THE DEVELOPMENT OF A GUIDELINE TO ASSIST WITH COMPILING ASSET MANAGEMENT PLANS FOR TRANSMISSION LINES

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ABSTRACT

The overhead transmission line is a fundamental component in the power supply system as it links electricity supply to the various points on the electrical network. Failure of the transmission overhead line will result in interruption of supply and depending on the network configuration may result in long term outages. It is therefore essential that the overhead transmission line asset is inspected and maintained regularly to prevent premature failure.

Newer approaches to maintenance management are required to improve the overhead transmission lines performance and reduce the cost and risk associated with the asset. Asset management is seen as the process that can be adopted to enhance overall management of the overhead transmission line.

The review of maintenance practices of various Utility's and that of a pilot site made up of selected lines within Eskom's North East Transmission Grid revealed numerous shortcomings in the current practices largely due to the application of traditional (non-holistic) methods. This situation supports the development of asset management plans which will cater for improvement in performance, reduction in the risk and cost and achieving service level targets.

This research has used asset management principles to design a guideline in the form of a flowchart for effective maintenance management for overhead transmission lines. The key benefits/advantages of the maintenance management guideline are as follows:

- It is closed loop and process driven.
- Decision making is more scientific because it requires the use of historical performance data, detailed asset condition information and encourages quantitative analysis.
- Promotes defect and condition assessment tracking via the condition database.

Rather than focusing mainly on defect management, the asset manager will be directed towards the performance specifications and the condition database to establish individual action plans which can be prioritized against short, medium and long term improvement plans per specific asset.

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LIST OF ABREVIATIONS

AAM	Advanced Asset Management
AM	Asset Management
AMP	Asset Management Plan
AMS	Asset Management System
BCTC	British Columbia Transmission Corporation
CAPEX	Capital Expenditure
CBRM	Condition Based Risk Assessment Management
CLN	Customer Load Network
CoS	Continuity of Supply
CR	Condition Rating
EHV	Extra High Voltage
EPRI	Electrical Power Research Institute
FMECA	Failure Modes, Effects and Criticality Analysis
GIS	Geographic Information System
GOM	Grid Operational Manager
HV	High Voltage
KPI	Key Performance Indicator
LCA	Lifecycle Assessment
MV	Medium Voltage
NEG	Eskom Transmission North East Grid
NGC	National Grid Company
NRS	National Regulatory Services
ODM	Optimized Decision Making
OHSAct	Occupational Health and Safety Act
OPEX	Operational Expenditure
PAS	Publicly Available Specification
PPE	Personal Protective Equipment
QoS	Quality of Supply
RCM	Reliability Centered Maintenance
TAP	Trans-Africa Projects

CHAPTER 1: INTRODUCTION

1.1 Background

Overhead transmission lines, with voltages ranging from 132kV – 765kV, are very critical components in the power flow from source to end user. These overhead lines are required to carry power from the power station to the various substations, which in turn feed power to the interconnected overhead transmission line network of the various customer load centres. It is of utmost importance that these overhead lines are in good condition to ensure continuous power flow. Failure of these overhead lines may result in temporary or permanent loss of supply, depending on the network configuration.

This research study will focus on reviewing and analysing best practices in terms of holistic management of the overhead line asset, in order to achieve optimised decision making in ensuring reliability and improving the performance of the overhead line asset. All field studies and the review of present practices will be conducted on Eskom Transmission's North East Grid overhead lines. The background to the pilot study and the challenges facing the Eskom overhead transmission line asset, are listed below.

Eskom Transmission consists of more than 27 000km of overhead lines situated across South Africa, with the purpose of providing power to all of South Africa and neighbouring countries within the Eskom Transmission reach. The entire Eskom Transmission network is divided into 8 Grids. These Grids are responsible for the management of their networks i.e. primary plant, secondary plant and overhead line assets.

Eskom Transmission's standards and guideline procedure documents guide the Grids in the development of their maintenance plans for the various assets i.e. one component of the asset management plan. This results in the Grid Operation Managers for the overhead line assets aligning their maintenance plans to meet the minimum required standards as stipulated in the Eskom Transmission standards and guideline procedure documents. This also results in their maintenance plans being generic plans for all similar assets (see Appendix 1 for example of plan).

Presently the Grids concentrate mainly on the traditional methods of inspection and maintenance of the overhead lines, without a quantitative condition assessment process. The line patrolmen conduct an inspection annually on each overhead line. The majority of these line patrolmen were ex-Eskom security guards with minimal formal education and limited training. These patrolmen are responsible for identifying and recording all defects related to the overhead line in their line patrol book (as indicated in Appendix 2). All of the defects identified by the line patrolmen are based on his/her experience and training on what defect to report or ignore. No formal identification rating process (low, medium and high) is in place to guide the line patrolmen in his/her identification of the defect. It is for this reason that defects identified by one Grid may differ from another Grid. Depending on the severity of the defect based on experience, maintenance activities to rectify the defect are executed either immediately or postponed till later to accommodate the maintenance plan, or are based on the availability of the maintenance teams to perform the maintenance task.

The majority of the North East Grid overhead lines were built in the late 1960's and are now showing signs of deterioration of the structure and hardware components. The present annual inspection activities carried out on each overhead line focus on hardware, servitude and performance related defects.

The overhead line asset has been identified as the asset which, if managed properly, would result in improved system performance and reliability, as well as reducing the maintenance frequency of other plant items.

1.2 Importance of the research

This research will set the platform for asset managers to develop a comprehensive asset management plan for all existing and new overhead lines. This research will also assist Eskom Transmission in aligning its asset management practices to PAS 55 requirements.

The asset manager will be able to establish individual action plans which can be prioritised against short, medium and long term improvement plans per specific asset, rather than the present generic approach of only focusing on inspection and maintenance activities.

1.3 Aim of the research

This research study will focus on the maintenance aspect of the overall asset management plan for the overhead line asset. It will benchmark international and local practices in establishing effective maintenance practice for the overhead line asset, thus ensuring reliability and finding the optimum balance between cost, risk and performance in terms of maintenance priorities.

Although Eskom Transmission has standard maintenance management procedures, they have no formal document/procedure/guideline or standard with regard to asset management. The aim of this research will be to provide the business with a direction in terms of effective maintenance practices which could be used to establish a foundation for an asset management policy, asset management strategy and a holistic asset management plan for individual overhead lines.

1.4 Hypothesis

By applying proper asset management principles and processes, (as compared to traditional and non-holistic maintenance practices), asset managers can achieve better performance and a reduction in the risks and costs associated with overhead transmission lines.

1.5 Research problem / statement

This research study proposes to evaluate deficiencies in current maintenance practices and to develop a guideline based on asset management principles to achieve effective maintenance management, which will lead to improved asset performance and a reduction in the risks and costs.

1.6 Delimitations

This research study will be limited to:

- Eskom Transmission Division, North East Grid;
- Overhead transmission lines i.e. hardware and servitude components;
- Voltages of 275kV and 400kV, and;
- Lattice steel structures.

1.7 Outline of chapters

Chapter 1 is an introduction to the research content. It provides the background of the transmission system in which the research will be carried out.

Chapter 2 explains the design specification and design planning process.

Chapter 3 reviews the literature related to the research. It provides information necessary for the analysis and interpretation of the results, as well as the establishment of the design.

Chapter 4 covers the research methodology. It describes the method and the techniques used to analyze the data.

Chapter 5 covers the analysis and discussion of the data leading to the development of the asset management plan.

Chapter 6 describes the development of the asset management guideline and highlights the design of the maintenance management process flow for effective overhead line maintenance.

Chapter 7 is the conclusion.

Chapter 8 is the recommendation.

Chapter 9 lists the references of the literature reviewed for this research study.

Chapter 10 contains the Appendices.

CHAPTER 2: DESIGN SPECIFICATION AND DESIGN PLANNING PROCESS

2.1 Design specification

The design specifications were formulated based on the research problem/statement stated in Chapter 1.

The student is required to design an asset management guideline to assist with compiling asset management plans for overhead transmission lines that can be used for effective maintenance management of a new or mature overhead line. The design will be based on reviewing asset management practices, effective maintenance management techniques and the knowledge gained through the development of an asset management plan for a selected pilot study of overhead transmission lines within the Grid.

2.2 Design planning process

The design process that was planned in order to meet the objectives of the design is shown in the flow chart below (Figure 2-1).

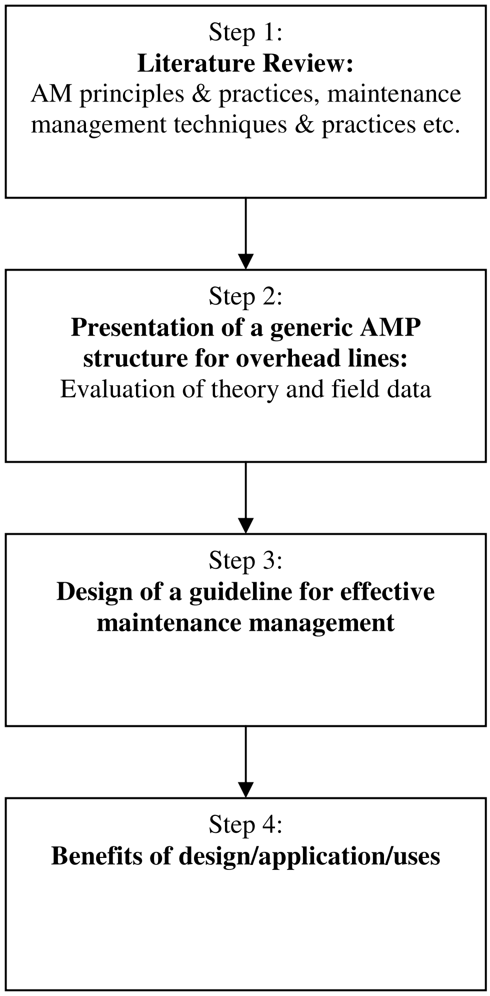


Figure 2-1: Flow of the design process

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

The term overhead line asset is defined as a single asset but in reality it consists of several interconnected components. These components collectively are grouped into two catergories, namely hardware and servitude. The hardware component of the group consists of the entire physical infra-structure of the overhead line whereas the servitude grouping consists of all vegetation and public interaction within the servitude width.

3.2 Understanding asset management

Asset management as a term can have a wide range of applications depending on the field or types of asset of interest, for this study we will focus on the overhead line asset. In the Cigre document (2002:09) it quotes EPRI's definition for asset management as it relates to transmission and distribution as indicated below:

'*A structured, intergrated series of processes aligned with business goals and values and designed to maximize societal value by minimizing the lifecycle costs and maximizing the lifecycle benefits of power delivery asset ownership, while providing required performance levels and sustaining the system forward*'.

PAS 55-1 (2004:5) defines asset management as:

'Systematic and co-ordinate activities and practices through which an organization optimally manages its assets and their associated performance, risk and expenditures over their lifecycle for the purpose of achieving the required level of service in the most cost effective manner'

Many organizations internationally are adopting the Lifecycle Asset Management practice in managing their assets. Lifecycle asset management practice as detailed in the International Infrastructure Management Manual (2006:1.10) involves taking into consideration all possible management options and strategies as part of the asset lifecycle, from planning to disposal.

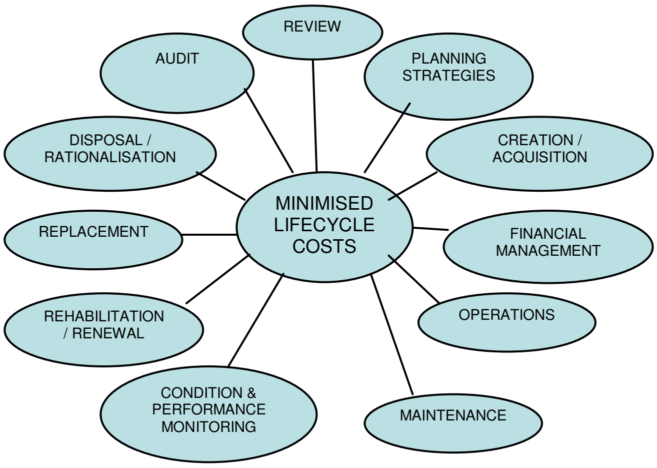


Figure 3-1: Lifecycle asset management (International Infrastructure Management Manual, 2006:1.10)

The organisational structure for asset management primarily consist of 3 functional roles as defined in the EPRI book titled Overhead Transmission Inspection and Assessment Guidelines (2006:2-4):

• **Asset owner: develops** performance constraints based on historical trending (for example, capital, operations and maintenance budgets) and performance goals for the organization (for example, customer satisfaction and earnings per share).

• **Asset manager:** establishes policies and strategies to achieve the required level of service.

• **Asset service provider: provides resources to meet the service requirements**. Service providers may be internal division or external contractors. It should be noted that non-core competencies are often outsourced.

3.3 Asset deterioration: Ageing process

In order to understand what maintenance to do on the overhead line, it is important to understand how the asset ages. According to the Cigre document titled Asset Management of Transmission and Distribution Systems (2002) the ageing process of the overhead line can be described as follows:

'Conductors: high loading levels combined with high ambient temperatures cause annealing of aluminum conductors resulting in a gradual loss of conductor strength over time'.

'Insulators: suspension insulators can be exposed to contamination and moisture which reduces electrical withstand strength'.

'Towers: when exposed to the elements corrode over time and lose strength. Footings subjected to frost and other environmental stresses, may age and crack exposing reinforcing steel and anchor bolts to atmospheric corrosion'.

The overhead lines inspected in the North East Grid depict various signs of ageing. The most common ageing process noticed is rusting of steel members and footing earth straps. In worse cases the footing earth straps are completely corroded and are not attached to the tower leg. The other noticeable ageing component of the overhead line is the glass insulator. On older overhead lines the glass insulators are showing signs of insulator glazing fading and visible corrosion on the pin and cap of insulators.

The ageing or deterioration process is influenced by three major factors as illustrated in Figure 3-2 below (CIGRE -Asset Management of Transmission and Distribution Systems, 2002:34):

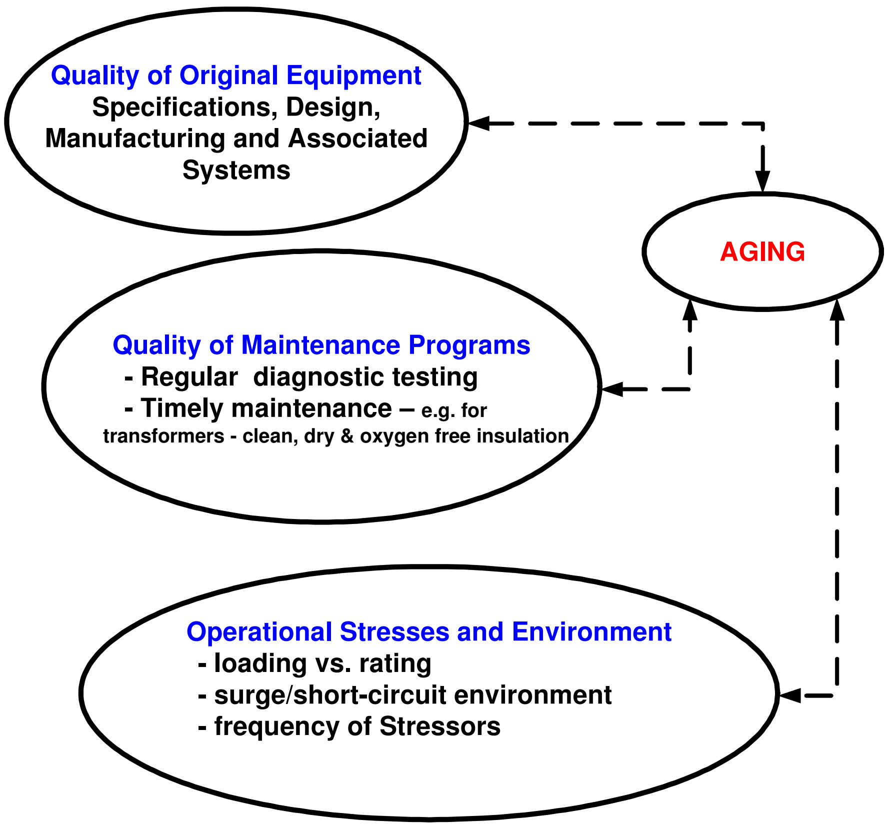
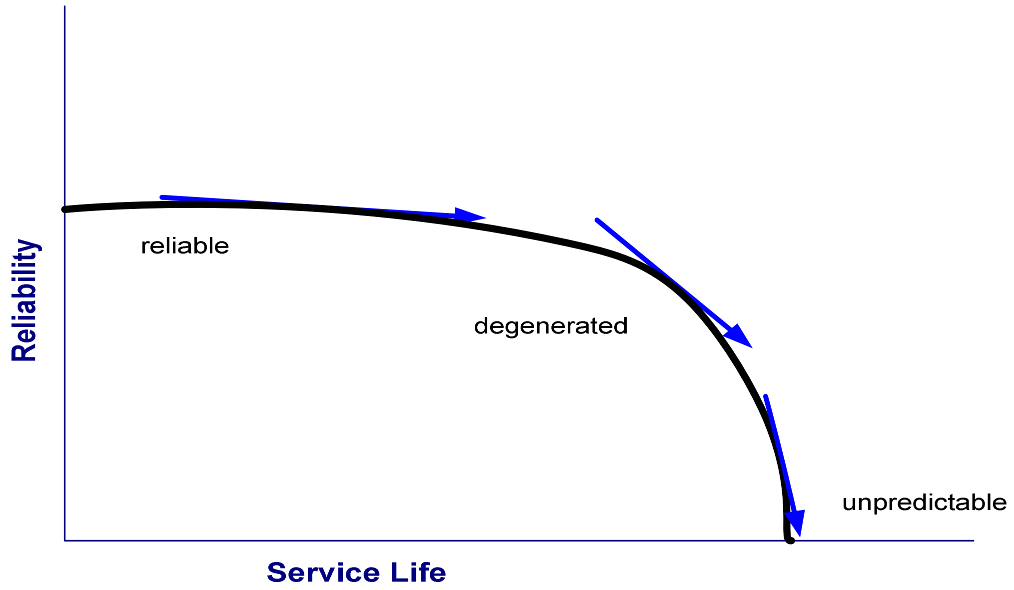


Figure 3-2: Influences affecting ageing (CIGRE, 2002:34)

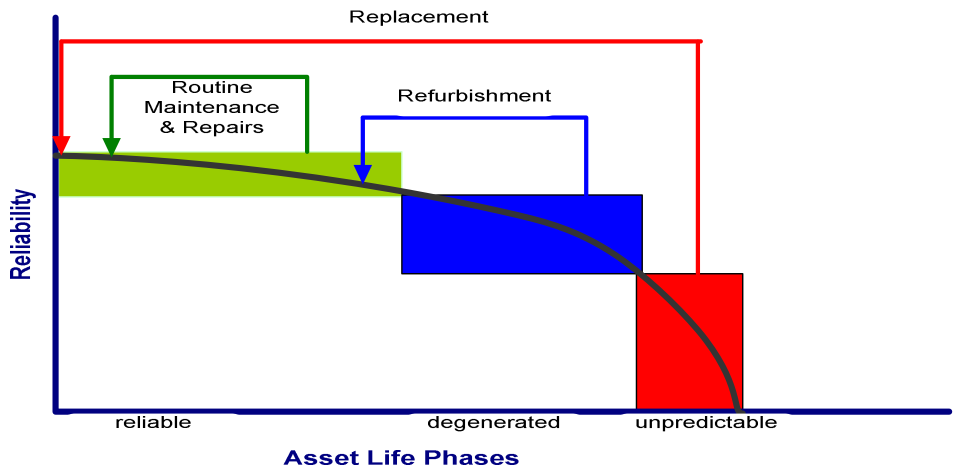
It was highlighted that as the asset ages, the rate of ageing may increase. As explained in CIGRE- Asset Management of Transmission and Distribution Systems (2002:36), '*In some cases the physical and chemical changes taking place under constant levels of stress may remain steady; but many of these processes accelerate as the asset materials age because although macroscopic stress may remain constant (for example the applied voltage) local stress levels may have increased significantly (for example through tracking or partial discharge* *activity in insulation systems). As well, many of the stresses can act synergistically to accelerate ageing processes'.*

Figure 3-3 below shows the relationship between reliability and service life of an asset.



<u>Figure 3-3: Asset ageing rates increase if no action is taken to extend life (CIGRE, 2002:36)</u>

Asset managers would benefit from having information as provided by Figure 3-3 as decision making will support their justification in investing in maintenance, refurbishment or replacement programs for any asset (CIGRE, 2002:37).



<u>Figure 3-4: States of ageing concept and possible asset management actions (CIGRE, 2002:37)</u>

Figure 3-4 above represents the effects of ageing within an assets lifecycle which are made up of three different states defined as reliable, degenerated and unpredictable (CIGRE, 2002:38).

The model reflected in Figure 3-4 depicts the approach or decisions asset managers have to consider to restore the asset to its reliable state i.e. refurbishment or replacement etc.

Zickler et al. (2008) explains that component reliability depends on the following factors, namely component age, maintenance history and operational stresses. It is further explained that in the past, equipment was designed with an assumed 40 year lifespan and a systematic replacement after 40 years of operation was standard practice. Unfortunately due to strong expansion of the networks in the 50's and 60's, many components have today reached the end of their assumed lifetime of 40 years. However, the majority of these components are still on the system and if not maintained or replaced, they could result in severe faults on the system.

3.4 Inspection and maintenance analysis

3.4.1 Inspection and maintenance objectives

The fundamental purpose of inspection of an overhead line is to evaluate the condition of the asset. When a noticeable deterioration in condition is found, maintenance is executed to restore the condition of the overhead line. The general objective of maintenance is to maintain the overhead line asset within the appropriate maintenance interval in order to prevent failure of the asset.

3.4.2 Overhead line asset performance requirements

The core function of the built overhead line is to transport the power from substation A to substation B. All interruptions of supply experienced by the overhead line are regarded as overhead line faults. A detailed analysis of overhead line faults will be discussed in the chapters to follow.

Eskom Transmission manages their overhead lines on 2 performance measures. The direct performance indicator is the number of faults experienced by the overhead line asset which relates to faults per 100km of total grid overhead line length. The formula is as follows:

$$\text{Fault per 100km} = \frac{\text{Total number of faults X 100}}{\text{Total grid km of lines}}$$

The present target for Eskom overhead lines at transmission voltages is 2.2 faults per 100km. The second indicator is an indirect measure which relates to quality of supply focusing on voltage dips measured at the various meter measuring points at selected substations.

Figure 3-5 below represents the various voltage dip classifications.

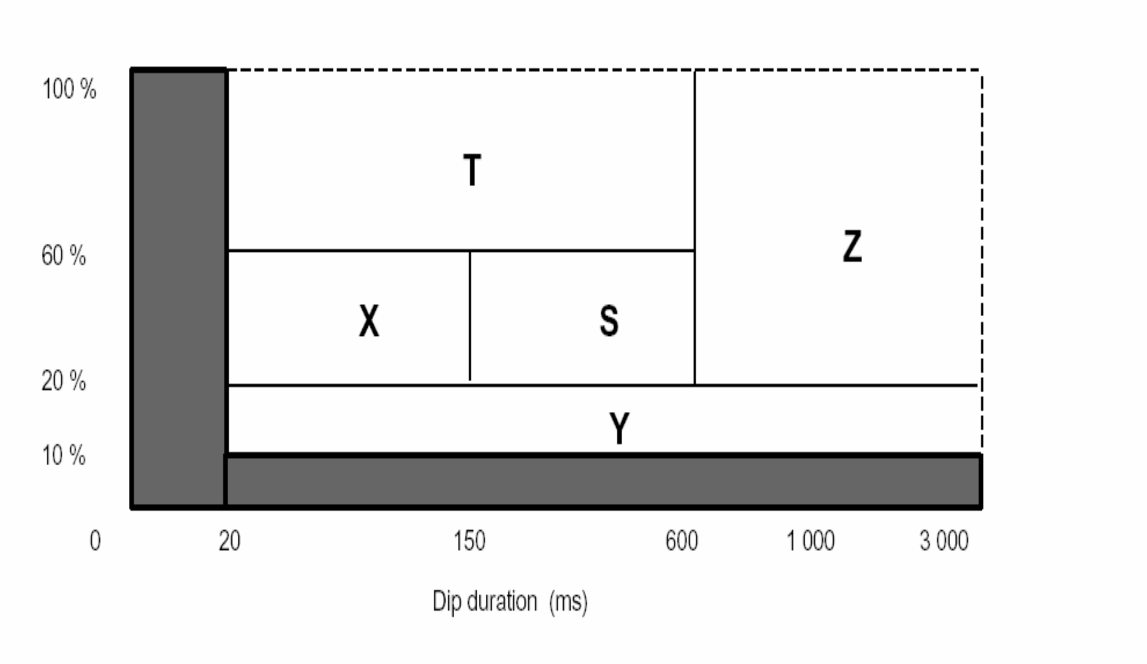


Figure 3-5: Voltage dip classification (NRS 048-2:2007)

A case study was conducted to investigate the impact overhead transmission lines have on voltage dips (see appendix 4 for details). Table 3-1 below is an example of a voltage dip matched to an overhead head transmission fault (extracted from the case study in appendix 4). Column B and C in Table 3-1 can be plotted on Figure 3-5.

Table 3-1: Voltage dip matched to overhead line fault

	DIP DATA				LINE FAULT DATA				
	A		B	C	G	H	I	J	K
Transmission Line Name	Data Info	Dip type	%Dip Depth	Dip Duration	Date	Time	Root cause	Tower Number	Fault Dist
Hendrina Vulcan No1 400kV Line	2010/04/02 04:45	X1	32.7	80					
	2010/04/02 04:48	X2	47	60					
	2010/04/02 04:56	X1	31.1	60	02-Apr-10	04:47	Bird Streamer	T 10	3.394
	2010/06/07 01:28	X1	38.8	90					
	2010/06/07 01:29	T	64.4	50					
	2010/06/07 01:42	X1	39	50	07-Jun-10	01:31	Unknown	?	**
	2010/06/19 01:49	X1	39.5	80					
	2010/06/19 01:50	T	64	50					
	2010/06/19 02:02	X1	39.3	50	19-Jun-10	01:52	Bird Streamer	T15	5.301

3.4.3 Maintenance strategies and practices adopted by power utilities / consultants

The development of a maintenance strategy is critical to establish a holistic view of what maintenance can be done to ensure that the overhead line will not fail. The overhead line has been identified as being a dynamic asset. The overhead line asset's performance and deterioration in its physical condition is greatly influenced by its environment i.e. nature, surroundings and associated activities executed in its vicinity.

Many utilities in the past followed the traditional trend of time based maintenance which was later modified to include a combination of time and condition based maintenance. Davies et al (2008), have summed up through their research, the maintenance practices adopted by the various utilties which are summarized below:

a) Electricite de France (EDF)

The present maintenance practices adopted are a combination of time and condition based maintenance. However in the future maintenance policies will rely more on Reliability Centered Maintenance (RCM) techniques.

b) Energie Noord West (ENW), The Netherlands

For many years, the maintenance policy was non holistic and focused on maintenance which was time based. Since then there has been a change from time based to a condition based preventative maintenance policy. A further intiative followed with the introduction of 'kayakteams'. These 'kayakteams' consisted of engineers and maintenance staff together with customer representatives (internal or external). The customer is also involved in the planning of maintenance.

c) Red Electrica (REE), Spain

In recent years great emphasis has been placed on the development and application of predictive and condition based maintenance techniques to increase reliability and reduce maintenance costs. For overhead line maintenance, periodic inspections carried out on foot are supplemented by extensive inspection by helicopter to identify preventative and corrective actions. Helicopters are also used to assist with insulator cleaning. Thorough inspection of tower earth connections is also performed.

d) NV Sep, The Netherlands

NV Sep's policy for maintenance of substation equipment is based on the manufacturer's recommended intervals. On completion of the maintenance, for example on a circuit breaker or arrestor, the maintenance staff rank the allocated complete work to one of 3 catergories: A, B or C.

'A' means the maintenance was unneccessary, it could have been done later.
'B' means the maintenance was performed at the right time, only normal maintenance was required.
'C' means the maintenance should have been done earlier, major faults were found.

Annually these simple characteristics are evaluated for each type of equipment. The manufacturer and age of the equipment together with how many A's, B's and C's it scored are taken into account. For equipment that mainly scored A's the maintenance interval is increased. For equipment that scored mainly B's, the maintenance interval remains unchanged. The 'C' catergory represents risk to the system and, hence, for every 'C' score the following actions are intiated :

- Immediate investigation to determine whether there is other equipment of the same type and age from the same manufacturer with the same problems.
- Decide if the maintenance interval should be reduced, avoid buying new equipment of this type or, let the manufacturer prove the problem will not occur again.

The benefits of this system has led to increasing maintenance intervals and has resulted in early discovery of major problems in surge arrestors and insulators of particular types.

e) The National Grid Company plc, UK

The National Grid Company plc (NGC) has adopted a maintenance policy consisting of a combination of condition assessment and routine invasive maintenance. The policy identifies basic, intermediate and major maintenance. Basic maintenance, typically every 2-4 years, consists mainly of tests and checks requiring an outage. Intermediate maintenance involves limited invasive work to restore the condition of the equipment. Major maintenance, typically every 12 years, includes further work to repair or replace components known to suffer long term deterioration.

Eskom Transmission's general maintenance philosophy for all its assets is mainly time based which is supplemented with the following information [Hamman, 2009]:

A) Operational information (usage)

B) On and off line condition monitoring

C) Plant performance information

D) Non intrusive functional testing taking preference wherever possible, especially in the case of secondary plant.

The various maintenance strategies and practices explained above have there own merits. As mentioned above, a combination approach of time and condition based maintenance should be part of the maintenance strategy /practice adopted for overhead lines. Each overhead line must be managed uniquely. The inputs for this strategy and determination of time based and condition based activities should be based on defect / condition assessment history, performance trending, lastest field concerns and quality of supply concerns.

3.4.4 Application of new / innovative maintenance practices

EA Technology (Ellam and Earp, 2006) have developed a system to reflect the condition of overhead line hardware by introducing colour coding corresponding to condition rating (CR) of the overhead line from aerial inspections. Each component from the aerial inspection is rated from 1 to 4 (4 indicating worst condition). The conventional green represents components in sound condition (CR 1 and 2), orange intermediate condition (CR3) and red poor condition (CR4). By looking at a comprehensive inspection report, it is easy to identify the condition by quick reference. EA Technology has developed a condition based risk management model (CBRM). This model is useful for predicting useful life and probability of failure of an asset. One of the major advantages of this model is that it provides a sound engineering basis for determining far more effective maintenance and intervention strategies based on risk rather than traditional time scheduled programs.

The technique described above is very good but costly to implement if not budgeted. In order to predict useful life many hours of flying will be required and currently helicopter cost ranges between R 4500 and R 6000 per hour depending on type of helicopter utilized. This technique may be considered for critical customer or performance problematic overhead lines i.e. where quality of supply and continue of supply is critical.

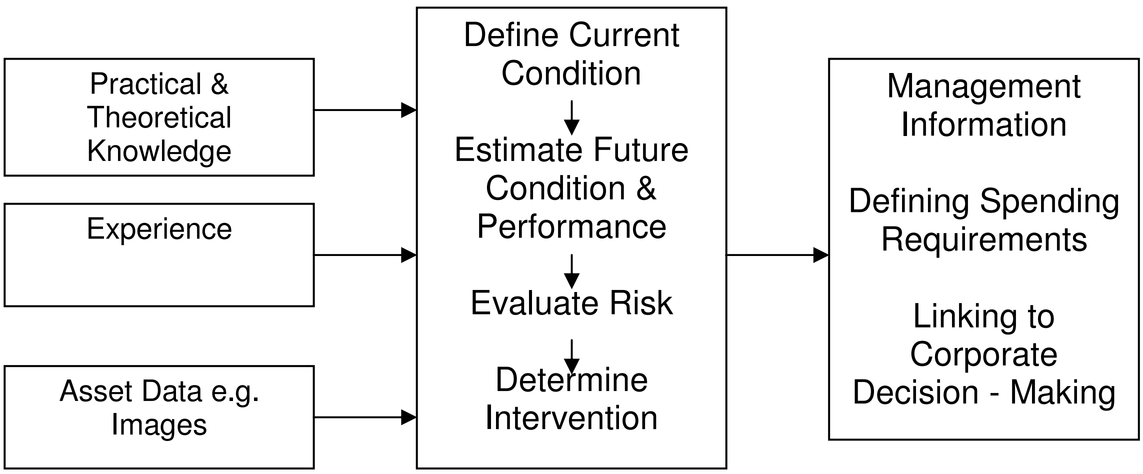


Figure 3-6: EA Technology CBRM model (Ellam and Earp, 2006)

Many companies collect a great deal of asset information through their maintenance and operative activities. All this information gathered is very seldom used in making asset decisions. The information tabulated below, in Table 3-2, is an example of how information on a particular asset can assist asset managers in making decisions.

Table 3-2: Examples of asset information (Hjartarson, 2007)

Types of Information	Some Examples
Demographics	Location, voltage level, capacity, age, etc.
Condition	Inspection, tests, maintenance history, etc.
Performance	Failure history, benchmarks, etc.
Functional	Capacity ratings, obsolescence issues, safety compliance, etc.
Criticality	Number of customers, priority customers, load, environment, safety, etc.
Costs	O&M, refurbishment, salvage, replacement costs, etc.

This information as reflected above in Table 3-2 is an example of asset information that is required to assist the asset manager in decision making. Through critical information and analysis of potential failure modes, a consequence cost of failure can be derived as reflected below in Figure 3-7 which could be used to prioritise different projects.

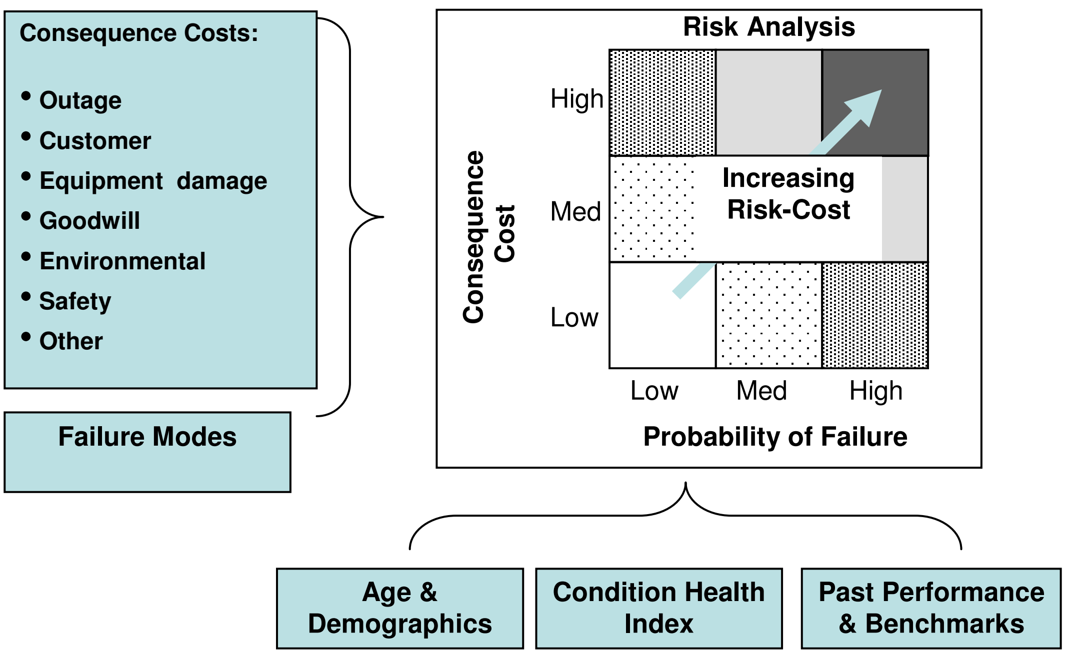


Figure 3-7: Assessing risk from asset information (Hjartarson, 2007)

3.4.5 Comparison of the various maintenance management techniques

The overhead line, as mentioned in the introduction in this chapter, is made up of several components and each of these components needs to be viewed individually as they collectively form a series system. If one of the components fails then the entire system or overhead line fails to transport the power. It is therefore important that each component and its failure modes are identified and ranked in terms of importance, i.e. low, medium and high.

The following maintenance management techniques/practices were found to be applicable to assess the overhead line asset, namely:

a) Reliability centered maintenance (which include failure mode analysis)

b) Failure mode effect and criticality analysis (only)

c) Condition based risk assessment management

A summary of each maintenance management technique/practice is listed below in Table 3-3.

Table 3-3: Summary of the maintenance management techniques

Maintenance Technique	Strength	Weakness
RCM (which include failure mode analysis)	1. Failure mode analysis. 2. Maintenance task planning. 3. Establishing condition monitoring program.	1. Technique more applicable for moving parts such as switch gear and generators.
FMECA	1. Failure mode analysis. 2. Functional block diagrams good to visualize problem areas. 3. Risk ranking method used is good to rate failure modes.	1. Ideally the analysis of the component needs to be done in detail and requires subject matter experts to be part of the review team.
CBRM	1. Very applicable to transmission lines but many of the initial steps in the formation of health index is a combination of RCM and FMECA techniques 2. Maintenance management is based on risk rather than time based schedules.	1. Risk rating may vary from utility to utility and therefore condition rating scores may vary. 2. Very dependant on level of service requirements from the utility. 3. The rating system is based on historical information and therefore utilities need to record all maintenance information.

By applying the FMECA technique, the functional block diagram of the overhead line is established. It should also be noted that failure of item number 1, 2 and 3 reflected below in Figure 3-8, will result in an interruption of supply of the overhead transmission line.

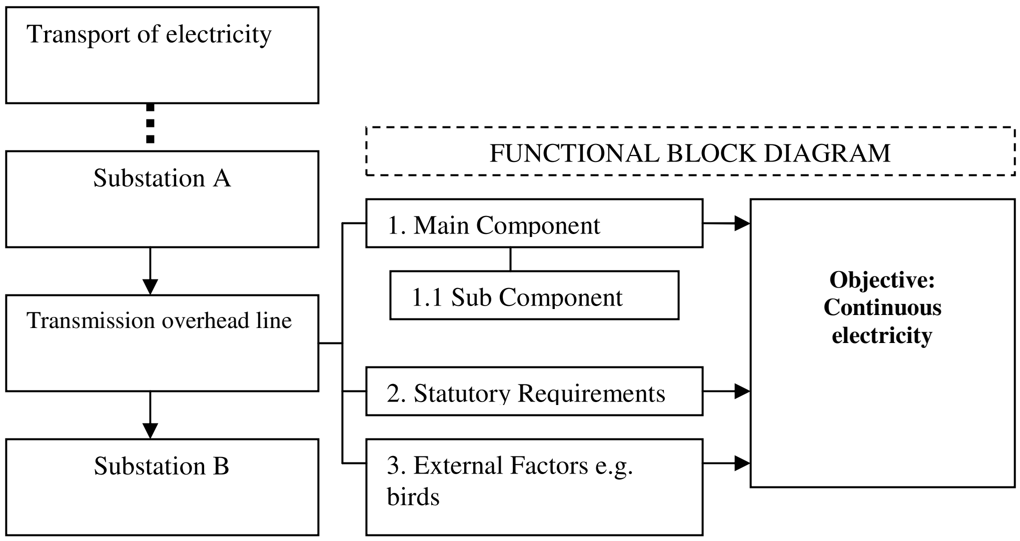


Figure 3-8: Functional diagram of an overhead line asset

Understanding the failure mode of components of the overhead line is critical to the maintenance and strategic decision making for that overhead line as defined in the International Infrastructure Management Manual (2002):

If the critical failure mode for an overhead line is determined, then it is possible to target and refine the maintenance plans, capital expenditure plans, and fault investigation activities, to address that failure mode. Condition assessment can be focused on the critical mode of failure of the overhead line or its components. Performance is only measured for critical aspects.

All decision making about refurbishment, replacement or disposal of the overhead line, and the timing of such activities, must be based on the critical failure modes.

The process for using failure mode information as defined in the International Infrastructure Management Manual (2002).

- Understand the critical failure mode of the overhead line.
- Monitor the performance of the overhead line with respect to the failure mode e.g. condition assessment.
- Develop deterioration curves and predict failure timing.
- Develop strategies covering maintenance and capital expenditure.
- Continue to monitor the performance of the overhead line.

The process mentioned above and the typical failure modes, effects and treatment are summarized in Figure 3-9 below (International Infrastructure Management Manual, 2002:3.61):

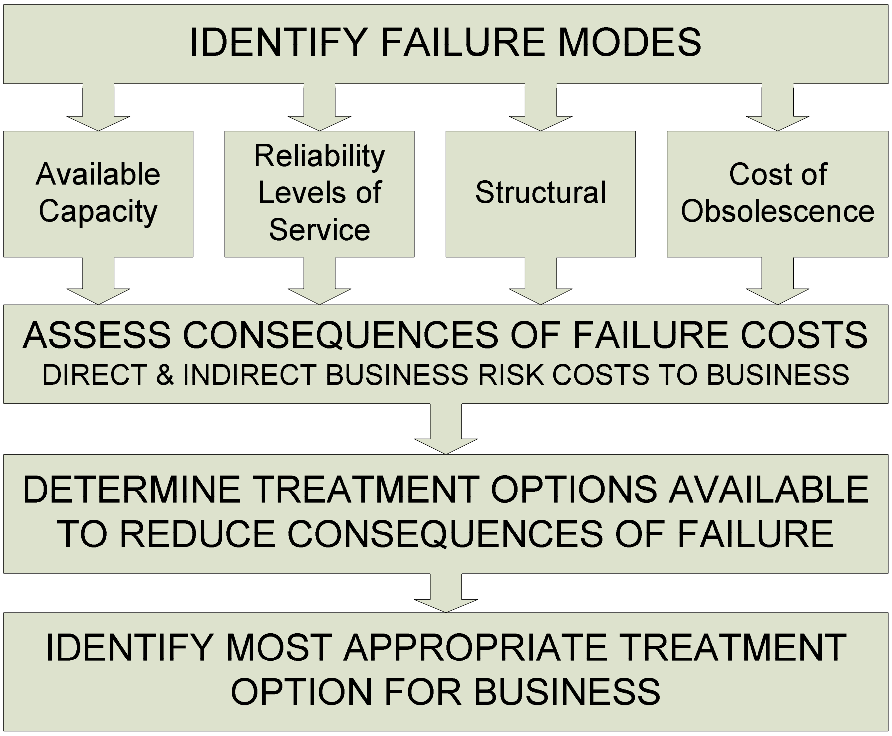


Figure 3-9: Failure modes analysis process

3.4.6 Risk Analysis

Risk ranking in terms of defect severity can only be determined once the failure mode for each overhead line component is known. The concept of establishing a risk score is based on establishing the appropriate risk matrix. The generic risk matrix table below as obtained for the HIRA manual (2004) represents the various risk categories. These risk categories are defined by scoring the risk. The risk result score is calculated as follows:

Risk Result = Consequences X Exposure X Probability.

Liklihood of Frequency	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
Almost Certain	High	High	Extreme	Extreme	Extreme
Likely	Moderate	High	High	Extreme	Extreme
Possible	Low	Moderate	High	Extreme	Extreme
Unlikely	Low	Low	Moderate	High	Extreme
Rate	Low	Low	Moderate	High	High

Figure 3-10: Risk matrix model (HIRA Manual, 2004)

There are several different types of risk matrix available and determining one appropriate type for the overhead line is not possible due to the fact that the risk matrix is designed to cater for utility requirements. After reviewing the risk matrix used by British Columbia Transmission Corporation (BCTC), Eskom Transmission's risk management process and FMEA/FMECA risk matrix utilized by Eskom Enterprises, it was concluded that it is important to detail as much information related to the utilities practices and management policy, for ease of selecting the appropriate choice. It is also important to ensure that the scoring or selecting of the appropriate choice should not be one dimensional and should also relate choice selection to other factors, e.g. legal, environment impact, asset condition, safety and health considerations.

3.4.7 Maintenance prioritization

In any technical environment where inspection is followed with some sort of maintenance, it is important to prioritize maintenance. If the maintenance prioritization process is established, it is easy for everyone to understand what is required and what should be done i.e. the sequence to follow in terms of what maintenance will be done in what sequence.

Listed below in Table 3-4, is a summary of the maintenance prioritization option different utilities are currently using.

Table 3-4: Summary of utilities practice on maintenance prioritization

Power Utility	Maintenance Prioritization Technique
1. Energie Noord West (ENW), The Netherlands	Maintenance prioritization and planning is executed in conjunction with utility and customer.
2. NV Sep, The Netherlands	Equipment performance in terms of maintenance task executed is reviewed annually to determine the equipment's maintenance cycle/prioritization for the new year.
3. The National Grid Company plc, UK	Maintenance prioritization is based on utilities grouping of maintenance task in the following categories namely, basic, intermediate and major.
4. Eskom Transmission	Maintenance is scheduled after inspection and scope of work is obtained from inspection report. The maintenance teams execute the maintenance as per scope of work. Depending on the resources of the maintenance team either all or few of the scope of work items are completed.
5. British Columbia Transmission Corporation (BCTC)	They have defined a simple approach to identify what maintenance is prioritized and when should the maintenance take place. The entire model of maintenance prioritization is based on 3 decision criteria namely: structural integrity, due diligence and impact.

All the 5 maintenance prioritization techniques mentioned above have their own merits but the technique used by BCTC has a constant output and is easy to use provided that the defects identified are ranked according to severity. However this method of maintenance prioritization may not be considered, or may have to be modified, when a set maintenance period is pre-defined for the overhead line.

The work prioritization flow chart used by British Columbia Transmission Corporation (BCTC) is shown below in Figure 3-11.

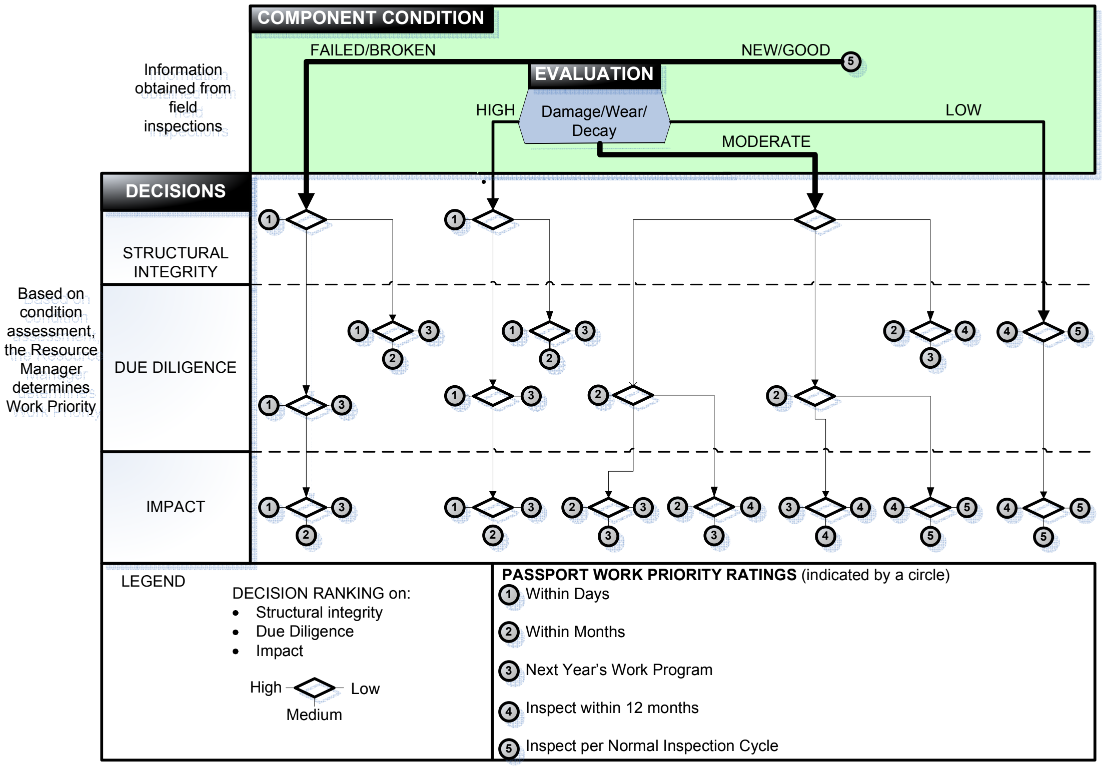


Figure 3-11: Work prioritization used by BCTC (Shantz and Duxbury, 2008:14)

3.4.8 Types of Maintenance Task

Maintenance in general consists of planned and unplanned tasks. Planned maintenance is defined as a time based maintenance approach as recommended by the manufacturer whereas unplanned maintenance is usually done or executed at the time of equipment failure.

Figure 3-12 below shows the different types of planned and unplanned maintenance task that can be performed on the overhead transmission lines (International Infrastructure Management Manual, 2006:3.102).

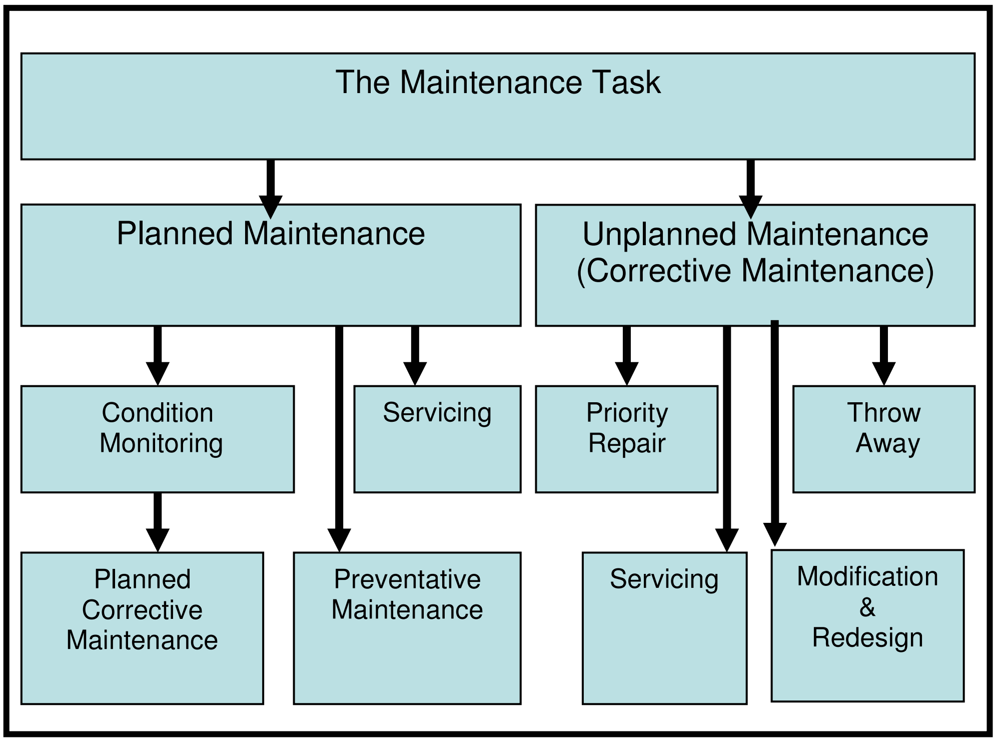


Figure 3-12: The maintenance task (International Infrastructure Management Manual,2002:3.102)

By comparing the maintenance practices of the utilities mentioned above with respect to maintenance tasks required for overhead lines, the following maintenance tasks were common for the management of the overhead line namely:

- The planned maintenance task consisting of :
  - Condition Monitoring
  - Preventative Maintenance
- The unplanned maintenance task consisting of :
  - Priority Repair
  - Modification & redesign (not common in execution but does occur. Occurs especially on newly built overhead lines)

CHAPTER 4: METHODOLOGY FOR DESIGN

4.1 Introduction

This chapter details the methodology used for the development of the design.

The scope of the research is to evaluate which components of the overhead lines (servitude and hardware components) fail or where defects were identified and to establish a realistic maintenance plan where early detection of these failures/defects can be identified.

4.2 Intended purpose of the research

The researcher's intention is to apply asset management principles for effective overhead line maintenance and thereby show the benefits that can be achieved with respect to cost, risk and performance. This will also allow asset managers to have a better handle on the assets that they are responsible for and provide guidance for the development of an AMP which will lead to improved decision making.

4.3 Steps of the research

The research was conducted in the following steps:

a) Literature Review
b) Data Collection
c) Analysis
d) Development of a Generic AMP for Overhead Transmission Lines
E) Design of Guideline for Effective Maintenance Management

4.3.1 Literature review

The literature reviewed provided the researcher with an understanding and appreciation for the theory and application of asset management principles. The literature also provided input into maintenance management practices adopted for the pilot site and other utilities.

4.3.2 Data collection

All field data was collected from the pilot site. The field data will be used to review present practices in conjunction with the theory and application of an AMP to develop an AMP applicable to overhead lines.

The following data was collected for this research:

- Maintenance technique application to the overhead line asset
- Inspection field reports (Tick sheets)
- Maintenance completed reports
- Refurbishment project/audit of selected Grid overhead lines
- Overhead line performance history
- General overhead line information.

4.3.3 Analysis

The data collected was analyzed to achieve results contributing to the development of the generic AMP structure.

A summary of the data analysis is listed below:

4.3.3.1 Maintenance technique application

This study was conducted with the pilot area staff (North East Lines and Servitude Department) where the various maintenance techniques (RCM and FMECA) were applied to the overhead line asset. The purpose of this study was to identify the various overhead line components and establish a rating of each components failure mode. This rating will reflect the importance of the component in terms of total overhead line reliability to supply continuous power in the event of a fault occurring.

4.3.3.2 Inspection field reports

The inspection field report is the report which is produced during the inspection of the overhead line asset. There are two types of inspections i.e. ground and aerial inspections. The ground inspection is done annually whereas the aerial inspection is done every 3 years. An inspection report is generated during the inspection of the overhead lines.

This report highlights all defects/failures of the various overhead line components. The report format is a tick sheet i.e. negative reporting (only defects are recorded). For this study the ground and aerial reports were analyzed for the 2007/08 financial year. Based on the inspection report data, trends in common defect types can be identified. These trends can be separated into hardware and servitude components.

4.3.3.3 Maintenance completed reports

The maintenance completed report is generated after the maintenance is completed. This report highlights all the maintenance completed as per the maintenance scope of work i.e. identified and prioritized from the inspection report. These reports will highlight where the majority of maintenance is occurring i.e. the hardware or the servitude component.

4.3.3.4 Refurbishment project / audit report of selected Grid overhead lines

The Grid has identified overhead lines where signs of deterioration were shown on certain hardware components. The affected areas were then audited by Trans-Africa Projects (TAP). An audit report was complied (TAP) with a list of defects identified during the audit. Based on the audit information, a trend can be established of typical failure components of an aged overhead line.

4.3.3.5 Overhead lines performance history

All overhead line faults are recorded on a fault database. The fault database contains fault data for the last 10 years. Information in terms of year, date, time, month, fault cause and tower/span number is captured on the database. For the purpose of this study the previous 3 years' data will be analyzed i.e. years 2005, 2006 and 2007. Through analysis of the data, trends can be identified. Trends in terms of time of day, month and Pareto graphs can be established from the performance data analysis. These trends will help in the scheduling of certain maintenance activities i.e. a proactive approach to prevent seasonal overhead line faults and reprioritization of the sequence of overhead lines to be maintained.

4.3.3.6 General overhead line information

The data obtained from this section of the review will be used to understand the operations, planning, costing and scheduling involved in the Grid's management of the overhead lines. The information will be used to establish a gap analysis in terms of the AMP for an overhead line.

4.3.4 Development of a generic AMP structure for overhead transmission lines

The analysis of the data collected and a review of the present overall overhead line management practices has highlighted gaps which contributed to poor management of the overhead lines. These gaps were mainly identified in the management of maintenance practices of the overhead line. This section of the research will identify the core components of an AMP applicable to an overhead line asset.

4.3.5 Design of a guideline for effective maintenance management

All gaps identified during the research study within the Grid in terms of maintenance management will be used to design a guideline for effective maintenance management.

4.4 Outcome of the research

This research has set out to establish a process for improved maintenance management (including refurbishment) through the use of AM principles i.e. planning, sequencing and type of maintenance. This process is presented in the form of a guideline for the development and application of an AMP for any overhead transmission line.

CHAPTER 5: ANALYSIS AND DEVELOPMENT OF A GENERIC AMP FOR OVERHEAD TRANSMISSION LINES

5.1 Analysis of pilot overhead lines for the development of a generic AMP

At the pilot site 66 overhead lines totaling 3 619km were assessed in terms of the AMP study. These overhead lines are located from the following customer load networks, namely: Pretoria, Highveld North (Witbank), Highveld South (Ermelo area) and Lowveld (Nelspruit). The majority of these overhead lines passes through or is located in areas of different environmental conditions. The outcome of the analysis is highlighted below under the various subsections.

5.1.1 Performance analysis

The performance analysis will be separated into two review areas namely: fault performance and component performance.

5.1.1.1 Fault performance

The Grid presently experiences seven fault categories. These seven categories of overhead line faults are namely: fire, lightning, bird, unknown, pollution, hardware and abnormal related faults. However in terms of fault categories the following main categories are used by utilities to identify the faults as reflected in the book, The Fundamentals and Practice of Overhead Line Maintenance (2004:28) namely:

A) <u>Mechanical Factors</u>

- Public contact such as vehicle or aircraft.
- Mechanical failure of conductor, overhead shield wires, insulators or supporting equipment.
- Terrorist activities such as placing of explosives or dismantling of towers.

B) <u>Electrical Factors</u>

- Bird streamers of wet excreta.
- Insulator pollution due to marine, industrial or pre-deposited bird contamination.
- Design constraints such as the upgrading of operating voltages.
- Malfunctions of protective relays.
- Human errors as a result of maintenance activities.

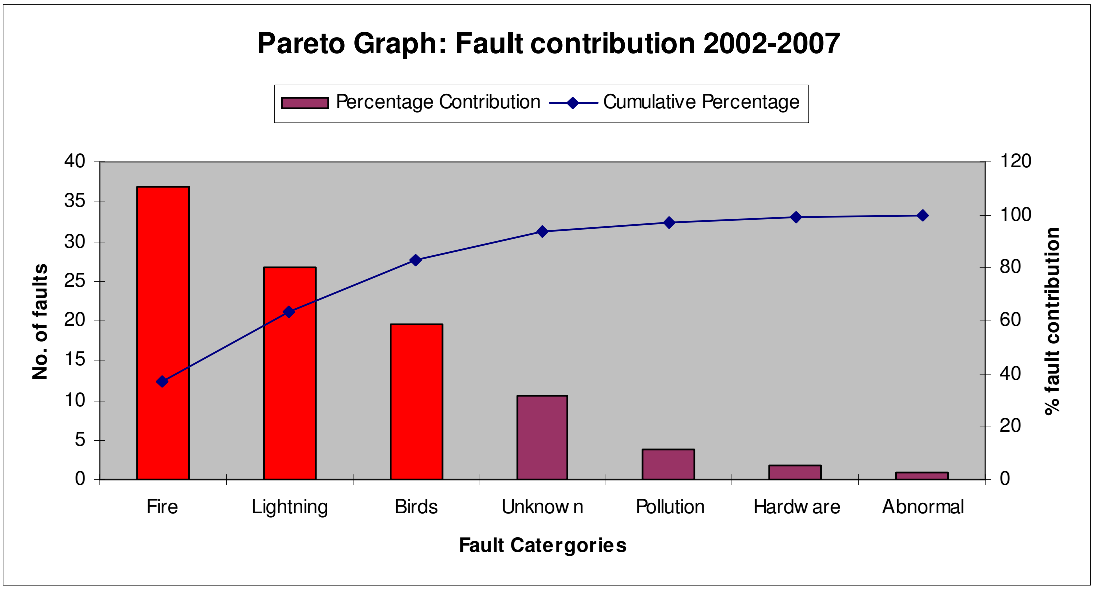
- Neighboring or supplying utility error or outage.
- Public contact.

C) <u>Environmental Factors</u>

- Vegetation growth within the servitude such as trees or shrubs causing flashovers.
- Fire: grass, sugar cane and reeds.
- Lightning induced flashovers.
- Severe weather conditions such as ice, snow or wind causing mechanical failure or flying debris causing electrical faults.
- Public contact such as vehicles or unauthorized climbing of towers.
- Vandalism such as gun shots and stone throwing.

Unknown causes for faults are relevant to all 3 categories mentioned above.

5.1.1.1(a) Fault Category Distribution



<u>Figure 5-1: Representation of 80% (Red Coloured Bars) of fault contribution</u>

The majority of the faults experienced are attributed to external/environmental factors (as indicated by red bar graph). These factors result in faulting of the overhead line either by phase to ground or phase to phase flashovers. The majority of these fault result in momentary outages (auto-reclosure). However sustained faults do occur depending on the severity of the fault condition. It is therefore important to correctly identify the root causes of these faults and to implement corrective action to minimize or prevent reoccurrences. The corrective action activity needs to be included in the overall maintenance management plan for the overhead line for budget allocation and for recording purposes.

5.1.1.2(b) Fault category trending

Trending and analysis of the external/environmental factors was done in terms of identifying any correlation between seasons (month of fault occurrence) and fault category. Figure 5-2 below represents the outcome of the trending.

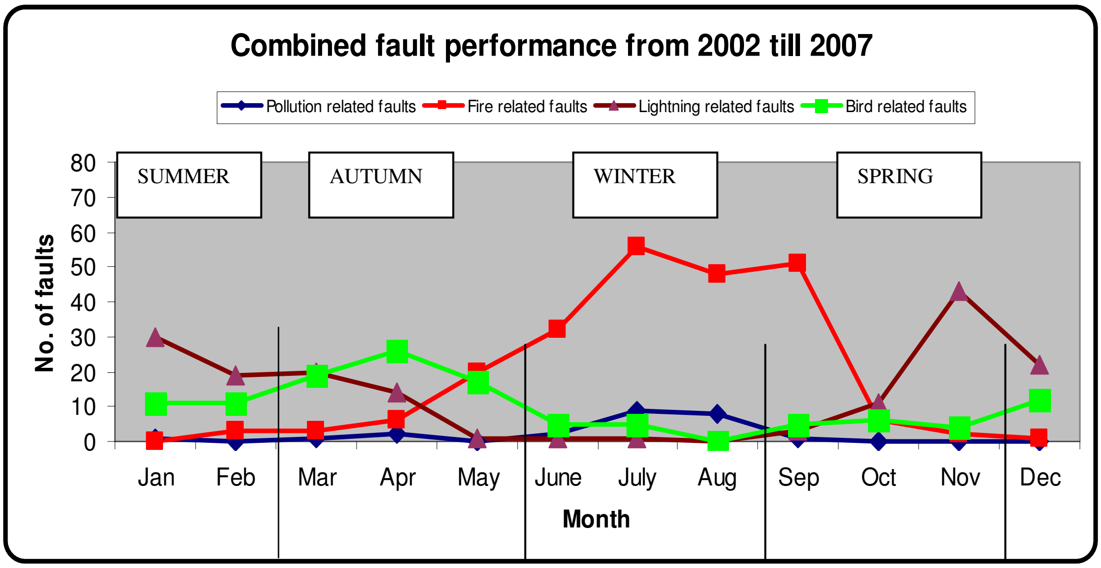


Figure 5-2: Seasonal representation of the various fault categories

Figure 5-2 indicates that all faults reflected above occur throughout the year. However the frequency of fault occurrence per fault category varies from month to month. For the purpose of the analysis it is assumed that where high frequencies of fault are occurring, these months will be considered as high risk months for that fault category and where the frequency is very low it is assumed that a potential risk exists.

Table 5-1 below reflects the summary of the analysis.

Table 5-1: Season vs. risk

Season	High Risk	Potential Risk
Summer (December,January,February)	1. Lightning 2. Bird	1. Fire
Autumn (March, April, May)	1. Bird 2. Lightning 3. Fire	1. Pollution
Winter (June, July, August)	1. Fire 2. Pollution	1. Bird 2. Lightning
Spring (September, October, November)	1. Fire 2. Lightning 3. Bird	1. Pollution

Based on the information provided above, there is a definite correlation between fault categories and seasons. It should be noted that it is only when a fault is found that it is categorized into one of the categories mentioned above or left as an unknown fault. The finding of the fault is linked to a tower number or spans i.e. the location of the fault. This fault location can be considered as a fault scar over the total length of the overhead line. The identified fault scar areas can be used to group certain fault categories and develop a fault profile for the overhead line.

According to the book, The Fundamentals and Practice of Overhead Line Maintenance (2004:30) utilities should determine which faults are most likely to be avoidable and which are most likely to be unavoidable. Based on the finding of the above mentioned book (2004:30) a summary is listed below in Table 5-2.

Table 5-2: Fault classification

Most Likely Avoidable Faults	Most Likely Unavoidable Faults
Fire Human errors Bird Streamer Pollution Vegetation Growth Contact Incidents Vandalism	Lightning Mechanical failure (breakage) Extreme weather conditions Pollution – location specific e.g. Sea Design inadequacies

The development of a pro-active (fault) condition monitoring program should focus primarily on the most likely avoidable faults and should also consider condition assessment of the most likely unavoidable faults as listed in Table 5-2.

Listed below is an example of a condition monitoring scope of work which is based on fault scar areas for Lowveld CLN. This scope of work can be used to schedule the various condition assessment programs per fault category.

Table 5-3: Example of a condition monitoring scope of work plan for Lowveld CLN.

No.	CLN	Plant Slot Description	Voltage (kV)	CATAGORIES			
				Birds	Fire	Pollution	Lightning
1	LOWVELD	Komatipoort Corumane No1	110				
2		Acornhoek Marathon No1	275		117-118		187
3		Acornhoek Marathon No2	275	63	92-100, 125-127		17, 188
4		Arnot Simplon No1	275	10, 34, 16, 17, 240, 197, 207, 125, 136, 36, 224, 75			2, 4, 8

5.1.2 Component performance

Component performance is related to establishing the present condition of the component based on similar component type, age, historical performance etc. In order to determine the condition of the component it is required to do random sample testing of components i.e. intrusive and non-intrusive testing. Listed in table 5-4 below, is an example of additional conditional assessments that can be done on the overhead line asset to determine the various components condition as reflected in the Cigre document titled Inspection Techniques for Detecting Defects on Overhead Transmission Lines (2000:59-84).

Table 5-4: Examples of condition assessment testing

Number	Component Condition	Inspection Types
1	Conductor Joint Defects	1. Visual (ground/aerial/support)
		2. Infra Red (IR) Thermography
		3. Joint resistance measurer (Live line or dead)
		4. Boroscope and Steel Sleeve Locator
2	Insulator Defects	1. Visual Inspection
	Porcelain and Glass insulators	
		2. Insulator Voltage Drop Measurer
		3. Electric Field
		4. Radio Frequency/Microwave Emission Detector
	Composite insulators	1. Visual Inspection
		2. Night vision equipment
		3. Electric Field
		4. Directional wireless acoustic emission
		5. Infra Red Thermography
		6. Radio Frequency/Microwave Emission Detector
3	Corrosion on joints on steel tower structure	1. Visual Climbing Inspection
		2. Electronic Paint & Galvanizing Thickness Measurer
		3. Cross Hatch Cut Test
4	Reduction in Stay Wire Tension and Stay Wire Corrosion	1. Hydraulic Method
		2. Vibration Method
		3. Deflection Method
		4. Corrosion Detector
5	Corrosion of Anchor Rods	1. Ultrasonic Pulser and Receiver
		2. Potential Measuring

One of the deficiencies of the pilot site study was that it was very difficult to establish from a visual inspection at what stage each component was within its lifecycle, i.e. reliable, degenerated or unpredictable [refer to Figure 3-3].

The overhead lines reviewed for the Grid's refurbishment audit project were chosen at random and the final list of overhead line selection was influenced by the field staff, i.e. based on previously identified concerns. The refurbishment audit focused on all items of the overhead line asset, i.e. servitude, hardware, statutory requirements and performance related components. The audit was conducted by Trans-Africa Projects (TAP) for the Grid. The summary of the findings are graphically represented in Figure 5-3 below.

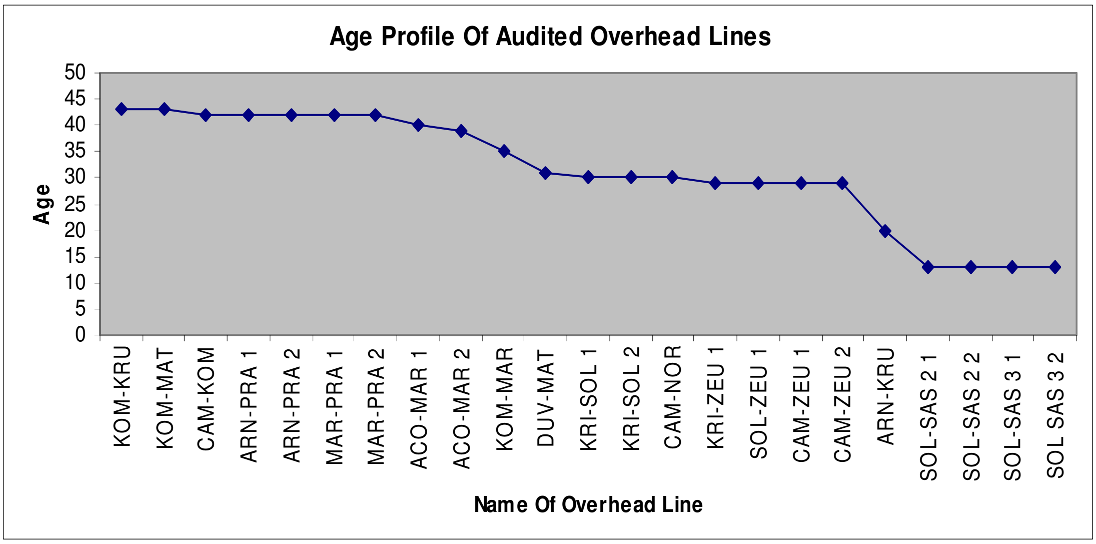


Figure 5-3: Represents the overhead line age profile of the audited overhead lines

The majority of the overhead lines audited were more than 25 years old. It should be noted that the scope of work for the refurbishment project of all the overhead lines audited was the same; however, some overhead lines were audited in selected areas (towers) whereas some overhead lines were audited over the entire overhead line, i.e. all towers from start to finish.

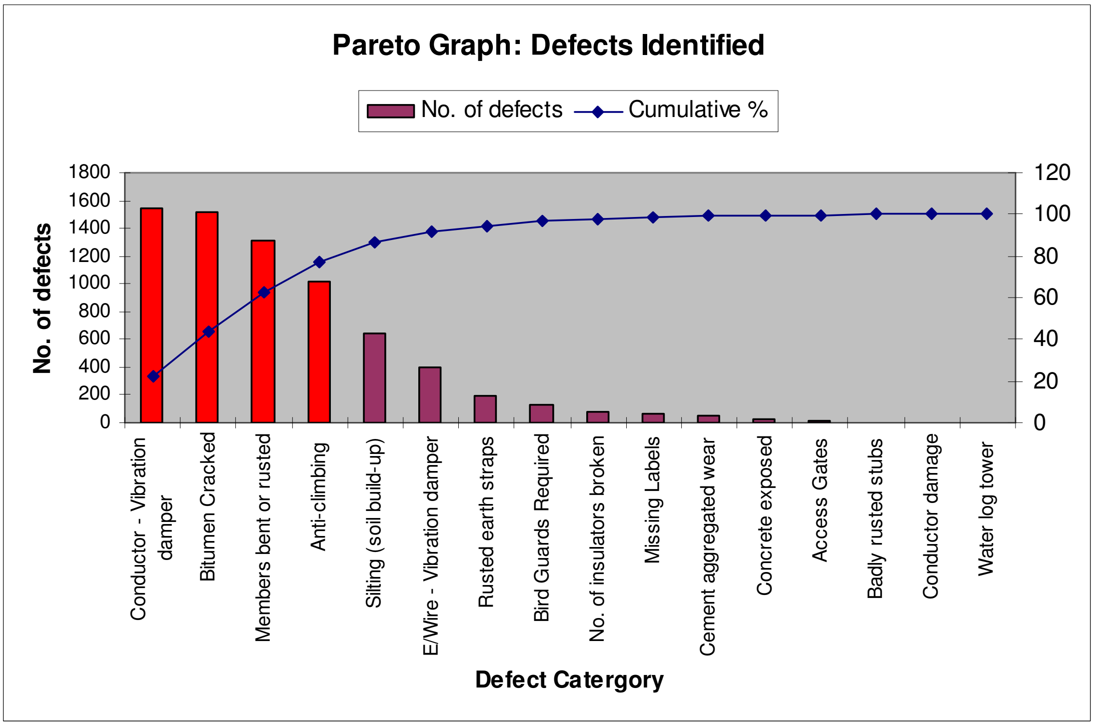


Figure 5-4: Representation of defects identified during the refurbishment audit

The majority of the defects identified above are defects normally identified during routine inspection of the overhead lines. Hence the refurbishment audit conducted was only a visual inspection (assessment) of the overhead lines asset.

5.1.3 Maintenance management analysis

It is stated in the EPRI document titled "Overhead Transmission Inspection and Assessment guideline" (2006) that:

"The roles of inspection and maintenance of overhead transmission lines are vital to any utilities' operations. In their absence, safety, availability, service life, and financial resources are exposed to undue risk. Safety and performance are the two primary drivers for inspection and assessment, as well as the requirement for maintenance".

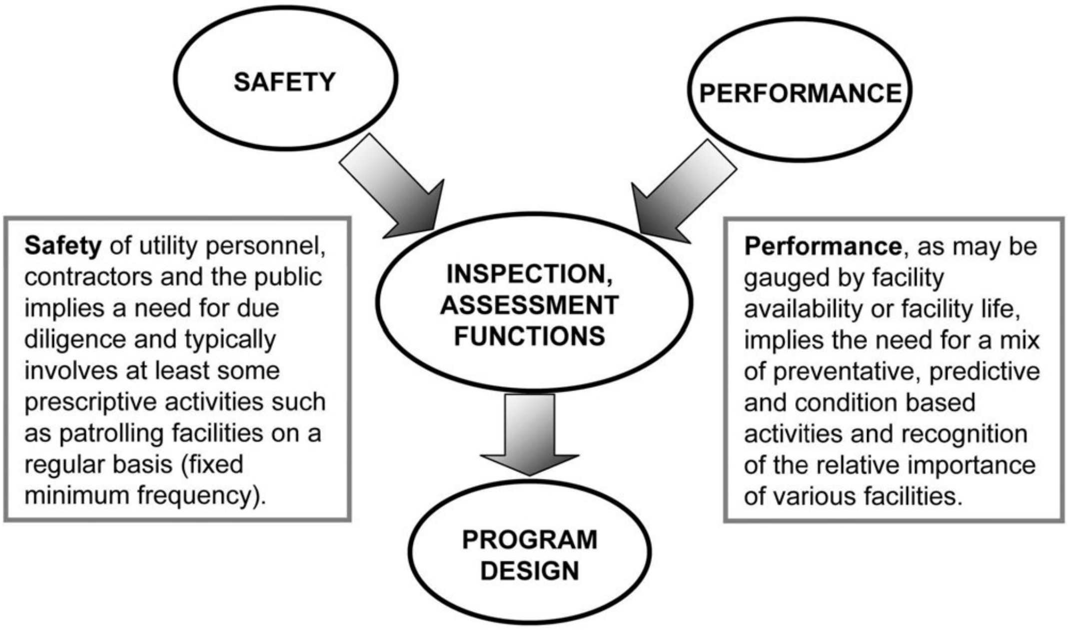


Figure 5-5: Key drivers for inspection and assessment (EPRI, 2006:3-5)

The annual cost of thorough overhead line inspection in Eskom is estimated at 0.025% of the total capital cost of an overhead line as explained in the book, The Fundamentals and Practice of Overhead Line Maintenance (2004:37). Overhead line inspections are carried out by utilities for four main reasons, namely (The Fundamentals and Practice of Overhead Line Maintenance, 2004:37):

- To verify that the overhead line was built to specification before commissioning.
- To determine the 'as built and maintained' status of the line being handed over from one owner to the next if it is not a new line.
- To do fault finding for maintaining optimum operational serviceability.
- To do condition monitoring to extend the lifespan of overhead line.

There are three important reasons for assessment of the condition of the overhead line which are summarized below (The Fundamentals and Practice of Overhead Line Maintenance (2004:39) :

- To ensure that the operational targets for continuity and availability of power transfer services are met.
- To ensure that the equipment will be in a serviceable condition until it reaches the end of its lifecycle.
- To make decisions on refurbishment when the overhead line reaches the end of its lifecycle.

5.1.3.1 Hardware defect identification

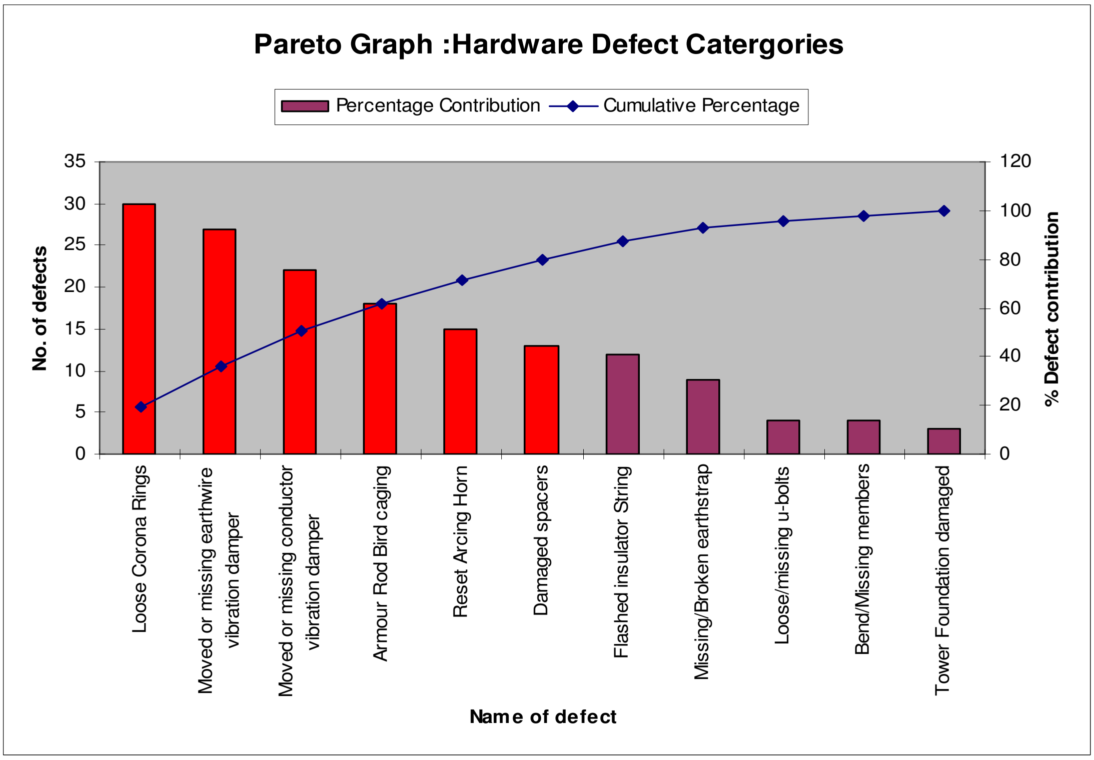


Figure 5-6: Representation of hardware defect contribution

The red bar graphs indicate defects which contribute to 80% of the total hardware defects identified. The defect category of broken insulators was removed from the graph due to the fact that the highest number of defects found was as a result of broken glass insulators i.e. 1 858 defects identified.

Based on the review of the Grids' overhead line inspection program, it was found to be effective in the sense that defects were regularly identified and recorded on the inspection sheets. However when it came to the maintenance of the hardware defects, not all defects were repaired. The neglected defects were ignored and not re-scheduled as once-off activities to complete the maintenance task.

On further analysis and discussion with the maintenance teams, it was identified that all hardware maintenance was executed by a centrally managed live line maintenance team. This central team performed maintenance for the entire Eskom Transmission overhead lines. They worked on a strict maintenance program to cover every overhead line within Eskom Transmission over a 3 yearly cycle. The live line teams' objective was to do as much maintenance identified over the duration of time allocated to the overhead line, i.e. restricted to time and resources availability. The weakness of this type of approach is that the live line teams decided what work should be done and no formal component rating system (high, medium and low) was utilized in terms of maintenance prioritization. Maintenance was prioritized on experience, time to execute the task and availability of resources, instead of importance to the network.

5.1.3.2 Servitude defect management

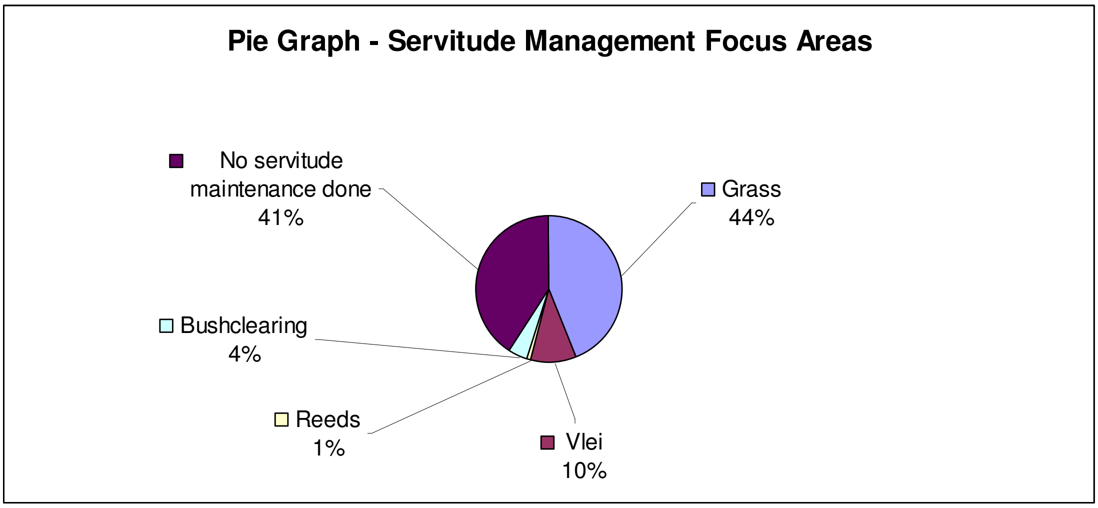


Figure 5-7: Percentage servitude management breakdown

A total of 59% of the present servitude total overhead line length (km) is maintained by performing grass management, vlei management, reed management and bush clearing.

The servitude underneath an overhead line may not be involved in the process of electricity transfer but an uncontrolled servitude in terms of vegetation management will interrupt the electricity transfer. Based on the performance history of the pilot site, the number one fault contributor is fire, i.e. burning of vegetation. It is for this reason that the Grid has to ensure that effective vegetation management is executed annually.

The overhead line is affected by vegetation in the following manner, namely (The Fundamentals and Practice of Overhead Line Maintenance, 2004:194):

A) Safe Clearances

Trees growing into the overhead line (The Occupational Health and Safety Act, Act 85 of 1993, of South Africa) stipulate the minimum clearances to be adhered to for a range of voltages).

B) Falling Trees

Large trees might fall on overhead line and cause a short circuit to ground. This type of problem will only occur on overhead lines which are located in the vicinity or close proximity to large trees associated with plantations and forests.

C) Fires

- Utilities in Europe and North America do not experience fire as a major high frequency cause of line faults, as is the case in South Africa. Utilities in South America, however, report similar problems with sugar cane, shrubs and grass fires as in the South Africa case, but at a lower incidence.

- Some utilities experience problems with fires resulting from agricultural activities such as the harvesting of sugar cane, the burning of fire breaks or veld management practices using fire.

Annually, North East Grid spends an average of R7.5 million on servitude maintenance. The Grid maintains 59% of the total servitude distance i.e. 2 135.21km. The vegetation management consists of grass, vlei, reeds and bush clearing. The Grid is also experimenting with grass burning instead of grass cutting. This vegetation management approach is new and not much information is available at the time of this research study.

Based on the Grids overhead line fault investigation report, it was found that all faults related to vegetation, mainly fire faults, have occurred at the mid span of the conductor. This fault mechanism is attributed to an air gap breakdown between the conductor and ground i.e. phase to ground failure. However, on the Komatipoort/Marathon 275kV overhead line, the majority of the fire faults have occurred as a result of phase to phase failure. On investigation it was found that the vegetation within the servitude was sugar cane and the tower configuration was a delta structure i.e. one conductor was above the other. Based on this finding it should be noted that mitigation of vegetation faults should consider tower configuration (air gap clearance), type and density of vegetation underneath the overhead line.

For effective vegetation management, it is required to properly identify what type of vegetation is growing underneath and in the vicinity of the overhead line. Based on the fault graphs depicted in Figure 5-2 above, fire faults occur from Autumn till Spring and peak in June till August annually. Based on the trend reflected in Figure 5-2 for fire related faults, it would be advisable to ensure that vegetation management in the Grid is planned and executed before April, to prevent or minimize fire related faults, i.e. grass cutting, reed cutting etc.

5.1.3.3 Establishment of a defect / condition assessment process

It was observed that the Grid focused mainly on defect management and had no records of any detailed component condition assessment conducted on the overhead line.

Defect management is defined as any form of defect that is found on the overhead line which differs from the original design specification of the overhead line, i.e. missing tower members, broken glass insulators etc. Defect management will tend to focus on short term, day to day, identified concerns.

Condition assessment is defined as performing sampling on an overhead line component by subjecting the component to a series of testing, that may be intrusive or non intrusive, with the objective of predicting the residual life of the component i.e. at what the stage the asset is in its lifecycle. Condition assessment will focus on the long term issues that have to be identified and corrected by implementing remedial actions e.g. refurbishment projects.

A group session was held with selected overhead lines and servitude staff of the Grid to establish a generic component defect risk rating which could be used to categorize component defect severity into high, moderate or low status. This rating system will assist the Grid to manage their defects more consistently. The first part of the session involved using RCM techniques to establish a baseline and understanding of the various components, i.e. function, failure mode and failure consequences.

The second part of the day session involved applying FMEA/FMECA techniques to the list created by RCM techniques, to establish the defect risk rating. The risk matrix utilized for this process is reflected in Appendix 3. The scale for the risk ranking system was as follows:

- 6-9 Intolerable Risk (commonly referred as a high risk) - corrective action must be taken.
- 4-5 Tolerable Risk (commonly referred as a moderate risk) – corrective action recommended.
- 1-3 Low Risk (commonly referred as a low risk) – improvements may be considered.

Listed below in Table 8 is a sample of the RCM risk ranking system utilized to obtain a risk rating for typical defects identified on the overhead line. The sample RCM table reflects that it would be possible to establish a defect severity rating for the overhead line asset. These maintenance management techniques will ensure that defects are prioritized correctly.

Table 5-5: RCM applied to the overhead line

Grouping	Failure Mode (Cause Of Failure)	Failure Effect (What Happens When It Fails)	Consequences/Severity	Frequency/Likelihood	Score
Tower Structure	1. Stealing of tower members (main/bracing members)	May result in tower leaning longitudinal/transversely or collapse	Major	Frequent	8
Foundation	1. Corrosion of steel surface of tower leg	Tower may collapse.	Major	Possible	6
Anti-climbing Device	1.Broken/damaged/rusted/stealing of anti-climbing device	Allows easy access to tower and could result in death.	Major	Frequent	8
Vegetation	2. High trees growing underneath the line	Result in a permanent fault	Major	Possible	6
Warning Spheres	1. Not visible anymore	Air traffic may fly into the overhead lines	Major	unlikely	5
Warning Labels	3. Tower number label not installed	Safety Hazard	Major	unlikely	5
Insulator	1. Wear on u-bolt/missing W pin and split pin for both glass and composite insulators	Result in string breaking form connecting points to tower and conductor	moderate	unlikely	4
Vibration Damper	1. Vibration damper missing/moved/broken or twisted	Results in conductor galloping.	moderate	Possible	5
Spacer	1.Damaged/broken/moving/loose	Results in clashing of insulators	moderate	Possible	5
Span conductor	2. Bird caging/broken strands.	If left unattended will result in conductor unraveling and breaking.	moderate	unlikely	4
Stay wire	4. Foundation damaged/soil erosion	If left unattended will result stay pulling out and result in tower collapsing.	moderate	unlikely	4
Joint/Crimps	2. Joint Incomplete	Result in unattended in the joint separating and conductor breaking	moderate	unlikely	4
Vibration Damper	3. Design (cannot tighten the bolt securely)	Make come loose and be unable to provide damping.	Minor	likely	5
Earth Straps	1. Substandard footing resistance	Result in back flash and result in flash occurring between the insulators.	Minor	likely	5
Vegetation	1. Result in veld fires.	Trip the overhead line	Minor	frequent	6
Vegetation	4. Burn without notification	May result in tripping the line	Minor	likely	5
Vegetation	5. Burning of old maize fields	Result in tripping the line	Minor	likely	5
Insulator	6. Corona ring not installed on composite insulators	Results in pitting occurring on the composite insulator, which will lead to puncture in the composite allowing water to enter the composite insulator internally.	Minor	Possible	3
E/W Insulator	1. No arcing horn installed/ Wrong arcing horn gap	No over voltage discharge taking place.	Low	likely	4
E/W Insulator	2. In correct earth wire connection (loop in/loop out)	Circulating current and may result in localized hot spot and breaking of supporting hardware	Low	likely	4
E/W Insulator	3. Broken Insulator	Reduction insulation surface area.	Low	Possible	3
Bird Guards	1. Fallen of the tower.	Result in bird tripping the line	Low	likely	4
Gates & Locks	1. Locks changed	Unable to access the servitude	Low	Possible	3

A similar process can be utilized to establish a condition assessment rating.

5.1.3.4 Condition database

During the pilot study it was found that historical defect management information was not available. This unavailability of information was attributed to the Grid not capturing the information electronically. Based on the lack of historical data the researcher was only able to find two year trends on similar defects reported and not attended on 3 overhead lines.

It is recommended that a condition database be implemented to support the capturing of defect data electronically. This condition database can be used to track defects historically for trending purposes and can be used for planning of condition assessment activities, i.e. scheduling problematic overhead lines first in the sequence for inspection etc.

5.1.4 Optimized Decision Making (ODM)

ODM is a formal process to identify and prioritize potential solutions taking based on financial viability, social and environmental responsibility and cultural outcomes as explained in the International Infrastructure Management Manual (2006).

The International Infrastructure Management Manual (2006) explains ODM as a decision making process and list the 2 processes below which is commonly used namely:

- *'Benefit-Cost Analysis (BCA): BCA involves quantifying and comparing benefits and/or cost over a period of time. The Net Present Value (NPV) can be calculated using Discounted Cash Flow (DCF). The project with the highest Net Present Value or Benefit-Cost ratio is usually selected'.*

- *'Multi-Criteria Analysis (MCA): In a MCA, a range of criteria is chosen to represent the different outcomes or aspects of each option being considered. The criteria (such as environmental benefits) may be weighted to reflect a business and/or community's interests. An overall score is given to each project option'.*

5.2 Establishment of key aspects for an AMP

The development of an asset management plan involves two approaches i.e. "Bottom Up" or "Top Down" analysis. According to the International Infrastructure Management Manual (2006:2.41), each approach has its advantages and disadvantages, as listed in Table 5-6 below:

Table 5-6: Top down Vs bottom up approach to developing AMP (International Infrastructure Management Manual, 2006:2.41)

Criteria	Top Down Analysis	Bottom Up Analysis
Advantages	• Supports the 80/20 rule (get 80% of the result from the first 20% of effort). • Identifies weaknesses in the plan earlier and focuses on the appropriate data as opposed to perceived data needs. • Initially less resource intensive. • Better use of limited resources and quick results.	• Outputs are data driven with a high degree of confidence. • Data is of a high quality. • Ability to undertake data modeling and improve decision making. • Continuous plan revision is simpler.
Disadvantages	• Potential for compromise quality and completeness of data. • Assumptions required to make decisions. • Potential for inappropriate decision making. • Inability to undertake detailed modeling and sensitivity analysis.	• Data collection takes time. • Time of production can impact on the ability to make urgent decisions. • Potential to lose focus on objectives – too focused on data issues. • Costly and time consuming. • Organization can become data rich and information poor. • Lack of focus on supporting AM activities.

Figure 5-8 below reflects the different types of asset management plans that can be established based on the top down and bottom up approach (International Infrastructure Management Manual (2006:2.41).

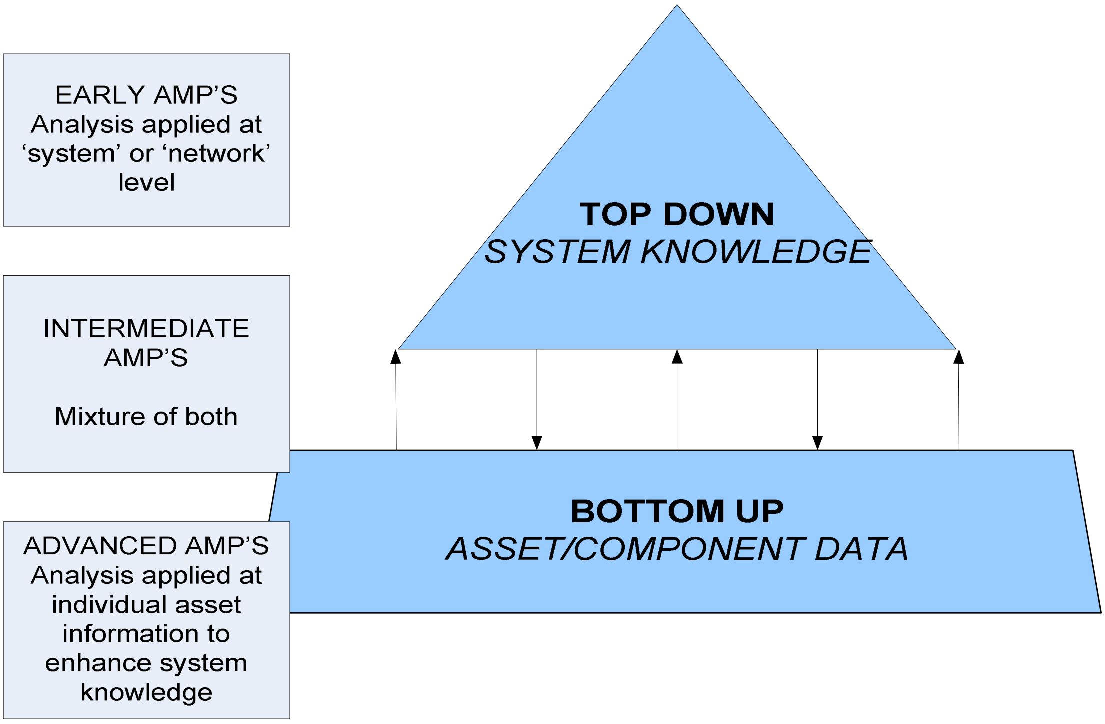


Figure 5-8: Different AMPs generated as a result of top down and bottom up approach (International Infrastructure Management Manual, 2006:2.41)

Every AMP will operate towards a set asset management system. The asset management system will guide the process for the development and review of the AMP. Figure 5-9 below is a summary of the asset management system highlighted in PAS 55-1:2004 (2004:3).

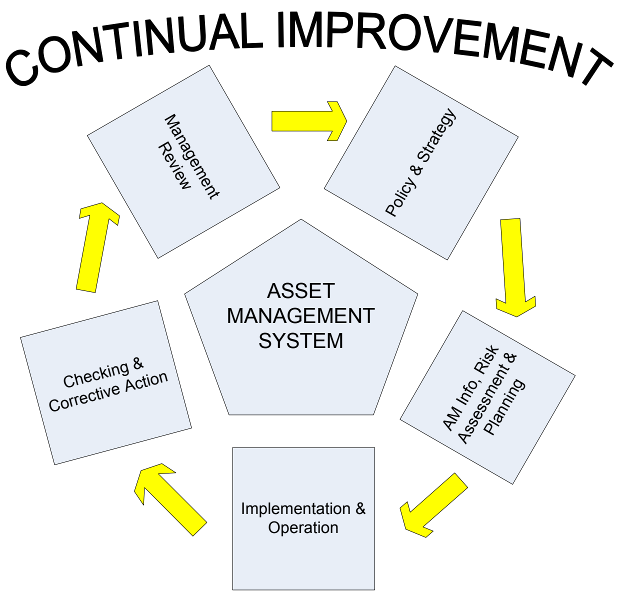


Figure 5-9: AMS elements (PAS 55-1:2004, 2004:3)

EPRI (2006) has also defined elements of an asset management system which is shown in Figure 5-10 below. The two AMS's reflect the same key issues.

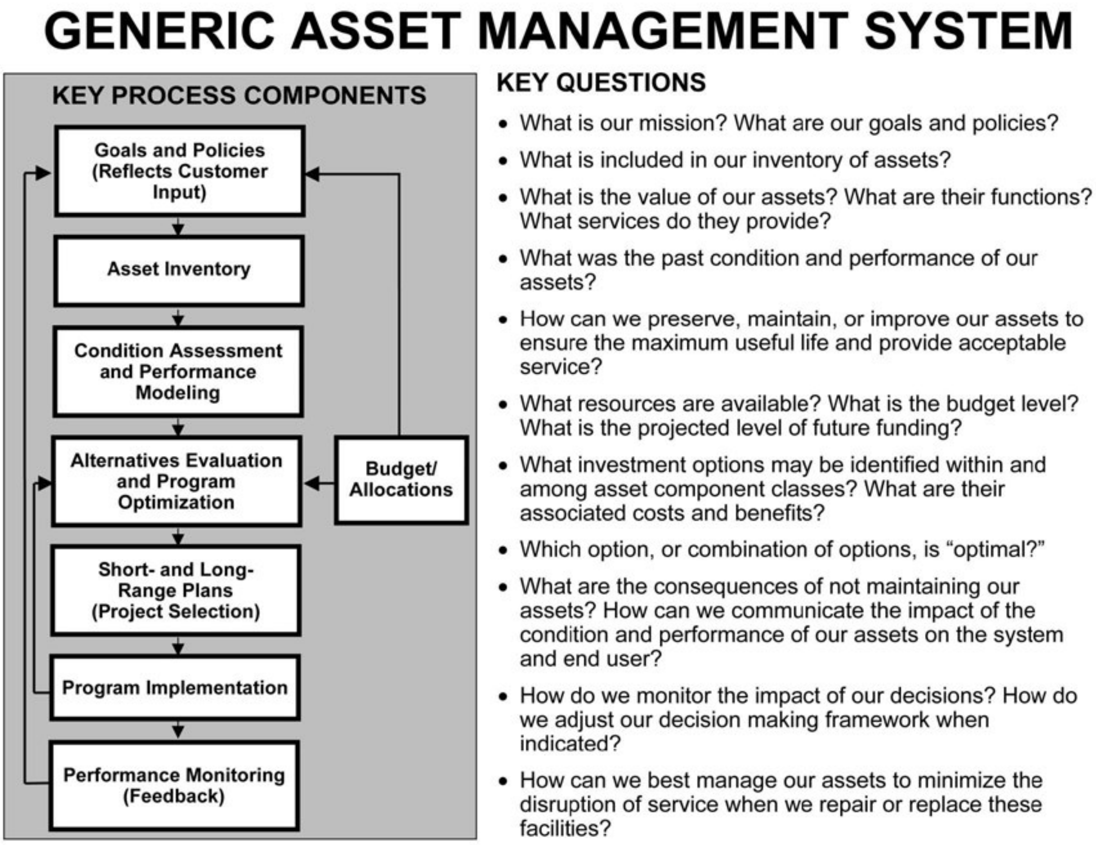


Figure 5-10: Key process components of and questions answered by a generic AMS (EPRI, 2006:2-4)

The following key aspects need to be included in the AMP:

A) Asset Management System (AMS)

The AMS or process is defined in the publicly available specification (PAS 55-1:2004). This specification defines how the AMS should operate and defines each section of the system as reflected in Figure 5-9. It is important to continually review and improve the effectiveness of the AMS and update the AMP accordingly.

B) System knowledge

It is important to understand the entire network system and how the specific overhead line impacts on the network. The overhead line asset as explained in earlier chapters connects two points on a system. When the network is reviewed from a holistic view and when load flow analyses are done in terms of potential plant failure and alternate route of supply, the level of importance of the overhead line can be defined i.e. n-1, n-2 etc. It is also advisable to have meetings with the operational team leader, or teams for primary and secondary plant, to get a better understanding of the risk facing their area of plant and build their concerns into the AMP.

i.e. increase frequency of inspection, prioritize performance improvement related projects etc. Where possible it is advisable to take an integrated system approach, and consider the generation links and distribution links to strengthen the transmission link.

C) Defining the physical asset parameters

The International Infrastructure Management Manual (2006) uses the terminology of level of service to define the asset performance/parameters. The levels of service are separated into 5 sections (International Infrastructure Management Manual, 2006) i.e.

- Customer research and expectations
- Strategic and corporate goals
- Legislative requirements
- Current level of service
- Desired level of service

The overhead line is defined as a component in the entire network and its impact on failure was seen as affecting the entire system, whereas in this section the asset is looked at in isolation, i.e. self analysis. It is very important to ensure that customers' expectations are understood and maintained, in order to have good customer relations and avoid penalties being imposed. All organizations and companies have strategic and corporate goals and all decisions in terms of the asset are based on these goals.

Legislative requirements are important in the planning, design and maintenance of the overhead line asset in terms for SHEQ. These requirements in terms of cost need to be built into the costing model of the overhead line asset i.e. OPEX and CAPEX.

The current and desired level of service defines the service being provided by the asset. In the pilot study, the overhead line's performance criteria were based at 2.2 faults per 100km. This in turn means each overhead line asset needs to maintain a performance of 2.2 faults per 100km. If the performance deteriorates from the criteria, then only should a performance improvement project (birds, fires, lightning etc) be implemented to correct the deviation. When the desired and current levels of service are far apart, a gap analysis should be done to identify what corrective actions can be implemented to reduce the gap.

D) Lifecycle management plans

Lifecycle management plans are associated with all the activities related to the physical asset. The following aspects should be covered in the lifecycle management plan:

- Operations (Inspection)
- Maintenance
- Condition and performance monitoring
- Rehabilitation/renewal (Refurbishment)

E) Risk management

A risk management study needs to be conducted to identify all the possible risks associated with the overhead line asset. The identified risk will then have to be evaluated in terms of a risk matrix and each risk will have to be ranked. Based on the risk ranking, the risk is prioritized. Mitigation activities are identified to reduce the risk impact.

F) AM information

Accurate information on the asset is required to support effective decision making with respect to the asset.

5.3 Generic structure for an AMP for overhead lines

A generic structure for an AMP applicable to an overhead line asset is set out below. The AMP structure will cater for a basic, intermediate or advanced plan which will be determined by the level of information used for the plan. Refer to chapter 5 for guidance on how statistical analysis can be conducted for example fault category distribution, seasonal fault trending, age profile etc.

The generic structure for an AMP for overhead lines is based on the fundamental key elements mentioned in the International Infrastructure Management Manual (2006:A1) for asset management plans.

Section 1: Executive Summary

The executive summary summarizes the issues contained in the body of the AMP.

1.1 The purpose and objective of the plan

- To demonstrate responsible management.

- To communicate and justify funding requirements.
- To comply with regulatory and best practice requirements.

1.2 Date of plan and the period to which the plan relates

- Reflect the validity of the plan.

1.3 Network and asset description

- Summary of factors affecting future demand.
- Summary of network concerns.
- Asset description, age, condition and justification.

1.4 Service level objectives

- Summarize levels of service and performance measures.

1.5 Risk assessment

- Summary of all risk facing the overhead line.

1.6 Lifecycle management plan

- Summary of lifecycle management strategies (inspection, maintenance, refurbishment etc.)

1.7 Financial summary

- Long term income and expenditure (cash flow) projections.
- Sources of funding.

1.8 Asset management practices

- Summary of AM data, information systems, processes (decision making) and implementation tactics.

1.9 Plan improvement and monitoring

- Summary of how performance of the AMP will be monitored.
- Summary of actions required to improve accuracy and confidence in the AMP.

<u>Section 2: Introduction</u>

The introduction must provide an overview of the business process, documentation and stakeholder concerns.

2.1 Background

- Purpose of the plan.

2.2 Interaction with other corporate goals, business planning processes and other plans

- Relationship with other planning documents.
- Organization structure.

2.3 Stakeholder interests

- Key stakeholders in the plan.

Section 3: Service Level

This section defines the levels of service that are proposed and confirm the basis of the level of service to be adhered.

3.1 Customer Expectations

- Defines the customer's requirements in terms of service delivery and response to customer complaints.

3.2 Strategic and Internal Business Goals

- Describes the organization goals facing the business.

3.3 Legislative requirements

- Background legislation or regulations which affect asset operation or require levels of service.

3.4 Business score card

- Targets applicable to the asset:
  - Finance – budget allocation, staff training etc.
  - Performance – statistics of failure rates, fault per 100km, etc.
  - Customer Surveys – targets (generation, distribution, major customers) etc.

Section 4: Network Integration and Expansion

This section provides details of network constraints in terms of load growth, status of other failed assets which may affect quality and continuity of supply.

4.1 Load forecasting

- Review status of load growth.

4.2 Other asset failure that impact on network reliability

- Get a system view to identify weak point on the network.
- Identification of critical corridors in term of load.
- Identify overhead lines where extra inspections would be required.

4.3 Strategic plans by area

- Identify areas where special plan need to be made to improve loading problems, i.e. condition monitoring of concern areas.

Section 5: Lifecycle Management Plan (Statistical Analysis)

This section of the AMP will outline the planned items to ensure the agreed level of service is maintained.

5.1 Background Data

- Physical Parameters.
  - General comments on assets, i.e. age, location and current issues.
  - Summary of total asset parameters in table or graph format, i.e. age distribution, voltage, etc.
- Asset Performance
  - Graphs depicting trends need to be presented in this sub section, namely:
  - Number of faults
  - Fault category contribution (80/20 analysis)
  - Time of day analysis
  - Seasonal trends
  - Worst performing overhead line (number of faults histogram) etc.
- Asset Condition
  - Summary of current asset condition based on best information currently available.
  - Details on how condition is monitored.
  - Age and condition profile graphs.
  - Fault profile per overhead line.
  - Vegetation profile per overhead line.

5.2 Routine Inspection and Maintenance Plan

- The routine inspection and maintenance plan is the regular day to day work activities plan.
- Inspection and maintenance plans.
- Trends (i.e. spending, complaints) and issues.
- Maintenance decision making process (planned and unplanned).
- Standards and specifications.
- Define materials, methods, service standards to meet required levels of service.
- Summary of future cost.
- Forecast of planned and unplanned maintenance work and costs.
- Note any maintenance deferred and the associated risk.

5.3 Condition Monitoring Plan

The condition monitoring plan will be based on the last 3 years' fault history. The scope of the work will be derived from the last 3 years' fault history performance.

- Development of the plan
- Analysis of 3 years performance fault history.
- Develop the scope of work per overhead line.
- Link the condition monitoring activity to commence before the fault category month.

5.4 Component Condition Assessment Plan

- Identify the overhead lines where sampling of the components will take place to determine the life span of the component.
- Development of a component condition assessment program
- The component condition assessment program will focus on the sampling of random hardware on the overhead line. The samples will be exposed to intrusive and non-intrusive testing.
- Assessment report
    - An assessment report will be generated after each sampling. The report will define what test was conducted and the component status.

5.5 Disposal Plan

Disposal is any of the activities associated with the disposal of a decommissioned asset, including sale, demolition or relocation.

5.6 Emergency Preparedness Plan (EPP)

The operation teams will have to ensure that all identified staff is trained on how to react to emergency situations. Proactive planning is required in terms of scenario planning and availability of the spares/personnel to execute repairs in terms of an emergency. All details in terms of EPP should be recorded in this section of the AMP.

Section 6: Financial Summary

This section contains the financial requirements resulting from all the information presented in previous sections.

6.1 Financial Statements and projections

- Cash flow forecast.
- Breakdown of expenditure.
- Trends in spending behavior.

6.2 Funding Strategy

- Provide details of how funding will be provided.

6.3 Valuation Forecasts

- Forecast of future value of asset and valuation methodology.
- Forecast asset depreciation.

Section 7: Asset Management Practices

This section outlines the information available on the asset, the information systems used and process used to make decisions on how the asset will be managed.

7.1 Asset Management Systems

- What type of data is available on the asset to help in AM decision making?
- Where is the data stored and how is the data utilized in decision making?

Section 8: Risk Management Plan

In this section the risks affecting the asset are identified, ranked and the mitigation process is tracked.

- Risk register.
- Progress on mitigation activities.
- Identification of new risks.

Section 9: Plan Improvement and Monitoring

This section provides details on planning for monitoring the performance of the AMP and any improvements to the AMS that will improve the level of confidence in the plan.

- Review of progress against plan, both physical and financial.
- Evaluation and comparison of actual performance against targeted performance objectives.
- Gap Analysis and identification of improvement initiatives.

Section 10: References

Section 11: Appendices

CHAPTER 6: DESIGN OF A GUIDELINE TO COMPILE AMP FOR OVERHEAD TRANSMISSION LINES

6.1 Introduction

The concept of asset management is based on effective information management to make optimized decision making for the asset, i.e. find the balance between cost, risk and performance. This AM concept may seem easy to achieve in principle, but in reality involves several inputs contributing to the holistic management of the overhead line asset. These inputs can be grouped into 3 distinct areas, namely strategic planning, tactical planning and operation planning (International Infrastructure Management Manual, 2006:1.6-1.8).

6.1.1 Strategic planning

Strategic planning will involve the process of reviewing the entire asset and include the tactical and operational plan. Strategic plans have a 10-25 year horizon and are mainly for financial planning purposes. Although asset managers may look beyond this period in order to develop optimum lifecycle strategies (International Infrastructure Management Manual, 2006:1.6).

The key aspects to be considered in strategic planning are as follows:

- Legal and stakeholder requirements and expectations
- Organization strategic plan (vision, mission, objectives, level of service, business policies, risk etc.)

6.1.2 Tactical planning

Tactical planning is the application of the detailed asset management processes, procedures and standards to develop individual plans that allocate resources to achieve strategic goals and meet the defined level of service (International Infrastructure Management Manual, 2006:1.7).

The key aspects to be considered in tactical planning are as follows:

- Customer service plan (understand both internal and external requirements and impacts)
- Human resources plan (staff requirements to deliver the desired level of service)
- Financial plan (budget allocation in terms of the various operational and non-operational activities)
- Development of AMP (documented details of asset management practices including asset performance, asset risk etc).

6.1.3 Operational planning

The operational plans are the detailed implementation plans and information, focusing on a short term outlook, i.e. 1-3 year view. These operational plans guide the maintenance management of the overhead line asset (International Infrastructure Management Manual, 2006:1.7).

The key aspects included in the operational plan are as follows:

- Human resources
    - Number of staff required to execute the task.
    - Competency of the staff (provide adequate training and assess competency).
    - Allocation of safety clothing, tools, vehicles etc.
- Risk management
    - Define methodology to assess and quantify risk.
    - Implementation of risk mitigation.
    - Review progress.
- Emergency response preparedness
    - Provide staff will training with respect to emergency preparedness.
    - Identify strategic spares in terms of emergency situations (review all overhead line spare requirement for the area).
    - Establish an overhead line restoration plan.
- Maintenance
    - Establishment of a defect management system.
    - Establishment of a defect database (user defined criteria).
    - Develop an overhead line inspection plan.
    - Develop a condition monitoring plan.
    - Develop a condition assessment plan (used to define refurbishment scope of work).
    - Conduct performance trending, i.e. faults and components etc.
- Financial
    - Link budget with operational plans
    - Trend spending patterns
    - Create funds for newly identified projects, equipment etc.

6.1.4 Gap analysis of pilot site overhead lines

6.1.4.1 Maintenance management focusing on short term objectives

The management of the operational aspect of the overhead line is executed according to the Grids minimum stipulated standards and policy. These policies and standards limit the operational teams to perform activities related to short term objectives. The Grids maintenance management is very limited in its scope for effective management of the overhead line. The primary focus on the Grid is to execute inspections, i.e. ground or aerial inspections. The challenge facing the grid is that defect management is inconsistent and in some aspects totally depends on other external departments to prioritize defects. The Grids inspection information management system is limited to paper copies. Older inspection reports are seldom available and the majority of the time is discarded. There is a definite requirement to establish a defect database for tracking defect management progress and defect component trending.

6.1.4.2 Inspection based on defect management rather than condition assessment

Based on the refurbishment audit conducted on the overhead lines, as discussed in previous chapters, the scope of work for the defects identified is the same as that which would be applicable to defects found under a routine visual inspection. The Grids' scope of work requirements for refurbishment needs to be defined. Component condition assessment sampling using either intrusive or non-intrusive testing on an overhead line will provide details of the components' estimated life span. Based on these test results, a refurbishment scope of work can be defined. This type of approach will separate the two activities, i.e. inspections and refurbishment.

6.1.4.3 Maintenance budget based on historical costing and activities rather than critical performance related activities

The financial planning was based on set operational activity costing. It was also observed that many unplanned activities were taking place with respect to overhead line breakdowns and additional maintenance was being undertaken which resulted in over expenditure of the budget.

6.2 Design layout

The design layout of the guideline consists of two parts as indicated below in Figure 6-1. Part 1 is the generic AMP for overhead transmission lines. The detail of this AMP was discussed in Chapter 5 i.e. basic structure is available. Part 2 comprises of the guideline for effective maintenance management in a flowchart format. Refer to Figure 6-2 for the details of the guideline for effective maintenance management.

Part 1: Generic AMP for Overhead Transmissions lines

Section 1: Excutive Summary
Section 2: Introduction
Section 3: Service Level
Section 4: Network Integration and
Expansion
Section 5: LifeCycle Management Plans (Statistical Analysis)
Section 6: Financial Summary
Section 7: Asset Management Practices
Section 8: Risk Management Plan
Section 9: Plan Improvement and Monitoring
Section 10: References
Section 11: Appendices

Part 2: Maintenance Management Flow Chart

- Refer to Figure 6-2.

Figure 6-1: Process for compiling AMP for overhead transmission lines

6.3 Design of the guideline for effective maintenance management

The guideline document reflected below in Figure 6-2 is a maintenance management flow chart which can be applied to any overhead transmission line. The guideline is designed to cater for both routine condition assessment activities and component condition assessment sampling. The guideline will ensure that maintenance activities are executed and recorded for trending purposes.

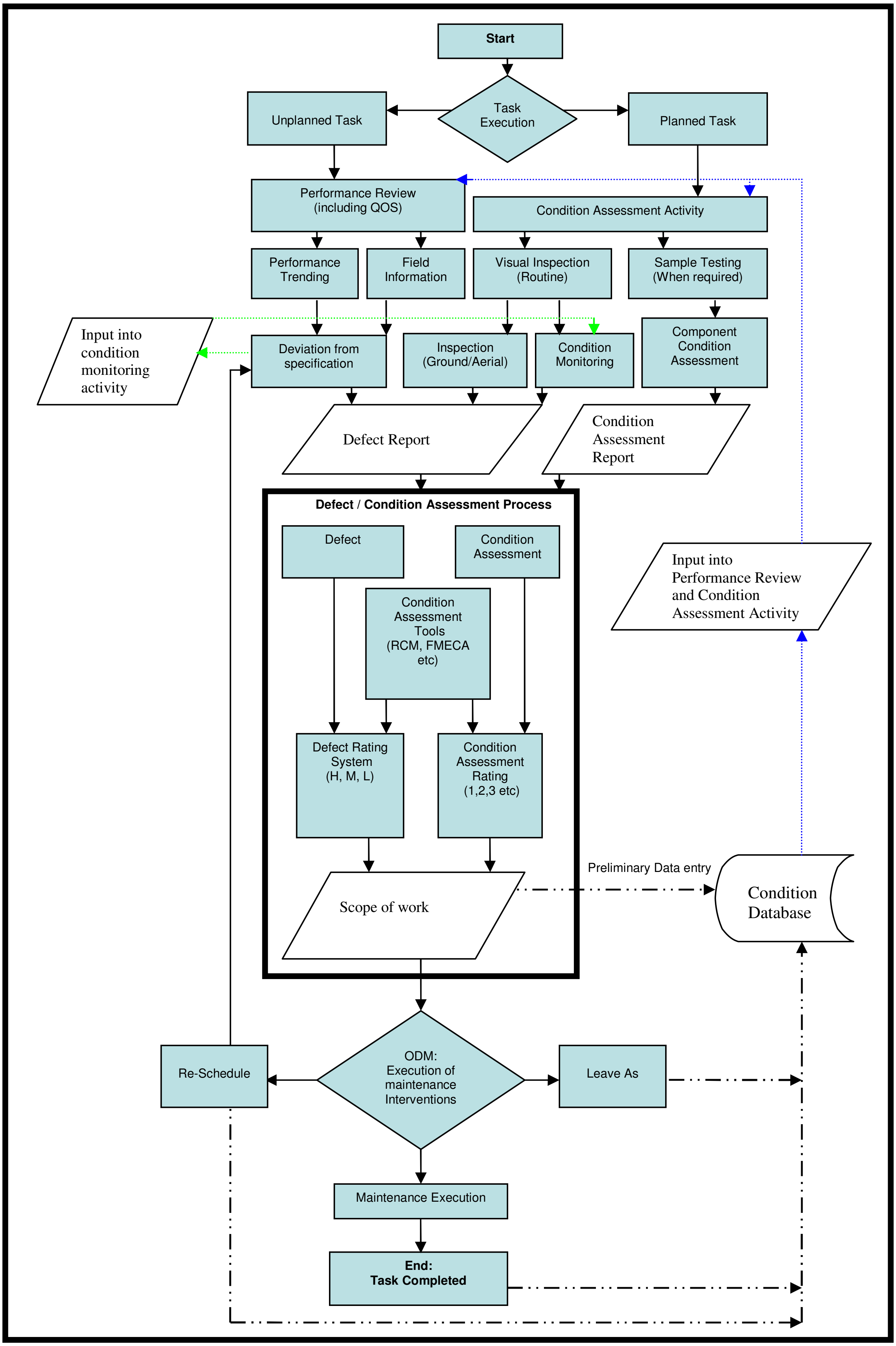


Figure 6-2: Maintenance management flowchart

The flowchart reflected above in Figure 6-2 is a holistic approach to maintenance management. The design caters for two types of condition assessment activities namely defect management and condition assessment.

The pro-active component of the guideline is reflected by performance trending, field information and re-scheduling of work. All identified defects from the 3 mentioned focus areas are captured in a defect report for execution. Any additional defects not included in the planned condition assessment activity are forwarded to the asset manager who will decide whether they should be included as part of the condition monitoring program.

The defect / condition assessment processes will determine the overall scope of the work. This process will be guided by the condition assessment tools which will assist in establishing standard severity ratings which can be used to prioritize the scope of work.

The ODM process will be applied to the scope of work. Based on the ODM process, the asset manager will review the various options and will make the decision i.e. re-schedule, leave as is or execute the project.

The most vital aspect of the design is the condition database. All information captured from the initial scope of work from the defect/condition assessment process is captured as first entry into the condition database. When the status of the activity is known, then the second entry of data is entered to close the task. The information gathered from the condition database can be used to monitor trends in defects, condition assessment concerns etc. The condition database can be used to provide inputs to the condition assessment activities.

6.4 Benefits of design / application and use

The benefits of the design reflected above in Figure 6-2 are as follows:

6.4.1 Performance improvement

- The overhead line assets need to be managed holistically and focus needs to be spread to include the level of services as described above in Section 6.1.2. However, the majority of the focus should be on effective management of the asset i.e. maintenance management. Poor performance of the overhead line will affect the performance of other equipment in the power system. The maintenance management flowchart in Figure: 6-2 above will assist in ensuring that defects are not neglected and proper decision making is done to determine the maintenance task status, i.e. leave as is, re-schedule or execute the project.

- Information captured by the condition database will be used in the following manner, namely:
- The performance review can include component defect analysis where trends can be established and, depending of the amount of information available, a component condition rating system can be developed.
- The condition database can also assist in identifying scheduling of the condition assessment activities, i.e. inspection frequency, time of year to conduct inspection etc.

6.4.2 Cost reduction

- The application of the maintenance management flowchart will ensure that all defects identified are prioritized and appropriate actions are taken. This approach will also support cost planning. Therefore the budget can be realistic and over expenditure will be avoided. For example, if the fault profile is established for an overhead line, only identified problem areas will be inspected. This will result in considerable saving on inspection cost. Presently the cost of inspecting an overhead line ranges from R550 to R1 150/km.

- Optimized Risk Management
  - The risk management components in the design are the RCM, FMECA and ODM. Here the risks affecting the overhead line are identified, assessed and an appropriate mitigation strategy is implemented. For example, the identified risk will be ranked and, depending of the level of importance, a funding plan supporting the mitigation can be done. This approach will prevent unnecessary spending and promote effective risk management of the overhead line asset.

CHAPTER 7: CONCLUSION

This research study has focused on the application of asset management principles with the view to achieving effective maintenance management of overhead transmission lines. The guideline that has been designed can however be adapted and used for other assets within the power delivery system.

The review of the overhead transmission line maintenance management practices, particularly that of Eskom's North East Transmission Grid which was chosen as the pilot site, revealed that traditional methods of inspection and maintenance of the lines are done, without a quantitative condition assessment process. The gaps in these practices are :

- The Grid has no standardised defect ranking system to prioritise day to day identified defects. The Grid relies on the internal maintenance department to prioritise defects in terms of work priority. All inspection reports are captured and stored in hard copies and are often misplaced i.e paper copies.
- Maintenance budgeting was executed from a central point and budgeting annually was based on previous years budget plus inflation.
- The Grid performs component condition assessment on an adhoc basis.

The guideline for effective maintenance management designed through this research is presented in the form of a flowchart. It provides for a more holistic approach to maintenance management as compared to the traditional approach which is primarily focused on defect management. The key advantages of the flowchart are:

- It is closed loop and process driven
- Decision making is more scientific because it requires the use of historical performance data, detailed asset condition information and encourages quantitative analysis.
- Promotes defect and condition assessment tracking via the condition database.

For the selected lines used as the pilot site, the most common types of faults experienced are fires (vegetation encroachment), bird (pollution, streamer etc.) and lightning (seasonal) faults. The application of the flowchart allows for performance trending and condition monitoring thus directing efforts towards key problem areas which makes the process more focused and thus cost effective.

The application of the guideline for the development of asset management plans will also contribute towards satisfying customers' requirements more effectively since level of services are defined, understood and documented. The asset management plan will directs the asset manager towards achieving the specific targets and promote customer confidence.

CHAPTER 8: RECOMMENDATIONS

On the basis of this research study the following recommendation are made:

1. The maintenance management guideline should be implemented for all overhead transmission lines.
2. A practical guideline on establishing a component condition assessment rating system needs to be developed to assist the asset manager in identifying maintenance requirements for the overhead transmission line asset.

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APPENDIX 1: INSPECTION AND MAINTENANCE PLAN

A) Servitude Plan

Table A-1: Example of servitude maintenance plan (2007/08) for Lowveld CLN

NORTH EAST GRID - OVERHEAD LINES & SERVITUDE - SERVITUDE YEAR PLAN 2007-2008												
No.	CLN	Plant Slot Description	Voltage (kV)	Txsis Line Length (km)	Age	INSPECTION	MAINTENANCE	EARTH RESISTANCE MEASUREMENT	SPRAY WASHING	WIND BREAK INSPECTION	GATES & LOCKS
						Planned Date	Planned Date	Planned Date	Planned Date	Planned Date	Planned Date
1	LOWVELD	Komatipoort Corumane No1	110	6.45	1996	28-29 May 2007	30-31 M ay 2007				
2		Acornhoek Marathon No1	275	97	1968	4-15 March 2008	18-22 March 2008	16-27 July 2007			
3		Acornhoek Marathon No2	275	96.99	1969	4-15 March 2008	18-22 March 2008	16-27 July 2007			
4		Arnot Simplon No1	275	88.66	1976	7-18 January 2008	4-8 February 2008	4-8 June 2007			
5		Komatipoort Infulene No1	275	6.04	1973	28-29 May 2007	30-31 M ay 2007	13-17 August 2007			
6		Komatipoort Marathon No1	275	117.12	1973	7-18 May 2007	21-25 May 2007	30-10 August 2007			
7		Marathon Prairie No1	275	91.19	1966	2-20 April 2007	23-04 May 2007	25-13 July 2007			
8		Marathon Prairie No2	275	91.28	1966	2-20 April 2007	23-04 May 2007	25-13 July 2007			
9		Merensky Senakangwedi No1	275	18.93	1976	28-1 February 2008	18-22 February 2008	18-22 June 2007			

NORTH EAST GRID - OVERHEAD LINES & SERVITUDE - SERVITUDE YEAR PLAN 2007-2008											
No.	**CLN**	**Plant Slot Description**	**Voltage (kV)**	**Txsis Line Length (km)**	**Age**	**INSPECTION**	**MAINTENANCE**	**EARTH RESISTANCE MEASUREMENT**	**SPRAY WASHING**	**WIND BREAK INSPECTION**	**GATES & LOCKS**
						Planned Date	**Planned Date**	**Planned Date**	**Planned Date**	**Planned Date**	**Planned Date**
10		Simplon Senakangwedi No1	275	50.33	1976	21-25 January 2008	11-15 February 2008	11-15 June 2007			
11		Arnot Merensky No1	400	152.23	1983	7-1 February 2008	4-22 February 2008	4-15 June 2007			

B) Hardware Plan

Table A-2: Hardware maintenance plan (2007/08) for Highveld South CLN

NORTH EAST GRID - OVERHEAD LINES & SERVITUDE - 12 YEAR HARDWARE MAINTENANCE PLAN																	
	CLN	**Plant Slot Description**	**Voltage (kV)**	**Txsis Line Length (km)**	**Age**	**2006/2007**	**2007/2008**	**2008/2009**	**2009/2010**	**2010/2011**	**2011/2012**	**2012/2013**	**2013/2014**	**2014/2015**	**2015/2016**	**2016/2017**	**2017/2018**
1	**HIGHVELD SOUTH**	Sol Sasol II No1	132	3.53	1995			3.53			3.53			3.53			3.53
2		Sol Sasol II No2	132	3.53	1995			3.53			3.53			3.53			3.53
3		Sol Sasol III No1	132	5.44	1995			5.44			5.44			5.44			5.44
4		Sol Sasol III No2	132	5.46	1995			5.46			5.46			5.46			5.46
5		Arnot Maputo No1	400	285.65	2000		**285.7**			285.7			285.7			285.7	
6		Camden Edwaleni II No1	400	133.18	2000		**133.2**			133.2			133.2			133.2	

NORTH EAST GRID - OVERHEAD LINES & SERVITUDE - 12 YEAR HARDWARE MAINTENANCE PLAN

	CLN	Plant Slot Description	Voltage (kV)	Txsis Line Length (km)	Age	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018
7		Camden Normandie No1	400	102.22	1978	102.22			102.22			102.22			102.22		
8		Camden Tutuka No1	400	79.69	1975	79.69			79.69			79.69			79.69		
9		Camden Zeus No1	400	101.09	1979	101.09			101.09			101.09			101.09		
10		Camden Zeus No2	400	100.65	1979	100.65			100.65			100.65			100.65		
11		Kriel Sol No1	400	34.54	1978		**34.54**			34.54			34.54			34.54	
12		Kriel Sol No2	400	34.51	1978		**34.51**			34.51			34.51			34.51	
13		Kriel Tutuka No1	400	99.55	1982		**99.55**			99.55			99.55			99.55	
14		Kriel Zeus No1	400	58.86	1979			58.86			58.86			58.86			58.86
15		Majuba Alpha No1	400	52.16	1990		**52.16**			52.16			52.16			52.16	
16		Majuba Tutuka No2	400	56.62	1993		**56.62**			56.62			56.62			56.62	
17		Maputo Edwaleni II No1	400	143.72	200		**143.7**			143.7			143.7			143.7	
18		Matla Zeus No1	400	54.12	1989		**54.12**			54.12			54.12			54.12	
19		Sol Zeus No1	400	18.29	1979	18.29			18.29			18.29			18.29		
20		Sol Zeus No2	400	18.36	1982	18.36			18.36			18.36			18.36		
21		Tutuka Alpha No1	400	6.3	1986	6.3			6.3			6.3			6.3		
22		Tutuka Alpha No2	400	6.4	1986	6.4			6.4			6.4			6.4		
23		Tutuka Alpha No3	400	6.63	1986			6.63			6.63			6.63			6.63

APPENDIX 2: EXAMPLE OF CURRENT INSPECTION SHEET

ROUTINE INSPECTION AND MAINTENANCE OF TRANSMISSION LINES

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Annexure A1

Eskom Transmission

ESKOM TRANSMISSION OVERHEAD LINES AND SERVITUDE INSPECTION REPORT

ROUTINE PATROL AND MAINTENANCE OF TRANSMISSION LINES - TST41 - 637

FEEDER: ______ **DATE:** ______

INSPECTED FROM SUB/TOWER: ______

WORK ORDER NO.:

NOTE: Only in problem/concern fields data is captured. Please capture comments/defect priority rating on last column.

TWR	TOWER TYPE			INSULATORS					POLLUTION							BIRDS					VIBRATION DAMPER		SPACER		SERVITUDE								GENERAL H/WARE					CONDUCTOR DAMAGED			SHIELD WIRE		COMMENTS / DEFECT PRIORITY RATING(L, M, H)
OR	Strain.		Susp.	Glass	Comp.	PHASE			Ind.poll	Mine/dust	Marine	Bird	Phase			BIRD GUARDS		BIRDS NEST			Moved	Missing	Broken	Missing	TREES		REEDS		GRASS		OULAND		ANTI-CLIMB	MEMBERS	LABELS	STAY	OTHER						
SPAN	A	B				L	C	R					L	C	R	Fail.	Miss.	H	M	L					H	M	H	M	H	M	H	M						L	C	R	L	R	

Figure A-1: Inspection sheet utilized by the Grid

APPENDIX 3: COMPONENT IDENTIFICATION AND RISK RANKING

A) The overhead line asset is divided into components as shown below:

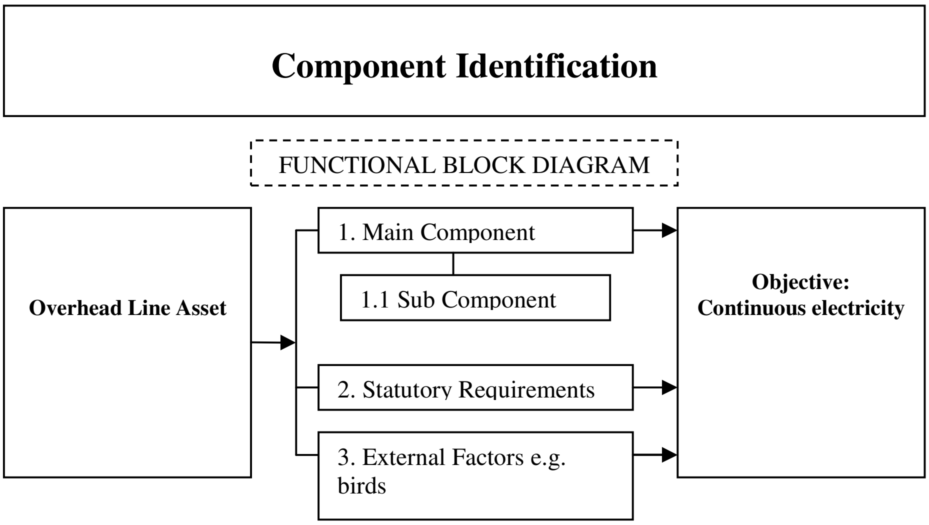

Figure A-2: Component identification

Figure A-3 reflects the details of the grouping of the various function block items shown in Figure A-2 above i.e. groups 1, 2 and 3.

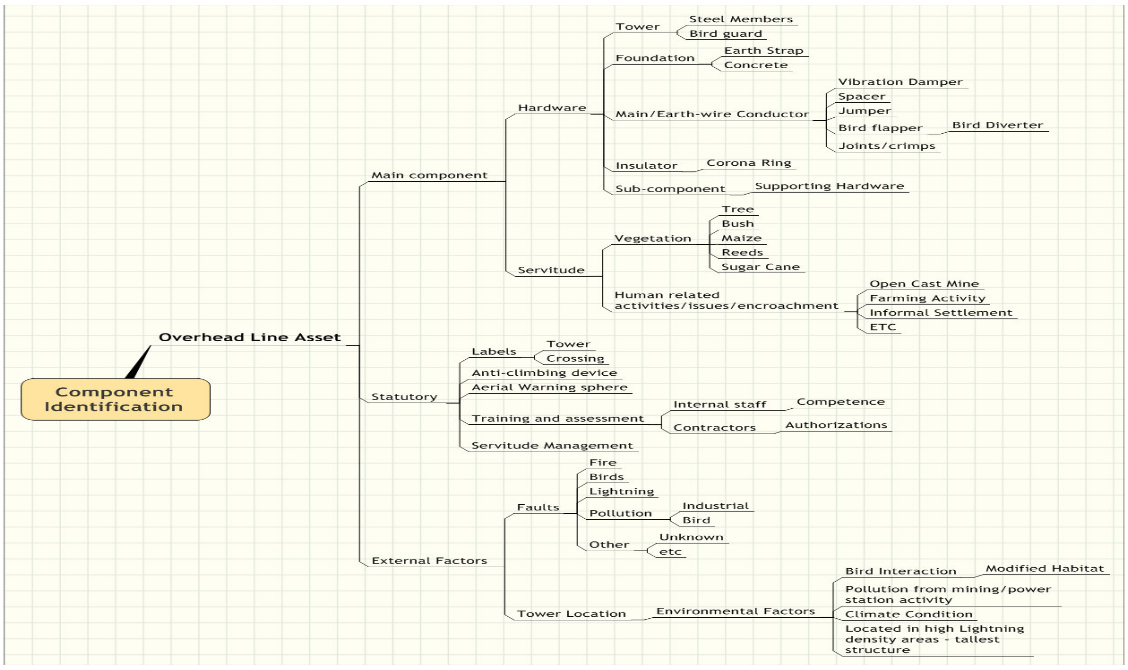

Figure A-3: Component Grouping

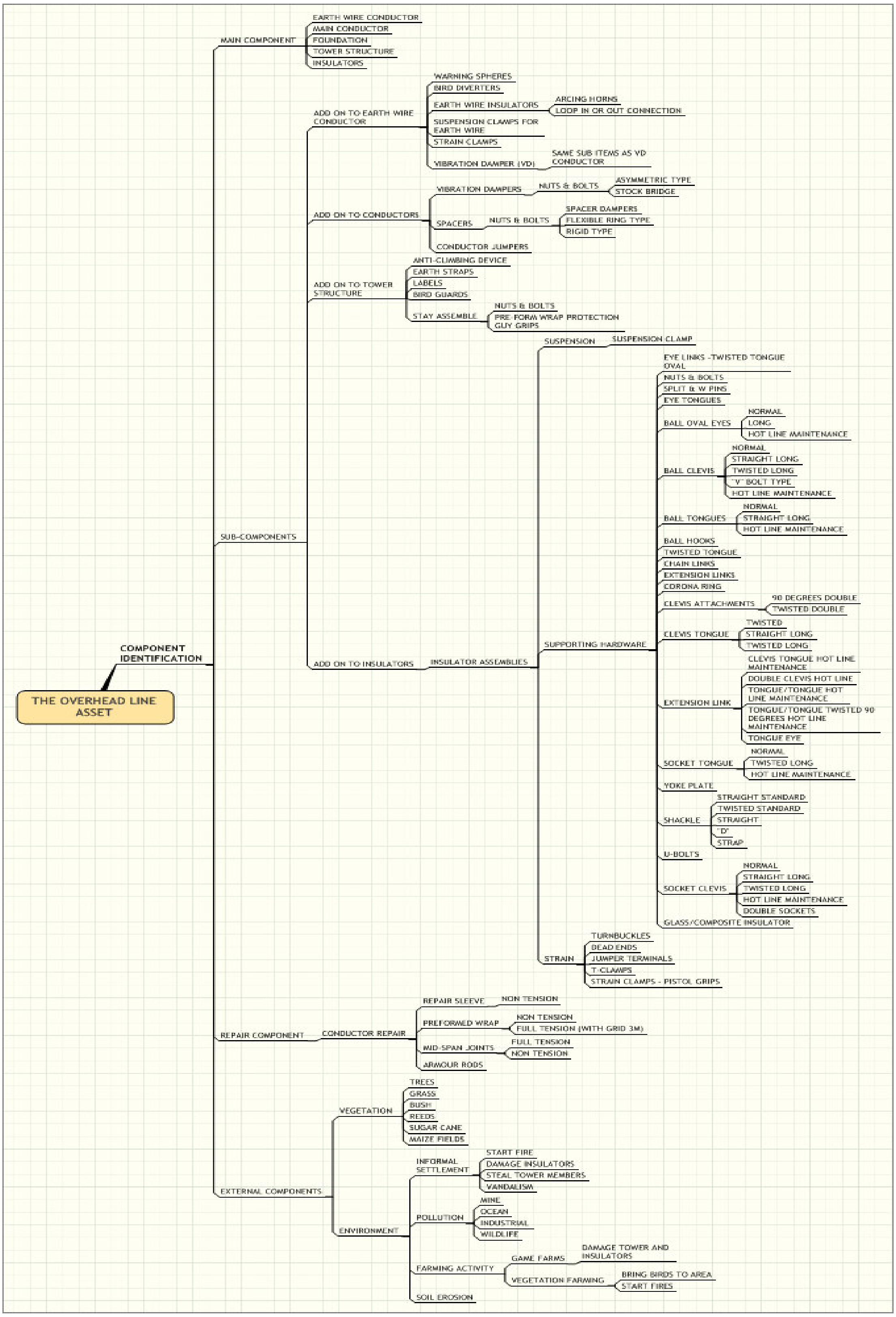

Figure A-4: Component Detail

B) FMEA / FMECA Risk Matrix

The following risk matrix shown below was used to rank the defects identified.

RISK MATRIX

		CONSEQUENCE / SEVERITY					
		Monetary Effect	R 0 – R 100,000	R 100,000 – R 1M	R 1M – R 10 M	R 10 M – R 100 M	> R 100 M
		Legal	Low level legal issue	Minor legal issues, non-compliances and breaches of regulation	Serious breach of regulation with investigation or report to authority with prosecution &/or moderate fine possible	Major breach of regulation. Major litigation.	Significant prosecution & fines. Very serious litigation including class actions.
		Community / Reputation / Media	Public concern restricted to local complaints	Minor, adverse local public or media attention and complaints	Attention from media &/or heightened concern by local community	Significant adverse national media/public attention	Serious public or media outcry (international coverage).
		Environment	Limited damage to minimal area of low significance	Minor effects on biological or physical environment	Moderate short term effects but not affecting ecosystem function	Serious medium term environment effects.	Very serious, long-term environmental impairment of ecosystem function
		Assets	Slight, repairable damage	Minor damage. Mostly repairable	Moderate damage	Major plant damage, unit trip or shutdown	Extensive damage. Multiple unit trips.
FREQUENCY / LIKELIHOOD		***Personnel Health & Safety***	Minor injury	Minor injury requiring hospitilisation	Moderate injury or occupational illness	Single fatality &/or severe irreversible disability to one or more persons	Multiple fatalities, or significant irreversible effects to persons
Likelihood	***Frequency***		**Low**	**Minor**	**Moderate**	**Major**	**Critical**
Continually experienced	More than once per year	**Frequent**	5	6	7	8	9
Occurs often	Once a year or Less	**Likely**	4	5	6	7	8
Occurs several times	Once in 10 years or Less	**Possible**	3	4	5	6	7
Unlikely to occur	Once in 100 years or Less	**Unlikely**	2	3	4	5	6
Extremely unlikely	Less than once in 100 years	**Rare**	1	2	3	4	5

Risk Classification:

(red)	**6-9**	**Intolerable level of risk – corrective action must be taken**
(orange)	**4-5**	**Tolerable level of risk – corrective action recommended**
(green)	**1-3**	**Low risk – improvements may be considered**

Figure A-5: Risk matrix table (Pininski, 2008)

APPENDIX 4: CASE STUDY ON THE IMPACT OF OVERHEAD TRANSMISSION LINE FAULTS ON QUALITY OF SUPPLY