significant loss of functionality and or element is close to failure / collapse.
Very Poor :	The element is non functional / failed

Table 4-5: Sample Budget Allocation Data Format

RIALWAY BRIDGE BUDGET ALLOCATION SAMPLE DATA

Budget Year 2016

ACTIVITY TYPE	BUDGET ALLOCATED
INSPECTION	$63,000,000.00
MAINTENANCE	$19,000,000.00
REHABILITATION	$15,000,000.00
REPLACEMENT	$50,000,000.00
TOATAL	**$147,000,000.00**

4.3. Input Data

Input data's which are very basic for proper function of the software and are classified in to three major parts,

i) **Frequently changing**: these are data including Routine Inspection data, Major Inspection data, and Yearly budget. Information on routine or major inspection and yearly budget are continuously changing every year according to the inspection schedule and the budget allocated for bridge asset management every year.

ii) **Occasionally changing**: are data which the information is updated after longer period of time; such as damage weight, component weight, material vulnerability factor and element significant factor. These data are changing when the given values are altered after the result of a research is conducted on these factors or the knowledge developed through experience.

iii) **Permanent data**: these are data never changing as long as the bridge exists or unless a major rehabilitation or replacement of the bridge is done. data like Bridge registration and inventory data are considered permanent because information about a bridge doesn't change from time to time unless it is demolished or rehabilitated.

A. Bridge Registration

Bridge registration will allow recording of the bridge with basic information which is complete enough to describe the bridge. Information like Bridge number, Bridge Name, Route, Sub route, Client, Consultant, Contractor, Bridge type, Purpose, X and Y Coordinates and Distance are the data requires to be filled during registration.

Route: route names recorded during route setting will be available hear. From the least one should choose the appropriate route of a railway line which the bridge exist.

Sub Route: sub route names shall be recorded first in sub route setting. Thus when we choose the route available sub routes will be available for the user to choose.

Bridge No.: any bridge should have its own unique number to be identified. The number shall be set by the authorized bridge management team and inserted here. It should have maximum of 15 characters.

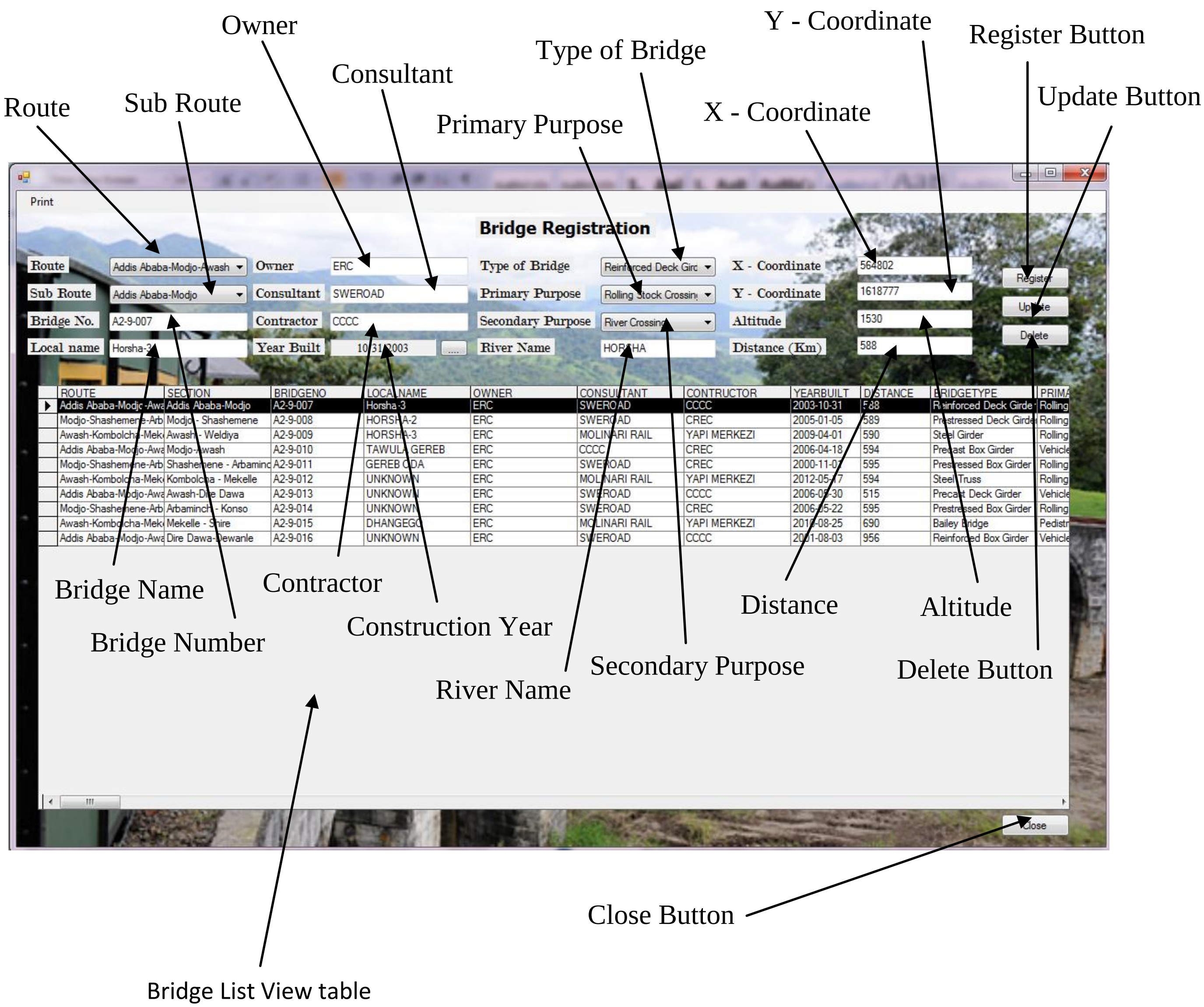

Figure 4-10: Bridge Registration window

Local Name: a bridge could have name known by the majority of users and people, though it is not given by the authorized body. Thus for better understanding of the bridge, this information could be used as bridge identification.

Owner: this box records the name of the client/owner for further documentation.

Consultant: this box records the name of the consultant during construction for further documentation.

Contractor: this box records the name of the contractor for further documentation.

Construction Year: from the calendar provided adjacent to the box year when the bridge is built should be chosen.

Type of Bridge: from list of available type of bridge registered suitable bridge type should be chosen from here.

Primary Purpose: indicates the purpose of the bridge serving on top of it. It may be for rolling stock crossing, vehicle crossing or pedestrian crossing, whichever is the reason it should be chosen from here.

Secondary Purpose: indicates the purpose of the bridge serving underneath it. It may be for river crossing, rolling stock crossing, vehicle crossing or pedestrian crossing, whichever is the reason it should be chosen from here.

River Name: whenever the secondary purpose is river crossing, the name of the river should be inserted here. Otherwise 'NA' should be inserted in order to indicate bridge name not available.

X & Y – coordinate: the easting and northing coordinate of the bridge referring the position should be inserted in the box provided for X-coordinate & Y-coordinate.

Altitude: is a box provided to allow the insertion altitude (amsl) of a bridge.

Distance (KM): is the distance in kilometer of a bridge from a centralized measuring station. In this for the national railway line we can take sebeta station as starting station to measure the distance.

Register: records the information provided about the bridge to the system.

Bridge List View Table: displays a list of bridge information registered in the system.

Update: due to mistake or any other reason whenever the data about a bridge is going to be changed. This button orders the procedure to update the data. But first the user should select a specific bridge to be updated from bridge list view table.

Delete: when a bridge serves its design life and demolished it will be removed from the system only leaving its past history as a document. This button orders the procedure to delete the data. But first the user should select a specific bridge to be deleted from bridge list view table.

Close: when done working with bridge registration, this close button returns the window to the home page of the computer program.

B. Bridge Inventory

Detail information regarding physical dimension, location, material type, structure type and other relevant data of bridges are collected in bridge inventory. Data collection is classified in to Track Structure, Super Structure, Sub Structure, Foundation and Ancillary groups.

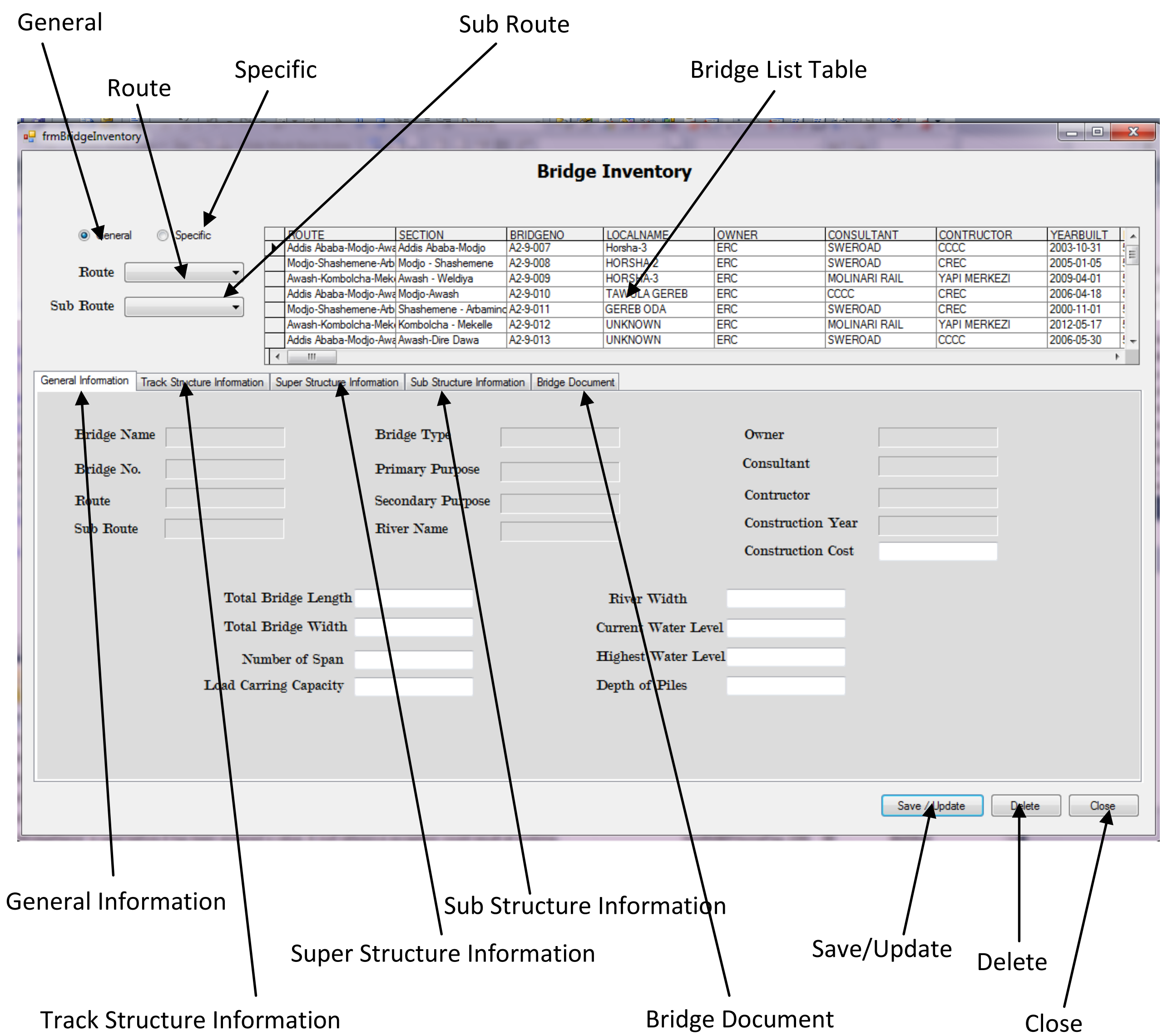

Figure 4-11: Bridge Inventory Window

General: is an option allowing the user to select a bridge from registered bridges listed on Bridge List Table which have the same route and sub route.

Specific: is an option allowing the user to select a specific bridge from registered bridges listed on Bridge List Table searching by its bridge number.

Route: route names recorded during route setting will be available hear. From the least one should choose the appropriate route of a railway line which the bridge exist.

Sub Route: sub route names shall be recorded first in sub route setting. Thus when we choose the route available sub routes will be available for the user to choose.

Bridge List Table: this table displays list of registered bridges. Besides it has a very important role in letting the user to choose which bridge inventory is going to be done.

General Information: is a tab that contain necessary information that could detail describe the bridge overall. In here information like construction cost, bridge length, bridge width, and number of spans, load carrying capacity, river width, CWL, HWL and depth of piles are inputted.

Track Structure Information: is a tab that contain necessary information that could detail describe the track structure. In here information like track type, ballast thickness (if there any), number of track, track gauge, track c/c spacing, track guard rail, rail type, rail joint fastener type, rail expansion gap, sleeper type, sleeper c/c spacing, type of middle joint faster are inputted.

Super Structure Information: is a tab that contain necessary information that could detail describe the super structure. In here information like span length, number of box or girder, box or girder dept, width of box or spacing of girder, expansion joint type, guard rail type, span support type, deck slab type, carriage way width, side walk width are provided.

Sub Structure Information: is a tab that contain necessary information that could detail describe the sub structure. In here information like abutment type, height, width, wing wall length, soil type, foundation type and size, number of piles, depth of piles, bearing type, used in abutment is inputted. In addition information about pier type, number, and height are provided.

Bridge Document: is a tab which allows the user to upload photos, videos, written documents in "pdf" format etc that could give the user a visual understanding of the bridge and read additional history about the bridge.

Save/Update: records the detail information provided about the bridge to the system. Besides if there is any change after saving, may be due to mistake or any other reason, this button orders the procedure to update the data. But first the user should select a specific bridge to be updated from bridge list view table.

Delete: when a bridge serves its design life and demolished it will be removed from the system only leaving its past history as a document. This button orders the procedure to delete the data. But first the user should select a specific bridge to be deleted from bridge list view table.

Close: when done working with bridge inventory, this close button returns the window to the home page of the computer program.

C. Routine Inspection

Following every routine inspection conducted according to the schedule, inspectors prepare a bridge inspection report describing the condition of damages. Each bridge's inspection data delivered from inspectors will be feed to the system using this window. Condition of the damages will be recorded by the provided entry point classified under Track Structure, Super Structure, Sub Structure, Foundation and Ancillary groups. If there is any video, photo or other written document it is provided place to upload. The contents of the inspection window are described here under.

Inspection Date: is a feature which allows the user to choose the date when the inspection is conducted.

Inspection No.: is a number given specific to this inspection by the officials.

Maintainer: a person or body assigned to maintain the defects after inspection is analyzed and the severity of damage known. It is not mandatory to fill during data encoding if not assigned.

QC Engineer: a person assigned to control the quality of maintenance work. It is not mandatory to fill during data encoding if not assigned.

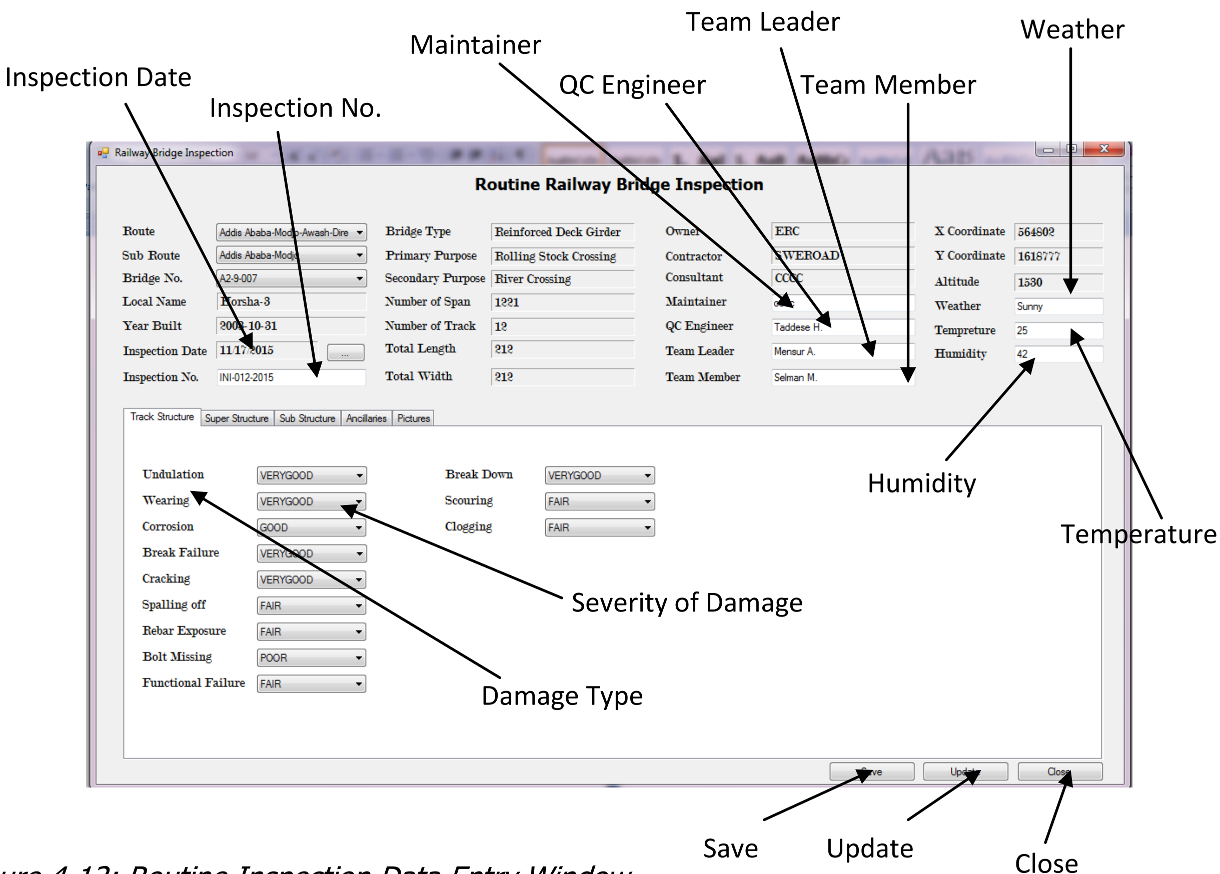

Figure 4-12: Routine Inspection Data Entry Window

Team Leader: a person assigned to guide and coordinates the inspection and also maintenance work.

Team Member: a person or group assigned to assist and facilitate the inspection and also maintenance work.

Weather: condition of the environment during inspection.

Temperature: temperature of the environment during inspection.

Humidity: humidity of the environment during inspection.

Damage Type: describes the type of damage the user has to insert in the place provided adjacent to damage type.

Severity of Damage: is a drop down list of conditions describing the severity of the damages from which the user chooses the condition that matches the inspectors report.

Save: records the information provided about the bridge to the system.

Update: due to mistake or any other reason whenever the data about condition of a specific bridge with specific inspection date is going to be changed. This button orders the procedure to update the data. But first the user should select a specific bridge and insert inspection date to be updated.

Close: when done working with inspection data encoding, this close button returns the window to the home page of the computer program.

D. Major Inspection

After every major inspection, inspectors prepare a bridge inspection report describing the condition and measure of damages. Each bridge's inspection data delivered from inspectors will be feed to the system using this window. Measured quantity of the damage condition, the measured quantity could be in length, area, piece or any other described on the inspection manual, will be recorded by the provided entry point classified under Track Structure, Super Structure, Sub Structure, Foundation and Ancillary groups. If there is any video, photo or other written document it is recorded during inspection, it will be uploaded using pictures tab. The contents of the inspection window are described here under.

Inspection Date: is a feature which allows the user to choose the date when the inspection is conducted.

Inspection No.: is a number given specific to this inspection by the officials.

Maintainer: a person or body assigned to maintain the defects after inspection is analyzed and the severity of damage known. It is not mandatory to fill during data encoding if not assigned.

QC Engineer: a person assigned to control the quality of maintenance work. It is not mandatory to fill during data encoding if not assigned.

Team Leader: a person assigned to guide and coordinates the inspection and also maintenance work.

Team Member: a person or group assigned to assist and facilitate the inspection and also maintenance work.

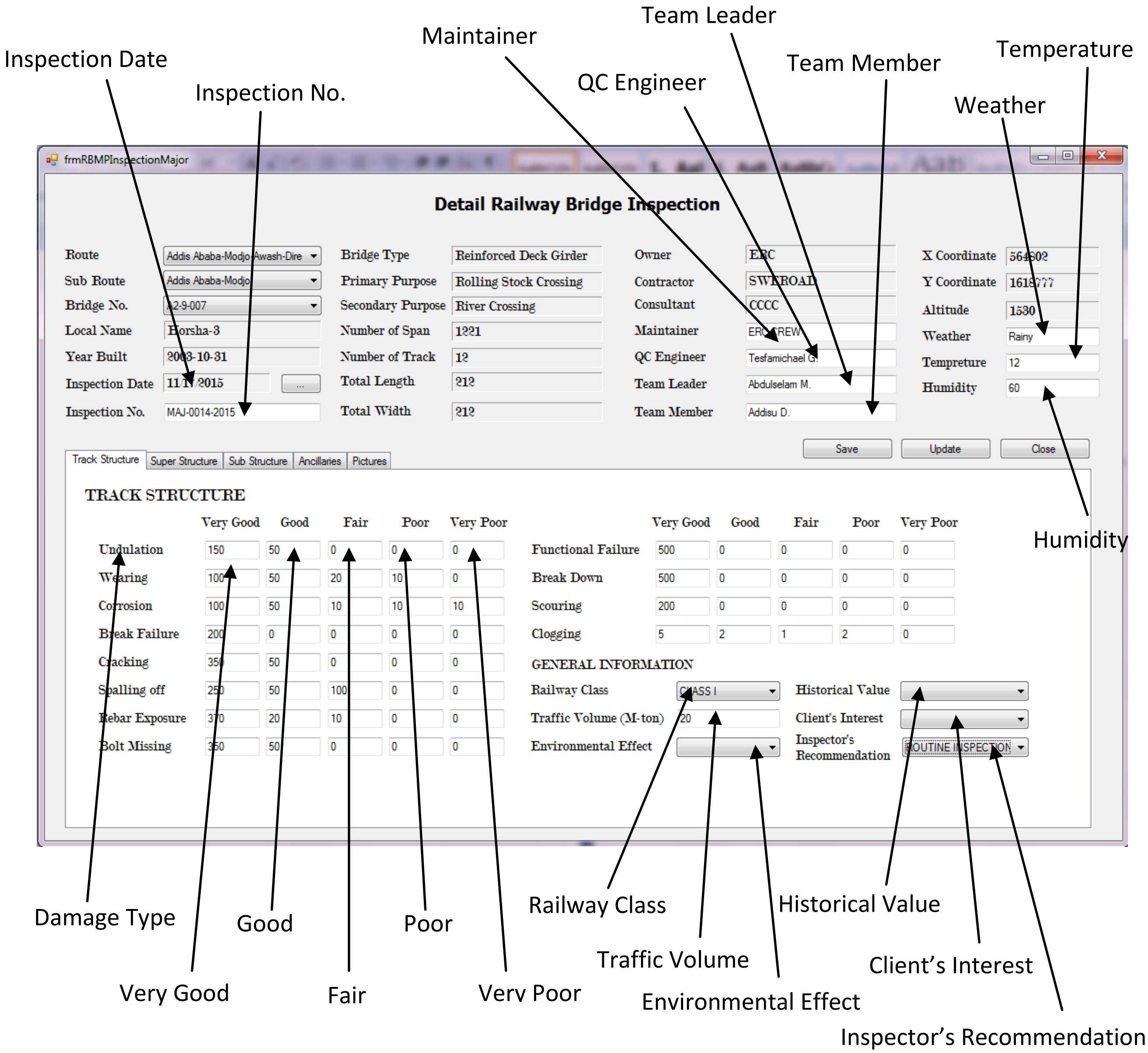

Figure 4-13: Major/ Detail Inspection Data Entry Window

Weather: condition of the environment during inspection.

Temperature: temperature of the environment during inspection.

Humidity: humidity of the environment during inspection.

Damage Type: describes the type of damage the user has to insert in the place provided adjacent to damage type.

Very Good Column: in the boxes provided under this column measured quantities, i.e. in length, area or pieces, of damage type designated as very good condition are inserted.

Good Column: in the boxes provided under this column measured quantities, i.e. in length, area or pieces, of damage type designated as good condition are inserted.

Fair Column: in the boxes provided under this column measured quantities, i.e. in length, area or pieces, of damage type designated as fair condition are inserted.

Poor Column: in the boxes provided under this column measured quantities, i.e. in length, area or pieces, of damage type designated as poor condition are inserted.

Very Poor Column: in the boxes provided under this column measured quantities, i.e. in length, area or pieces, of damage type designated as very poor condition are inserted.

Railway Class: is the class grade of a railway classified according to its role in railway network, properties, volume of passenger traffic, goods traffic volume, maximum allowable axle load, design speed, etc. It is classified as Class I, Class II or Class III listing from highly, moderately and low importance respectively.

Traffic Volume: this box receives a volume of passenger traffic and goods traffic volume being transported in that railway line annually. It is very important to measure the contribution of the railway line to the economy of the country.

Environmental Effect: the extent environmental contribution to the damage on the structure is expressed under here. The extent of contribution is quantified in increasing order as Very Low, Low, Medium, High and Very High.

Historical Value: Some bridges have historical value and some are also heritage-listed. The value of the bridge in history of the organization or the country is expressed under here. Its value is quantified in increasing order as Very Low, Low, Medium, High and Very High.

Client's Interest: The nature of a bridge site and the extent of the bridge remediation treatment may cause decision makers to close bridge or create alternative routes or bypasses to control the traffic flow. The client's influence in decision making regarding the bridge is expressed under here. Its value is quantified in increasing order as Very Low, Low, Medium, High and Very High.

Inspector's Recommendation: Engineers recommendation after conducting the inspection is very important. The recommendation could be Inspection, Maintenance, Rehabilitation or Replacement and each recommendation will be given a weight to be considered in addition to the computed bridge condition.

4.4. Data Changing and Updating

Data entered at each input data levels can be changed or updated after finalizing data entry procedure. During data entry procedure the data clerks could make a mistake, thus before initializing the analysis procedure the user should check for error data. Besides bridges registered at one time could be demolished after service their life time, or bridges that gone through rehabilitation could have a different physical dimension from the original. All this cases require either data changing or data updating.

Update button provided in each entry window is the one that commands the update procedure. To update data, the user should select the specific row data that is displayed in the data entry window. For example when bridge registration data is going to be corrected, the user should open bridge registration window and select the bridge from the list of bridges displayed on the table and click update button after changing the data.

4.5. Output Data

The computer program outputs the followed data:

- Bridge List
- Inspection Schedule List
- Bridge Condition by
    - Element detail
    - Routine inspection detail
    - Routine inspectioin summery
    - Major inspection detail
    - Major inspection summary
- Priority Ranking
- Maintenance Action Plan by
    - Maintenance plan detail
    - Maintenance plan summary

Print out of output data are attached in the appendix.

5. Discussion, Conclusion and Recommendation

5.1. Discussion Summary

This research study is focused to develop and introduce a computer program that could assist specially bridge asset management decision making. Transportation accesses are critical to the well being of the nation. And one of the biggest factors to influence transportation is railway transport service. It supports everyday social, political and economic activities by linking communities and connecting people with services. Hence, keeping the railway infrastructures in good condition is keeping the railway transport service efficiently.

Bridge asset management is about doing the right thing at the right time, to maximize the serviceable life of assets. Decisions can be made about making timely interventions to reduce the cost of maintaining bridge assets through the duration of their life. If the right thing is done at the right time the serviceable life of assets can be maximized.

Bridge asset management is about making sound financial decisions. It is very valuable in using available finance to maximize the usable lifetime and serviceability of bridge assets. This means decisions need to be made that balance short term needs with the longer term objectives.

For an organization to have a proficient bridge asset management, incorporating BMS in the system is very important. BMS is a formal procedure for collecting, processing, and updating data, predicting deterioration, identifying alternative actions and predicting their costs, and identifying optimal preservation policies.

Different countries have developed and used BMS to assist their decision making while managing assets.

Data collection for BMS is conducted through; Bridge Registration and Inventory, Initial, Routine and Major Inspection of Bridge Condition.

Bridge inventory is a procedure where data and general information about a bridge is gathered. In inventorying a bridge, bridges are classified material and mode of construction in to four types; Reinforced Concrete, Pre-cast concrete, Pre-stressed Concrete and Steel Bridge. Commonly bridges contain about 10 – 12 components or bridge elements according their function.

Physical condition of a bridge can be assessed by using different types of inspection techniques. The common ones are initial inspection, routine/ regular inspection, major/detail inspection and emergency/ special inspection.

The purpose of bridge inspection is not simply to collect the latest information about the present bridge conditions but, more importantly, it should be understood that the inspection is to provide essential information for BMS decision making.

For better support of decision making, results of inspection are analysed and interpreted to be simple to understand. Bridge's condition is analysed using bridge scoring system is proposed which takes into account the conditions of bridge elements, the degree of their contribution to bridge integrity and the contribution of bridges to the overall bridge stock condition.

One thing that matters the asset management is financial limitation. Thus knowing the condition of bridge doesn't mean nothing unless they are given priority for maintenance by balancing their condition and available fund. Thus remedy action and financial need for implementing remedy will be planned and executed according to the priority rank.

Currently in Ethiopian many railway bridges are constructed and also many are under constuction in both Light Railway and National Railway Cases. But yet there is not as such organized asset management activities with in the sector.

5.2. Conclusion

Currently in Ethiopian many railway bridges are constructed and also many are under constuction in both Light Railway in Addis Ababa City and National Railway at Federal level. But yet there is no as such organized asset management activities with in the sector.

Even though most of the railway bridges are recently constructed, as time goes by these bridges and other Infrastructures that are currently in good condition will deteriorate and become structurally deficient due to the actions of weather, traffic and other various causes. These deficient structures potentially endanger the safety and economical use of the railway transportation system. To keep on top of the deterioration of our asset, we must invest continually in maintenance.

Any organization responsible for asset management especially bridge administration is expected to monitor potentially ruthless hazards due to any structural failure or natural disaster.

Decision Support Systems like BMS is an answer for this. BMS is widely used to assist decision makers across an extensive spectrum of unstructured decision environments. Thus, to improve the system by computer aided program, this research is conducted in developing a BMS computer program.

The program is developed by using Visual Basic 2010 for graphical Interface and SQL database for manipulating data. In developing the computer program the following activities are conducted.

- Hence there is no format found for bridge asset management from Ethiopian Railway Corporation, further review of literatures was necessary to conduct. By doing so necessary information required as input is identified. Accordingly formats for input data, like; bridge registration format, bridge inventory format, initial inspection format, routine inspection format and major inspection formats are developed.
- Flow chart that could describe the whole process of the software is developed and presented graphically. As per the flow chart and the formats gathered the graphical interface of the computer program is designed.
- Data base system for manipulation of data and storage is developed using SQL Server 2008. And different tables created to be used as data storage.
- Since there is no bridge data found from the organization, pseudo bridge data for bridge registration, bridge inventory, routine inspection and major inspection that could replicate the realistic case are generated and used as input data. The data generated are tried to mimic the reality by considering different bridge types, length, and construction year.
- Sample bridge photo, video are taken plus bridge document is prepared.
- Generated data are provided to the software for further analysis. Analysis is conducted for Element condition assessment, Bridge condition assessment, Bridge stock condition assessment, prioritization and remedy treatment selection based on requirements-driven methodology.
- Access for observing output results, like; bridge list, inspection schedule, routine and detail inspection results, priority rank, remedy treatment, etc., are designed with the ability to print output results.
- Output results found by software computation are compared with the one computed manually and it shows is a very efficient and reliable outcome.

5.3. Recommendation

Experiences of other countries show that implementing BMS after assets gone through physical damage is very difficult. Bridges in this case doesn't have any detail history that could tell the cause of damages and this makes the maintenance or repair complicated.

Railway bridges in Ethiopia are very new and found in good condition. But this doesn't mean the bridges will keep this condition all the time. Through time of service, they will face damage to the elements and the bridge as a whole. To prevent sevier damages to the structure implementation of BMS is necessary.

The computer program developed during this research is very useful in managing the railway bridiges. It is very useful in bridge monitoring and maintenance by processing bridge condition inspections and find the best remedial treatment with the aim of maintaining a bridge within acceptable limits of safety, serviceability and sustainability.

Organization like Ethiopian Railway Corporation and Addis Ababa Light Rail Transit could benefit by implementing this computer aided bridge management system in thir asset management.

The computer program could be modified and used by other organizations working on asset management to yield better management system.

In using this computer program one could:

- facilitate its management system
- speed up working and communication time by making decision in time
- get safe and reliable information
- get efficient starage of file and documents, (huge amount of data in limited space)
- minimize the amount of paper work required
- provide a searchable database of all past inspections
- provide an automated channel for the public to request information

As a recommendation for futher study on this area:

- Culvert management software and Railway line track structure management softwares should be developed.

- Bridge life estimation from inspection result can be studied for better supporting of the management process.

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Appendix

1.Sample Photograph Input

Sample 1: Arch Bridge (Under pass railway line)

Figure 1a: Approach View

Figure 1b: Plan View

Figure 1c: Downstream view

Figure 1d: Upstream View

Figure 1e: Inside View

Sample 2: Steel Truss Bridge (Under pass railway line)

Figure 2a: Upstream View

Figure 2b: Downstream

Figure 2c: Left Stair View

Figure 2d: Right Stair View

Sample 3: Deck Slab Bridge (Over pass railway line)

Figure 3a: Approach View

Figure 3b: Upstream View

Figure 3c: Downstream View

Figure 3d: Right Abutment

Figure 3e: Left Abutment

Sample 4: Deck Slab Bridge (Over pass railway line)

Figure 4a: Approach View

Figure 4b: Upstream view

Figure 4c: Downstream view

Figure 4d: Right Abutment

Figure 4e: Left Abutment

Sample 4: Deck Slab Bridge (Over pass railway line)

Figure 5a: Upstream View

Figure 5b: Downstream View

Figure 5c: Left Abutment

Figure 5d: Right Abutment

Figure 5e: Approach View

2. Software outputs

ETHIOPIAN RAILWAY CORPORATION

BRIDGE LIST

6/22/2016

BRIDGE NO	SUB ROUTE	BRIDGE NAME	YEAR BUILT	BRIDGE TYPE	PRIMARY PURPOSE	SECONDARY PURPOSE	NORTHING	EASTING
NR01-01-001	Addis Ababa-Modjo	Lebu	2005-01-01	Prestressed Box Girder	Rolling Stock Crossing	Vehicle Crossing	991085	470834
NR01-01-002	Addis Ababa-Modjo	Bishoftu	1985-01-01	Reinforced Box Girder	Rolling Stock Crossing	Vehicle Crossing	498271	967137
NR01-02-001	Modjo-Awash	Beseka	1960-01-01	Reinforced Concrete Arch	Rolling Stock Crossing	River Crossing	595162	985901
NR01-03-001	Awash-Dire Dawa	Unknown	1995-01-01	Precast Box Girder	Vehicle Crossing	Rolling Stock Crossing	1002098	635105
NR01-04-001	Dire Dawa-Dewanle	Unknown	2000-01-01	Prestressed Deck Girder	Vehicle Crossing	Rolling Stock Crossing	1002098	635105
NR02-01-001	Awash - Weldiya	Ataye	2010-01-01	Steel Girder	Rolling Stock Crossing	River Crossing	1078532	991085
NR02-01-002	Awash - Weldiya	Unknown	2005-01-01	Steel Girder	Rolling Stock Crossing	River Crossing	1201400	586966
NR02-02-002	Kombolcha - Mekelle	Weldiya	1970-01-01	Steel Truss	Vehicle Crossing	Rolling Stock Crossing	1310834	564643
NR03-01-001	Modjo - Shashemene	Ziway	2010-01-01	Prestressed Box Girder	River Crossing	River Crossing	893781	475702
NR03-01-002	Modjo - Shashemene	Arbaminch	1990-01-01	Precast Box Girder	Pedistrian Crossing	Rolling Stock Crossing	673355	341408

ETHIOPIAN RAILWAY CORPORATION

BRIDGE LIST

8/9/2016

BRIDGE NO	SUB ROUTE	BRIDGE NAME	YEAR BUILT	BRIDGE TYPE	PRIMARY PURPOSE	SECONDARY PURPOSE	NORTHING	EASTING
NR01-03-001	Awash-Dire Dawa	Unknown	1995-01-01	Precast Box Girder	Vehicle Crossing	Rolling Stock Crossing	1002098	635105
NR03-01-002	Modjo - Shashemene	Arbaminch	1990-01-01	Precast Box Girder	Pedistrian Crossing	Rolling Stock Crossing	673355	341408

ETHIOPIAN RAILWAY CORPORATION

BRIDGE LIST

8/9/2016

BRIDGE NO	SUB ROUTE	BRIDGE NAME	YEAR BUILT	BRIDGE TYPE	PRIMARY PURPOSE	SECONDARY PURPOSE	NORTHING	EASTING
NR03-01-001	Modjo - Shashemene	Ziway	2010-01-01	Prestressed Box Girder	River Crossing	River Crossing	893781	475702

ETHIOPIAN RAILWAY CORPORATION

BRIDGE LIST

8/9/2016

BRIDGE NO	SUB ROUTE	BRIDGE NAME	YEAR BUILT	BRIDGE TYPE	PRIMARY PURPOSE	SECONDARY PURPOSE	NORTHING	EASTING
NR02-01-001	Awash - Weldiya	Ataye	2010-01-01	Steel Girder	Rolling Stock Crossing	Rolling Stock Crossing	1078532	991085
NR02-01-002	Awash - Weldiya	Unknown	2005-01-01	Steel Girder	Rolling Stock Crossing	River Crossing	1201400	586966

ETHIOPIAN RAILWAY CORPORATION

SCHEDULE FOR INSPECTION

SCHEDULE

Date : 6/22/2016

BRIDGE NO	ROUTE	SUB ROUTE	BRIDGE NAME	BRIDGE TYPE	YEAR BUILT	YEAR SCHEDULED
NR01-01-002	Addis Ababa-Modjo-Awash-Dire Dawa-Dewanle	Addis Ababa-Modjo	Bishoftu	Reinforced Box Girder	1985-01-01	2016

ETHIOPIAN RAILWAY CORPORATION

BRIDGE ELEMENT CONDITION

DETAIL

6/22/2016

BRIDGE NO	YEAR	ELEMENT TYPE	DAMAGE TYPE	CONDITION
NR01-01-002	2016	ABUTMENT	CRACKING	3.00
NR01-01-002	2016	ABUTMENT	CONC PEELOFF	2.00
NR01-01-002	2016	ABUTMENT	REBAR EXPOSURE	1.00
NR01-01-002	2016	ABUTMENT	HONEY COMB	1.00
NR01-01-002	2016	ABUTMENT	VOID	2.00
NR01-01-002	2016	ABUTMENT	WATER LEAK	3.00
NR01-01-002	2016	ABUTMENT	DISPLACMENT	2.00
NR01-01-002	2016	ABUTMENT	BULGING	2.00
NR01-01-002	2016	BEARING	TOTAL DAMAGE	3.00
NR01-01-002	2016	BEARING	PARTS MISSING	2.00
NR01-01-002	2016	BEARING	ANCHOR DAMAGE	3.00
NR01-01-002	2016	BEARING	BED DAMAGE	3.00
NR01-01-002	2016	BEARING	MOVEMENT	3.00
NR01-01-002	2016	DECK	CRACKING	4.00
NR01-01-002	2016	DECK	CONC PEELOFF	4.00
NR01-01-002	2016	DECK	HONEY COMB	4.00
NR01-01-002	2016	DECK	VOID	3.00
NR01-01-002	2016	DECK	WATER LEAK	4.00
NR01-01-002	2016	DECK	CORROSION	1.00
NR01-01-002	2016	DECK	PAINT PEELOFF	1.00
NR01-01-002	2016	DECK	DEFORMATION	1.00
NR01-01-002	2016	DECK	REBAR EXPOSURE	4.00
NR01-01-002	2016	FOUNDATION	CRACKING	2.00
NR01-01-002	2016	FOUNDATION	CONC PEELOFF	2.00
NR01-01-002	2016	FOUNDATION	REBAR EXPOSURE	2.00
NR01-01-002	2016	FOUNDATION	HONEY COMB	2.00
NR01-01-002	2016	FOUNDATION	VOID	2.00
NR01-01-002	2016	FOUNDATION	WATER LEAK	2.00
NR01-01-002	2016	FOUNDATION	DISPLACMENT	1.00
NR01-01-002	2016	FOUNDATION	SCOURING	3.00
NR01-01-002	2016	GIRDER	CRACKING	4.00
NR01-01-002	2016	GIRDER	CONC PEELOFF	4.00

BRIDGE NO	YEAR	ELEMENT TYPE	DAMAGE TYPE	CONDITION
NR01-01-002	2016	GIRDER	REBAR EXPOSURE	4.00
NR01-01-002	2016	GIRDER	HONEY COMB	4.00
NR01-01-002	2016	GIRDER	VOID	3.00
NR01-01-002	2016	GIRDER	WATER LEAK	4.00
NR01-01-002	2016	GIRDER	CORROSION	1.00
NR01-01-002	2016	GIRDER	PAINT PEELOFF	1.00
NR01-01-002	2016	GIRDER	DEFORMATION	1.00
NR01-01-002	2016	JOINT	NOISE	2.00
NR01-01-002	2016	JOINT	WATER LEAK	4.00
NR01-01-002	2016	JOINT	DEFORMATION	2.00
NR01-01-002	2016	JOINT	PEELOFF	3.00
NR01-01-002	2016	JOINT	MISSING	2.00
NR01-01-002	2016	PARAPHET	CRACKING	4.00
NR01-01-002	2016	PARAPHET	CONC PEELOFF	3.00
NR01-01-002	2016	PARAPHET	REBAR EXPOSURE	3.00
NR01-01-002	2016	PARAPHET	CORROSION	2.00
NR01-01-002	2016	PARAPHET	PAINT PEELOFF	3.00
NR01-01-002	2016	PARAPHET	DEFORMATION	2.00
NR01-01-002	2016	PARAPHET	MISSING	1.00
NR01-01-002	2016	PIER	CRACKING	2.00
NR01-01-002	2016	PIER	CONC PEELOFF	2.00
NR01-01-002	2016	PIER	REBAR EXPOSURE	2.00
NR01-01-002	2016	PIER	HONEY COMB	2.00
NR01-01-002	2016	PIER	VOID	2.00
NR01-01-002	2016	PIER	WATER LEAK	2.00
NR01-01-002	2016	PIER	CORROSION	1.00
NR01-01-002	2016	PIER	PAINT PEELOFF	1.00
NR01-01-002	2016	PIER	DEFORMATION	1.00
NR01-01-002	2016	PIER	DISPLACMENT	2.00
NR01-01-002	2016	PIER	SCOURING	2.00
NR01-01-002	2016	RIVER	CHANNEL SCOUR	1.00
NR01-01-002	2016	RIVER	EMBANK EROSION	1.00
NR01-01-002	2016	RIVER	SLOPE PROTECT	1.00
NR01-01-002	2016	RIVER	WATER WAY	1.00
NR01-01-002	2016	SIGN	SIGN MISSING	2.00
NR01-01-002	2016	SIGN	BOLT MISSING	2.00
NR01-01-002	2016	SIGN	LOOSE WELDING	2.00
NR01-01-002	2016	TRACK STRUCTURE	UNDULATION	3.00
NR01-01-002	2016	TRACK STRUCTURE	WEARING	3.00

BRIDGE NO	YEAR	ELEMENT TYPE	DAMAGE TYPE	CONDITION
NR01-01-002	2016	TRACK STRUCTURE	CORROSION	4.00
NR01-01-002	2016	TRACK STRUCTURE	BRK FAILURE	4.00
NR01-01-002	2016	TRACK STRUCTURE	CRACKING	4.00
NR01-01-002	2016	TRACK STRUCTURE	SPALLING OFF	4.00
NR01-01-002	2016	TRACK STRUCTURE	REBAR EXPOSURE	4.00
NR01-01-002	2016	TRACK STRUCTURE	FUNC FAILURE	3.00
NR01-01-002	2016	TRACK STRUCTURE	BRK DOWN	3.00
NR01-01-002	2016	TRACK STRUCTURE	SCOURING	1.00
NR01-01-002	2016	TRACK STRUCTURE	CLOGGING	4.00
NR01-01-002	2016	TRACK STRUCTURE	BOLT MISSING	3.00

ETHIOPIAN RAILWAY CORPORATION

DETAIL INSPECTION RESULT

ELEMENT CONDITION

DATE : 6/22/2016

BRIDGE NO	YEAR	TRACK	DECK	GIR	BEAR	PIER	ABUT	FND	PRT	JNT	RVR	SGN
NR01-01-002	2016	2.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

ETHIOPIAN RAILWAY CORPORATION

DETAIL INSPECTION RESULT

SUMMARY

DATE : 6/22/2016

BRIDGE NO.	YEAR	BRIDGE CONDITION AVE.		BRIDGE CONDITION CRITICAL			RECOMENDED ACTION	
		SCORE	CONDITION	SCORE	CONDITION	ELEMENT	FOR AVERAGE	FOR CRITICAL
NR01-01-002	2016	96.84	VERYGOOD	81.00	FAIR	TRACK STRUCTURE	INSPECTION	INSPECTION

ETHIOPIAN RAILWAY CORPORATION

DETAIL INSPECTION RESULT

BRIDGE STOCK CONDITION

6/22/2016

YEAR	BRIDGE		BRIDGE INSPECTED		BRIDGE CONDITION AVERAGE		BRIDGE CONDITION CRITICAL	
	REGISTERED	INVENTORED	ROUTINE	DETAIL	SCORE	CONDITION	SCORE	CONDITION
2016	10.00	1.00	1.00	1.00	96.88	VERYGOOD	81.00	FAIR

ETHIOPIAN RAILWAY CORPORATION

PRIORITY ORDER

LIST

DATE : 6/22/2016

RANK	BRIDGE NO	YEAR	RANKED BY	CONDITION	MAINT. COST	REP. COST
1.00	NR01-01-002	2016	DAMAGE	4.98	0.00	0.00

ETHIOPIAN RAILWAY CORPORATION

MAINTENANCE STRATEGY

ELEMENT CONDITION

DATE : 6/24/2016

RANK	BRIDGE NO	YEAR	ELEMENT	DAMAGE TYPE	MAINTENANCE TYPE	MAIN. COST	REP. COST	RECOMENDED ACTION
1.00	NR01-01-002	2016	ABUTMENT	CRACKING	Hydraulic Cement Grout	9,945.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	ABUTMENT	WATER LEAK	Surface Sealing	39,942.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	BEARING	ANCHOR DAMA	Replace new Anchor	441,777.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	BEARING	BED DAMAGE	Reconstruct bed surface	336,592.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	BEARING	MOVEMENT	Replace with new	126,210.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	BEARING	TOTAL DAMAGI	Replace with new	953,148.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	DECK	CONC PEELOFF	Re Surfacing	126,210.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	DECK	CRACKING	Hydraulic Cement Grout	126,210.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	DECK	HONEY COMB	Shotcrete/Gunite	126,210.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	DECK	REBAR EXPOSU	Re Surfacing	2,103,080.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	DECK	VOID	Shotcrete	2,103,080.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	DECK	WATER LEAK	Surface Sealing	2,103,080.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	FOUNDATIO	SCOURING	Protection with Gabion	262,500.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	GIRDER	CONC PEELOFF	Re Surfacing	262,500.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	GIRDER	CRACKING	Hydraulic Cement Grout	262,500.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	GIRDER	HONEY COMB	Shotcrete/Gunite	262,500.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	GIRDER	REBAR EXPOSU	Re Surfacing	262,500.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	GIRDER	VOID	Shotcrete	2,691,084.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	GIRDER	WATER LEAK	Surface Sealing	2,691,084.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	JOINT	PEELOFF	Re Surfacing	18,600.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	JOINT	WATER LEAK	Surface Sealing	2,691,084.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	PARAPHET	CONC PEELOFF	Re Surfacing	152,575.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	PARAPHET	CRACKING	Hydraulic Cement Grout	18,600.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	PARAPHET	PAINT PEELOFF	Re Paint	11,500.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	PARAPHET	REBAR EXPOSU	Re Surfacing	130,060.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	TRACK STRI	BOLT MISSING	Fitting New Bolt	35,000.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	TRACK STRI	BRK DOWN	Replace with New	238,500.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	TRACK STRI	BRK FAILURE	Replace with New	1,410,000.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	TRACK STRI	CLOGGING	Cleaning	238,500.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	TRACK STRI	CORROSION	Surface Cleaning and Antirust Paint	1,410,000.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	TRACK STRI	CRACKING	Hydraulic Cement Grout	1,410,000.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	TRACK STRI	FUNC FAILURE	Replace with new	1,305,000.00	0.00	MAINTENANCE

RANK	BRIDGE NO	YEAR	ELEMENT	DAMAGE TYPE	MAINTENANCE TYPE	MAIN. COST	REP. COST	RECOMENDED ACTION
1.00	NR01-01-002	2016	TRACK STRU	REBAR EXPOSU	Re Surfacing	1,410,000.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	TRACK STRU	SPALLING OFF	Re Surfacing	1,410,000.00	0.00	REHABILITATION
1.00	NR01-01-002	2016	TRACK STRU	UNDULATION	Replace with new	1,758,750.00	0.00	MAINTENANCE
1.00	NR01-01-002	2016	TRACK STRU	WEARING	Replace with new	1,410,000.00	0.00	MAINTENANCE

ETHIOPIAN RAILWAY CORPORATION

MAINTENANCE STRATEGY

ELEMENT CONDITION

DATE : 6/24/2016

RANK	BRIDGE NO	YEAR	RECOMENEDED ACTION	MAINT. COST	REP. COST
1.00	NR01-01-002	2016	INSPECTION	30,348,321.00	0.00