TRANSMISSION ASSET MANAGEMENT

by

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A Thesis Submitted to

The University of Western Australia

for

The Degree of Doctor of Philosophy

Department of Electrical and Electronic Engineering
January 2002
ABSTRACT

The thesis develops an original model of asset management applicable to a wide range of work areas and business functions associated with the management of assets in the electricity transmission business.

Central to the new model is a way in which those individual areas and functions, although widely used in other existing models and systems, are systematically integrated in a composite dynamic model including business function interactions encountered in transmission asset management.

The model also serves to ensure that each of those areas is defined and executed on time and in alignment with all other relevant areas, with a proper and timely influence of each function to the other relevant functions.

The model firstly identifies the main areas and functions of transmission business asset management. Secondly, it identifies and defines improvements and requirements for each of these work areas (model components). Thirdly, it defines the required asset management business functions and a proper mechanism for those functions to perform their work to cover all work areas of asset management in the transmission business.

The developed model leads to an asset management environment where the individual model's functions and areas will be implemented in a coherent and integrated way.

The model sets out the ongoing and timely interactions amongst the model functions, and then defines all required exchange information blocks and their contents for information they need to share among themselves during those bilateral or multilateral interactions.
It is recognised that some aspects of this new model have been known for some time, and have been explored in various ways in some organisations.

The main work areas would be those activities that cover asset maintenance and repairs, replacement of assets, asset condition assessment, planning for new assets in network, asset failure reports, and asset reliability studies.

Prior to the development of the new model, the thesis reports the results of a comprehensive survey of literature for existing approaches to asset management in general and to transmission asset management in particular.

It also gives asset management and maintenance policies and practices in use in many national and international companies.

Key deficiencies in the existing approaches have been identified. The work in these areas has been mainly performed in business functions independently of one another or with occasional individual interactions with one or a few other functions.

However, full interactions and the timely transfer of information for work areas amongst different business functions have not been a focus in the existing asset management models.

The existing models are still based on the functions individuality when they performing their work, and with significant time lags for any transfer of information between them where such an information transfer is being requested by any of them.

The transfer is represented by a loose one-way street traffic, ie it might not even happen as it is based on a voluntary effort of other functions. The
significant lag in the case of an eventual access to the information could at best make the information irrelevant, where it has become redundant or even worse superseded.

At the worst it could be misleading or even dangerous for the work outcomes in other areas if it is used without the knowledge of its possible obsolescence.

In the past these areas and functions have previously not been developed with fully defined and documented requirements and procedures. They have also not been interconnected into an integrated dynamic model where there is full integration and almost an instant interaction of all individual functions that achieves the envisaged aim of this research.

The thesis has searched for ways to remove those drawbacks, and new developments for functions and their links, that would lead to process improvements, have been investigated and incorporated in the new model.

The thesis formulates a framework for the documentation necessary for the definition of all the required business functions, activities that these functions must perform to cover all work areas, and the process they need to follow in doing so.

The thesis also sets out procedures and their sequence to link them in a dynamic integrated way to achieve all the objectives set up in this new model for successful asset management in the transmission business.

Finally, the thesis formulates the above-referred documentation and procedures in sufficient details so that the developed asset management model may be fully implemented.
STATEMENT OF ORIGINALITY

The main original research contributions made in the thesis are as follows:

(i) A new asset management model;
(ii) The development of a general framework for any new model with general policy documents;
(iii) The development of a comprehensive business case analysis;
(iv) The development of databases together with data acquisition process for supporting functions;
(v) The development of comprehensive documentation procedures.

The new model developed in the thesis has the following key features:

❖ Addressing the deficiencies of the existing models;
❖ Including integrated and dynamic process presentation and optimisation;
❖ Taking into account the interactions amongst business functions;
❖ On-going linking of procedures for a continuous risk assessment.

The thesis is supported by a series of fourteen publications published in the open literature, presented at conferences and at invited lectures on related subject area of the thesis, detailed in Chapter 18:

3 papers at National Conferences [1,2,14];
3 papers at International Conferences [3,7,13];
3 publications at Industry Forums [4,5,12];
5 lectures and presentations at Technical Society Meetings and University Workshops [6,8,9,10,11].
LIST OF PRINCIPAL SYMBOLS

CHAPTER 3:

HEP  Hrvatska ElektroPrivreda (Croatian Electricity), Zagreb, Croatia
NPV  Net Present Value
IT   Information Technology
HR   Human Resources
LV   Low Voltage
US   United States of America
UK   United Kingdom

CHAPTER 5:

AMP  Asset Management Plan
AM   Asset Management
SLA  Service Level Agreement

CHAPTER 6:

CEO  Chief Operating Officer
AC   Alternating Current
DC   Direct Current
KPI  Key Performance Indicator
TPMS Transmission Plant Management System
TLMS Transmission Lines Management System
TRIS Transmission Ratings System
CHAPTER 6 (continued):

TLGIS  Transmission Lines Geographical System  
TPES  Transmission Protection Equipment System  
TPAS  Transmission Plant Allocation System  
SOD  System Operation Disturbances  
NOIW  Notice of Intended Works  
MIMS  Mincom Information Management System  
NDPS  Network Development Plans Summary  
ESAA  Electricity Supply Association of Australia  
UMS  Utility Management Services, Parsippany, New Jersey, USA  
CIGRE  International Organisation of Large Electrical Networks  

CHAPTER 7:

XLPE  Cross-linked polyethylene (insulation)  
SO  System Operation  
Q/T  Query Trouble (Report)  
PEA  Project Erection Authority  
PPRF  Primary Plant Return Form  
WOB  Work Order Block (in NOIW)  
WO  Work Order (in MIMS-Work Order Management Module)  
MST  Maintenance Standard Task  
MSJ  Maintenance Standard Job  
CB  Circuit Breaker  
TVI  Television Interference  
CT  Current Transformer
CHAPTER 7 (continued):

VT Voltage Transformer
SA Surge Arrester
MSA Microsoft Access
ER Equipment Register
ETF Equipment Tracing File
EGI Equipment Group Identifier
OSP Operating Statistics Profile

CHAPTER 8

N-1 Planning criteria that allows one plant item to fail without loss of supply
SWIS South-West Integrated System (of WPC)
WPC Western Power Corporation, Perth, Western Australia
RRST Rapid Response Spare Transformers
N-1/1% Modified N-1 criteria that allows one item of plant to fail with loss of supply during only 1% of year
NCR Normal Cyclic Rating

CHAPTER 9:

MVA Million Volt Amperes
K One Thousand
MIN Minimum
MAX Maximum
kV one thousand Volts
CHAPTER 10:

ISP Internal Service Providers

CHAPTER 11:

GPS Geostationary Position System
POI Points of Isolation

CHAPTER 13:

RRF Relay Return Form
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1. **INTRODUCTION**

The overall performance of an electricity system depends on the reliability of its transmission network, which in turn relies on the performance of its individual assets.

The condition of the assets and their operational availability ultimately govern the performance of the relevant transmission network, as these assets are the building blocks of the transmission network itself.

With the ageing of transmission network assets and rising expectations for an increase in the rate of utilising these assets and the reliability of their service performance, an organised and well executed management for those assets for the short- and long-term periods has therefore become the first priority for transmission network businesses.

In addition, there are increasing political pressures and pressure from the electricity industry (national and international) with the introduction of external competition (through open access policy and general wheeling arrangements in the transmission networks), and an internal desire to achieve better management practices than those of other national and international companies.

Transmission networks consist of many different assets (lines, substations, primary and secondary plant). They all have a definitive life expectancy, and some of them have a high capital cost. As their condition deteriorates with age and operation, it is reasonable to expect their failure in service at a certain point in time. When they actually fail, the impact of such a failure could be serious, from a major loss of supply and prolonged restoration
period, endangering of public and employees safety, serious environmental aspects, to significant unplanned maintenance and capital budget blow-outs.

Assessment of the asset condition and planning of its replacement just before the failure is not a simple task. It requires the collection of much data from a number of sources through many procedures, often over a considerable period of time.

Only then can any useful information be produced through various reporting formats for the necessary asset performance and condition reviews, which would enable meaningful solid decision making.

The actual decision to replace an old or suspect asset is further complicated by a number of important influences to the relevant work areas from many other functions of the transmission business.

Their inputs have to be taken into account with a particular emphasis on the timing of those influencing factors.

The main influencing factors include:

- current and future planning and reliability criteria;
- current and future operational circumstances;
- estimated load and fault level growths;
- assessment of the future reliability levels and their impact on the transmission network and overall system;
- subsequent possible liability risks;
- repercussions of increased maintenance requirements on the maintenance costs;
• asset availability and impact on adjacent circuits;
• future and present environment risks;
• possible emerging technologies and their impact.

Literature survey and research undertaken and presented in Chapter 2 found a few available references relevant to the area of transmission asset management, with most of the researched references based on conventional methods. Those references did not cover all of the aspects of asset problem identification, and subsequent decision making about the asset future.

That prompted the need for the survey of other literature covering asset management modelling in general, and also placed more emphasis on the review of models currently in use by various transmission businesses around the world.

It resulted in the candidate visiting and analysing a large number of relevant Australian and international electricity companies.

The review of findings from those visits and a comparative study summary are presented in more detail in Chapter 3.

At present, transmission asset management is most commonly performed in separate, often disjointed, areas of individual companies, where some of the required important functions are analysing or reviewing necessary work on a limited and separate basis.

While some of the approaches are fairly sophisticated and detailed, two main aspects of the proper transmission asset management have not been covered.
One is the identification of all transmission business functions required for
the asset management in a complete framework with a full definition of
their parameters and requirements for their work and input and output
information. That includes the databases and procedures necessary to
maintain them to provide the defined information required in the asset
management process.

The other is the definition of links between the main asset management
function and other relevant transmission business functions to integrate
their defined interactions in a timely manner.

The aim of thesis has been to produce a practical and streamlined
transmission asset management process based on a new model that will
address the above mentioned problems.

It is necessary to define all relevant work areas and business functions that
need to be included in the model process, and then to implement a number
of procedures that will ensure those functions and areas are fully covered
irrespective of the organisational structure of the transmission business.

Extensive reviews and discussions with fellow engineers and university
scholars, both nationally and internationally, during the above research,
through other business visits, and attendance of relevant conferences and
workshops have revealed no such encompassing model is currently
available.
The research that aims to cover those areas by a dynamic integrated model that provides solutions to present limitations in asset management is well timed and deserved.

The model, arising from this research, presents a significant step forward on improving the existing situation in asset management specifically for the transmission business by offering such comprehensive solution to those problems.

The model could also be used as a guide for the development and application of similar models in other organisations wanting to adopt a holistic approach to the management of their assets.
2. **CRITICAL REVIEW OF THE PUBLISHED LITERATURE**

The need for taking care of one's assets becomes apparent to the uninitiated user of any asset only when the item fails. It is then that the unsuspecting user is confronted with two major facts:

- the failed item requires repairs to hopefully return it back to service, or replacement;
- the failed item also causes the failure of a part of or for the whole process that uses it to come to a halt until the failed item is repaired or replaced.

The above situation has raised a number of questions about the issues of:

- readiness and appropriateness of the response to failures and repairs (corrective response);
- could the failure have been prevented (asset maintenance system by earlier attention to the item, or predicted (asset management system) so that action could have been planned prior to the failure.

It is the awareness accumulated over time that there is an ultimate prize for the business in terms of financial, operational and legislative performances and other gains by:

- knowing one's assets ongoing condition;
- required adequate attention level and timing;
- long-term asset maintenance plans, and their timely adjustments;
- and long-term plans for a controlled asset renewal process.
The comprehensive review undertaken is not confined to the literature covering transmission electricity type businesses only.

The review also covered a range of other available approaches in the field of managing assets in the areas of maintenance and renewal (intervention and replacement) that could be helpful in assessing the needs and options for managing assets in the transmission business environment.

The researched literature can be split into five distinctive categories:

a) dealing with maintenance and repair works, and their optimisation in a narrow sense of asset maintenance management;

b) realisation that there is a need for asset replacement policies as all asset have a definite life expectancy and will fail in service eventually;

c) how to achieve an optimal mix of the above requirements;

d) information and use of databases and computer systems to collect and report on them;

e) discussion about the need for and implementation of suitable systems in various companies, especially in electricity transmission businesses.

The presentations in Sections 2.1 to 2.5 show the background, thinking, discussions and proposed solutions from the analysed literature about many aspects of the above areas with their critical review.

The obtained and analysed information has been used to indicate where and what major improvements could be made when attempting to build a new complete model to ensure the model answers the questions, challenges and process gaps that have been identified throughout the research.
2.1. Maintenance

A concept of maintenance management and the need to be prepared for repairs has been previously used mining operations, always perceived as being at the forefront of maintenance management. The presentation by Dyson[5] is a good starting point showing a number of areas that should be considered for asset maintenance. It is also a good example of a process where individual parts are not fully connected with clear links among them.

Developments that took into account variations in the maintenance approach with the costs of corrective maintenance compared to that of applying only preventive and scheduled maintenance are given in paper by Sheu[26]. It presents an attempt to assess the cost impacts between the two approaches and then to decide which one to apply.

This theme continues in paper by Parikh[22] and with the acknowledgment of the importance of a structured approach to data collection to enable decision making for the area of maintenance itself. There is an awareness that condition monitoring helps with the appropriateness of the maintenance levels to be applied and of their correct timing.

This indicates that, with most of the aspects of maintenance well defined, the next step would have to be to somehow integrate them into a framework that will link them and allow further work. An attempt is given in a presentation by Dekker[3] that clearly indicates such a need for integration of planning, setting and combining maintenance activities, with reference to their optimisation.
In further work by Dekker[4], the need for more work highlighting the need for proper data about maintenance activities is necessary to be able to apply such optimisation.

Dekker's brief overview of objectives and history of asset maintenance in this paper is a good example of all the issues at the heart of the problems raised, and forms the heart of this thesis.

The paper continues to discuss the many problems in maintenance management as compared to other known management areas, and the importance of setting correct asset and data hierarchies to be able to manage the assets properly.

It further identifies the need for maintenance optimisation models and for the introduction of computer software applications to enable such optimisation.

It also quite rightly highlights that this area will need much future work, as many more areas are likely to be identified and will need to be connected into a complete picture, with further economic pressures and when the need for change in the culture of asset management develops in the industry.

Some literature deals with improvements in the maintenance area itself by reviewing different maintenance categories and their place in maintenance management. The discussion by Eby[9] is useful as it points out possible benefits of having correctly defined and used maintenance categories and the right mixture in their application.

It also refers to various techniques used for analysing maintenance data to assess the asset condition and optimise its maintenance.
Similar area is detailed in the presentation by Pintelon[23] on improvements in maintenance management decision making by having proper classification and understanding of the maintenance work.

It refers to management policy and objectives, a good point as it indicates that, for a successful maintenance outcome, there is the need to know the aimed targets up front.

There is also a good suggestion on the need for performance reporting and computerised maintenance management systems support to be able to improve maintenance decision-making.

Another approach to maintenance in this paper given by Langan[14] champions the importance of excellence in maintenance process management, as achieved by preparing, implementing, and ensuring a strict and constant use of relevant and easy to access documentation.

It also acknowledges that information is the key to success, and that having a good information system and procedures in such a process are critical business issues. He stresses that further benefits for the business could be gained by the implementation and use of new computer maintenance management software packages that can offer quick information turnarounds.

In addition to the above aspects, de Haas[33] brings into focus the integration of the maintenance and production functions within the company’s business plan, and an alignment of its working areas to understand and support those functions.

The paper identifies the need for some important elements for achieving a systematic model for maintenance work such as maintenance mission, strategy and policies.
It then concludes that there is the need to have a proper organisational structure, planning and scheduling process and support systems for understanding the process, so that other procedures, eg continuous improvements, can succeed.

The summary by Moubray[18] is a good indicator of how to enable transformation of the maintenance management area into the asset management area. It deals with common perceptions in many companies of what constitutes maintenance, and what is expected of the maintenance management area to perform its function.

It develops an argument to prove that all of the above is still not enough, by indicating the changes necessary to take the quality and outcome of this whole work to another level, bringing substantial benefits to the business.

The paper also warns that the path is not an easy one, as it requires changes and a shift in the culture of thinking and working patterns to be able to overcome those entrenched paradigms. It will take time to do it properly, and each area should be fully covered.

The final work arrangements should be set up in such a way that the set-up process makes improvements part of the journey, and not the one-off destination.

This theme of efforts to transform a simple maintenance activity into an organised asset maintenance process, with a detailed asset and maintenance strategy documentation and links to corporate objectives, is shown in detail by Wilson[34].

It also indicates a possible way of developing, planning and implementing such an approach to the maintenance process.
2.2. Replacement Issues

A partial or full replacement of an asset is a logical step in asset life, and a relevant decision to replace it or discard it will have to be reached at some point in its life.

This step must be included in any complete model, together with the procedures to obtain the necessary information about the asset, its purpose and surroundings, and how to deal with the new step within the many business functions of the organisation.

Jardine[11] supports the issue of a complete approach, and gives aspects of replacement approach requirements. The paper documents the need for a defined framework to be able to reach such decisions with confidence.

It also points out the requirements for information and proper tools, including decision-making software, required to optimise the process for the correct decision.

A short review of the maintenance process and where and how it should start considering plant replacement as the part of the process is given by Lambert[16] as an aim in improving the asset performance (asset being the whole of plant operation).

It is an analysis of the effects of the individual components and information about their performance, obtained from the proper registering and monitoring of performance of the individual components, on the operation of the whole system.

That should eventually enable the asset operator and asset maintainer to make the right decisions about either completing further repairs on the asset or initiate its replacement.
In his editorial paper on models for maintenance management of assets, Van der Duyn Schouten[29] has elaborated on a number of papers dealing with the various aspects of that topic.

But most importantly the paper makes a significant reference for the need to have better-suited asset replacement policies than those available, as most companies currently adopt mainly replacement policies based on asset age and general asset distribution.

2.3. Optimal Policy Mix

It has become obvious to a number of authors that, having developed a replacement policy on the top of maintenance works, there needs to be a mix of both repairs and replacement, as in presentation by Borg[2], which shows how to apply marginal cost analysis.

The presented model relies on cost analysis, but confirms that more is required in the form of planning availability of recommended replacements. There are also other presented factors that should be reviewed and addressed within an eventual complete model.

A similar approach is taken by Dekker[6], in explaining that there is the need to adopt a better way of looking into the maintenance process and that by introduction of maintenance optimisation. It also highlights important requirements to have data specified and collected for a meaningful operation for any optimisation to work.

It then supports clear requirements for proper and relevant software packages to enable such an optimisation between various aspects of maintenance works, which is supported in other papers discussed in Section 2.4.
Another good presentation about the need to achieve a proper mix of maintenance expenditure and capital funds for asset renewal projects is given by Kaiser[13] through the positioning of such work within the company.

The presentation starts with useful explanation of commonly used terms in the asset management area, and continues to define how the problem of planning asset replacement has originated.

It also presents comments on the size of the replacement problem, particularly if not dealt with for a long period of time.

There is helpful insight into the approach of striking a balance between the required capital funds for asset renewal and the maintenance funds for planned and deferred maintenance work through a good asset management programme.

The paper rightly draws the attention to the fact that long-term capital asset renewal plans are absolutely necessary to make such a programme successful.

There also needs to be a good monitoring system in place to ensure the programme and all its activities achieve a target set-up when introducing such a programme.

In the presentation about the need to move away from maintenance as an isolated process of fixing things as they happen, Newton[20] very effectively shows that many other areas should be involved in an expanded process. The presentation then explains the requirements for a good mix of all those areas to improve the whole process.

In that way, the expanded maintenance process will better support the company's assets throughout their life, and truly achieve benefits to the business as a whole.
Thinking in a similar fashion is a presentation by Townsend[27], where the notion of incorporating the narrow asset maintenance management to a wider arena of asset management is correctly expanded.

It supports the need to have a proper relationship established between the two areas, which will improve an overall contribution to the transmission business bottom line. It also briefly mentions the process of decommissioning and disposal of the asset, but without any more information about that process.

There is an important and valuable observation that for any asset management system to be effective, properly defined responsibilities need to be placed on organisational areas whatever their outlook.

2.4. Information and Use of Databases and Computer Systems

Even the earliest works acknowledge the difficulties for organisations when they attempt to implement an asset management strategy without having the right information to start with and then to waste time working on it afterwards. It is becoming obvious that for a good management of assets there is the need for good data and efficient systems to access necessary data quickly so that it always provides the right information on time for the proper decision making.

To achieve those goals the basic maintenance management process must first be under control, as presented by Newby[21] in the work about integration of maintenance work control.

Implementation of collection and assembly of all relevant data about the maintenance activities for its control, through a proper maintenance management software, serves initially only to enable proper planning and programming of maintenance work.
But the wealth of such information, once achieved, will form the basis for a more advanced asset management process to improve decision making between maintenance and other problem resolution options.

Similarly, a project to have asset maintenance management under better control by designing and implementing a combined planning and control system has been explained by Ulusoy[28] through defining the required structure of the database, classification of assets and their maintenance tasks, and then running reports and analysing asset performance.

Another example of the value of the development and implementation of an integrated technical information system to support maintenance work is presented by Lundberg[15] where he shows the experienced preparation and use of such a system.

The previously used system had a number of independent procedures for planning, scheduling and for management of contractors, with very difficult and time limited data transfers between them. The new system enables efficient operation and maintenance recording so to achieve an improvement to the whole process.

The paper concludes that developing optional graphic and geographical functions could make further improvements.

Such individual systems (maintenance activities, technical support) later lead to a more complex approach to data management, especially in the area of transmission business assets, as shown in an elaboration by Drye[7].

It guides well through the main points to justify the need for such data management in the relevant asset management process.
It explains the asset data requirements must be defined as well as the performance and failures. It is therefore very important to determine what a failure is for a particular asset type and a coding to properly register it when it happens.

It then highlights the need for proper information systems for the asset management business, and provides some leads for what those systems should cover. They include the registration of all assets, definition of the assets maintenance requirements and then setting them into a maintenance management application, and ensuring that the defined and required work is planned and executed through a suitable work management application.

There is also a good reference to the importance of proper data flow and its sequences, ie acquisition, entering and processing data.

An integrated and structured approach as an attempt to improve the maintenance procedure through setting up an information system to enable data recording, later reviews, and further analysis of asset performance and condition is shown in paper by Vanneste[30]. It presents the experience of implementation of such an information system in a typical manufacturing line. It supports the notion that such arrangements must be in place to have any real chance of understanding and controlling the above maintenance procedure.

A more complex and sophisticated system for the collection and recording of the data and exchange of information is presented by McRae[19] as developed and implemented in one company.

It shows how such a system is an absolute necessity for a business aiming to be truly successful in the management of its assets.
An important aspect in the benefits of collected data and output information through the use of business computer applications and databases to improve the overall asset management and maintenance standards is raised by Smith[25] in the presentation on the benefits of benchmarking.

This is the process of taking relevant data from various similar companies, comparing them in agreed ways, and providing feedback on an industry average, existing best practices, and one’s own standing in relation to those two yardsticks.

It is essential that a proper baseline of areas intended for comparison is ensured so that the benchmarked companies can be compared accurately. That will sometimes call for significant time and effort in any business attempting to take part in the benchmarking to work out the necessary information and to present it in the right format.

The benchmarking can be done internally and externally, and a deep and honest review of the results can reveal many opportunities for improvements in many areas in the business ways. But it is especially important to be very careful when examining results from the external benchmark studies. Many specific circumstances (whether one’s own or those of other companies) may render good ideas and practices unsuitable, impractical or just too expensive to use.

But it is clear that such tools should be incorporated in any complete model to ensure good auditing of the process, its functions and the results it produces, then making comparison with other companies to find the best solutions.

An interesting contribution for the need to have as much information as possible about the asset maintenance process and asset itself to enable further inroads in the areas of maintenance optimisation, prediction of asset
end of life, and the correct mixture of maintenance and renewal asset activities is given by Noortwijk[31].

It shows how a complex expert judgement technique could eventually be introduced when enough data is available.

2.5. Need For a Whole System

It is evident from the literature that there is a growing need for an integrated asset management system suitable for any complex business, and of course, specially the one suitable for an electricity transmission business.

Paper by Moubray[17] points out some distinctive requirements for a complete solution. A maintenance mission statement should be a logical starting point that will clearly identify the main players (asset owner, operator and maintainer, and society as a whole represented through various government and other bodies) and their roles and responsibilities.

Then defines different maintenance work categories and rules for the most cost-effective application that will satisfy all stakeholders.

The next step would be the development and implementation of one’s own maintenance strategy. The strategy should recognise several main factors; need for a maintenance policy for each asset, proper structure to cover all required work, and define, acquire, deploy and operate the systems needed to execute the strategy.

The paper makes a brief reference to monitoring of asset performance that in turn requires a suitable computer maintenance management system, which should be selected with a due diligence and care only when the previously described documentation, systems and culture are in place. That covers some aspects of the issues already reviewed in Section 2.4.
It highlights the requirement for an audit of the asset management process and its functions and procedures, which has not been properly included and acted upon in asset management activities in the past. Any new model offering a complete approach should ensure that regular audits are included. It should also prove that not only the right things are being done, but also demonstrate in writing the reasons for doing them.

It also shortly refers to the need for accounting and financial functions embedded in the asset management process and to work with them hand in hand for asset maintenance, repairs and replacement strategies. It is definitively something that any new complete model must achieve.

A similar need for a new approach to asset management is given by Eyre-Jackson[8], with discussions on the merits of various new ideas about the planning and introduction of a full life-cycle asset management.

The paper defines the asset itself and its position and role in the asset life-cycle. It correctly identifies the start and finish of asset life, and the possible steps in the asset life. It then explores various points regarding a strategy for adopting a modern business system to be able to achieve the benefits of the full life-cycle approach.

It hints at the possible benefits that full utilisation of such a complete system might have on the bottom line of public utilities with long life assets and how it could assist them with their long-term plans to smooth their future expenditures. That is exactly what any new model should strive to achieve.

Paper by Hancock[10] correctly identifies that the definition and the configuration of asset management programme is the main prerogative in achieving a proper control of operation and maintenance procedures and
costs. It is aiming for such a programme through the definition and implementation of a comprehensive documented process. Once in operation, it should provide significant dividends to the company.

It is also important to consider that the final step of any good programme is that there is no final step. Instead, the programme itself, once working, should also receive the ongoing attention in some shape or form to cater for its own continual support and improvement.

Integration of various steps and functions as a useful step forward to enable better maintenance of assets is shown by Powys[24] through an extensive presentation on improving the planned maintenance of assets within the public sector.

The main focus is to assemble a complete picture with the input of community demands and government goals combined into the corporate plan to create an asset strategy to guide the asset manager.

There is a good understanding and presentation of necessary major steps towards the implementation of maintenance from the above-agreed strategy, including the need to monitor and review performance based on developed performance indicators.

There is also brief reference to renewals (adaptations) throughout the asset life and its final disposal somewhere down the line as categories in the asset life cycle, as a positive sign of understanding the importance of those categories. As no more information is provided, it is probably only an indicator of what should be done, so that in the future the renewals would be accounted for in the process.

An excellent example of a successful system is given in paper by Jones[12] in explaining the flow of process as adopted in an electricity business.
It begins with a decision to introduce an asset management culture, then produces an asset management mission and strategy, and then aims to implement an integrated approach to asset management process of the own making. There is a distinctive set-up of asset life-cycle phase and a strategy in place for each of the identified phases.

The phases include many important aspects that are considered to be essential parts of a good asset management process, although links and requirements to other parts of the organisation are not given.

There are brief references to the need to look into modelling of the impact of asset performance and decisions within asset management of the whole company, and to have cross-organisational reviews of results of asset maintenance and performance.

Both of those references are valid and helpful as they point out the necessities of a complete model in order to be judged successful.

Similar support from the reviewed literature for an integrated asset management system suitable for electricity transmission businesses is well explained in a presentation by Allison[1].

It points out some distinctive requirements of a complete solution, starting from a basic necessity to ensure monitoring of asset performance in service. That would obviously require data to analyse, which in turn requires a proper network for incident recording.

The presentation also highlights the need for a suitable computer database and maintenance management computer system, which covers those needs as shown in other reviews in Section 2.4.

The presentation then follows with a need to develop and implement a maintenance policy for the asset and to attempt to assess asset condition, to be able to make predictions about its life expectancy.
It also briefly refers to the need for an asset replacement strategy and explains the effects that uncontrolled asset failures could have on the transmission system reliability.

A similar approach with implementation of a basic asset management planning and management tool for an electricity utility is given in presentation by Vainberg[32] that shows the significant benefits gained through adopting the presented tool.

It is not only financial benefits that are important, but also knowledge of one’s assets condition and possible impacts on the system and environmental repercussions of its failure, which eventually might end up with a substantial financial burden for the company.
3. **COMPARISON TO OTHER ORGANISATIONS**

There are many electricity supply companies currently operating in Australia and overseas that include the transmission business component and a selection of them have been visited in the course of this research.

The visits have been used to review the way each operates, to assess their asset management process and its main work and business functions.

Subsequently, a brief summary of findings has been prepared about the knowledge and information gained in each visit.

The summary has also been used as a guide to identify improvements to the current process, which will improve their asset management and point out issues that any new model needs to address.

The visited utilities are listed below:

- National Grid Company (NGC), Coventry, UK;
- Yorkshire Electricity, Leeds, UK;
- Midland Electricity, Birmingham, UK;
- London Electricity, London, UK;
- Boston Edison, Boston, MA, US;
- Tennessee Valley Authority, Chattanooga, TN, US;
- TransGrid, Sydney, NSW;
- Powernet, Melbourne, VIC;
- Hydro-Quebec, Montreal, Canada;
- HEP, Zagreb, Croatia.

A comparative summary of all findings from the individual visit briefs has been prepared to show:
- share commonalities and what they are;

- drawbacks in the way they operate;

- missing components and the links in the process;

- what is missing in the sense of integration of the interlinking for feedback information, and in the proper timing for their feedback relevance;

- requirements of a new model in order to address all of the above to lead to improvements, and the ability to properly manage the relevant areas as identified and explained in the comparative summary in Section 3.2.

3.1. Brief of Individual Companies

The summary of findings from visits to the listed companies is presented in Sections 3.1.1 to 3.1.11.

3.1.1. National Grid Company

One group looks after substation, switchgear and protection areas with the responsibility for maintenance management, ie to prepare an annual maintenance work plan and the corresponding required outage plan, and to prepare and submit proposed annual maintenance budget.

Service providers have implemented a work management system for use in maintenance planning but many modules are not in use yet. There are no
links to the equipment register or to failures database, which are run independently on a separate indication system.

The important asset management work (population and age statistics, failure investigations and failure statistics, asset condition investigations, and assessment of remaining life estimates) is done by other groups, ie substation and line design sections, also charged with producing maintenance policies.

Refurbishment, modification and replacement recommendations, together with economical and technical aspects of business case preparation, with its financial evaluation for justifying asset replacement decisions (NPV timing and age profile of plant type) are again done by another group.

There has been an attempt to provide an assessment of the importance for all active transmission circuits in a system by assigning a factor 1-5 to identify how critical they are in the system operations.

No significant contingency planning to handle emergency power restoration and plant replacement arising from unexpected plant failures, apparently due to a lot of spare capacity. The purchasing group centrally registers all plant on order, and provides services for the plant data input in the equipment register.

3.1.2. Yorkshire Electricity

Asset management group plans maintenance and has a service level agreement with field operations, supported by technical people in the
technical operations group, while the IT group produces reports to monitor
the work and finances.

Asset management also does budgeting, cost control, extra funding
for additional corrective work, emergency work funding, produces
maintenance criteria, analyses feedback, and updates manuals.

The annual plan is not prepared and submitted annually, as the work
arrangements are left to the technical operations for major refurbishment
projects and to the field operations for the regular maintenance work
throughout the year.

There is a work management computer system for maintenance work linked
to an asset register database, but there is no asset management software.

Asset management of long-term planning is rudimentary as population and
age statistics are not used very much.

Major failure investigations, with subsequent asset condition investigations,
are used to determine replacement candidates on an individual case-by-case
basis.

Assessment of remaining life estimates are taken into account to determine
possible blow-outs in future replacement requirements, but the whole of the
life cost factor is low in priority when deciding on refurbishments,
modifications and replacements of plant.

Business case recommendations use predominantly safety, customer
implications, legal and regulatory issues, environmental performance, and
company perception of impacts (for customers and the regulator).
Contingency plans for emergency conditions do not exist as there is apparently enough capacity everywhere, and the emergency replacement plant is sourced from the pool of the incoming plant ordered for projects or asset replacement programme.

Asset condition monitoring is considered of no practical value to the business.

Asset data register updating is a basic one through paper sheets filled in situ by construction staff, and sent to the information technology group to be entered. Registration of the plant on order together with data input in the equipment register does not exist in that early phase.

3.1.3. Midland Electricity, Birmingham

Maintenance is planned annually by the depot maintenance groups, which arrange for the budget and perform the work.

The work progress is monitored through some reports to the service provider and asset manager.

The maintenance criteria and update of manuals are done by the asset manager and entered into the plant maintenance recording database, which other groups then refers to.

A work management system is partially used, to provide mainly financial reporting. There are also no line asset database and no asset management software.

Asset management nominally owns the asset data register, but updating is completed manually based on forms filled in by construction teams on site.
Another group analyses population and age statistics; performs failure investigations and asset condition investigations; and estimates asset remaining life.

The business case preparation includes some economical and technical aspects, but is mainly based on financial evaluation models to justify asset replacement decisions (NPV of timing and age profile of plant type).

There has been some reference to the future age profiles and questions on the ability to manage all these in the future, as the total capital expenditure commitments are based on overall plant profiles and asset values with the assessment of remaining life.

All prepared and approved proposals for refurbishment, modification and replacement of an asset are then included in the company’s normal annual plan.

Contingency plans for emergency conditions of major assets are not considered necessary and are not prepared.

There is no central registration of the plant on order, and subsequent input of their data in the equipment register.

3.1.4. London Electricity

Asset management group does the long-term maintenance plans but the service providers prepare the annual maintenance plans, required budgets and system access applications for the maintenance work. They also do maintenance criteria, with feedback and updates of manuals.
A separate section monitors their work and reports to the service provider and the asset manager with various reports.

The maintenance service providers perform budgeting, scheduling, work and finance monitoring, cost control and arrange for extra funding for additional corrective work and emergency work.

All their requests for major asset repairs or requests for modifications need to be referred to the asset management department for the review and approval of those requests.

All requests for new plant are also referred to the asset management, who in consultation with plant purchasers decide which new plant to allocate, budget for and purchase for a particular case. The replacement plant is sourced from the project pool, and no strategic spares are held. Purchasing department arranges with projects to issue drawings and updates the equipment data register.

Financial management system where maintenance costs are registered is separate from the work management software.

Population and age statistics and failure statistics are performed based on estimates of an overall population to calculate expected funds that would be necessary for the replacement of assets. Individual asset failure investigations are used of to assess asset condition and its remaining life to determine the life expectancy of each plan type.

Economical and technical aspects, including financial evaluation models for justifying asset replacement decisions rely heavily on the total plant
profiles, and general capital expenditure commitments are based on the overall asset reliability assessments (no detailed asset databases).

Contingency plans for emergency conditions are not prepared with respect to the relevant contingency scenarios, with no instructions on the response options, responsibility, ownership and updating.

The concept relies heavily on the expectation that the network has sufficient redundancies in itself to cover outages, where operational staff will pursue repair requirements through various groups when the contingency occurs.

3.1.5. Boston Edison

One group does life cycle planning annually and on a long term. Various other groups, mainly on their own, do the work through service level agreements. Most reports are produced for all groups by one performance-monitoring group that also owns the asset data register. The service provider crews though maintain the register.

All budgeting, scheduling, work and finance monitoring, cost control, extra funding for additional corrective work, emergency work funding, maintenance criteria, feed-back, and update of manuals are done by the maintenance service providers. A separate contracts group looks after all internal and external service providers. Their work management system is basic with no asset management software.
There is a separate group for investment planning that prepares standard costing for all asset projects, and provides feedback for all maintenance and capital works progress against the initial approved plan.

Another group performs population and age statistics, failure investigations and failure statistics, asset condition investigations and an assessment of the remaining life of the asset.

The same group prepares business case recommendations for refurbishments, modifications and replacements of plant, which includes some economical and technical aspects in the business case preparation, but with little financial evaluation.

No standards for business case preparation models are available when preparing and justifying asset replacement decisions.

There is no registration of the plant on order and subsequent input of their data in the asset register.

3.1.6. *Duke Energy Company*

Corporate accounting section advises the funds available in the ensuing periods for the maintenance and capital expenditures to be transferred into the plans that will be prepared in such a way to match these funds.

Asset management plans the work that is handed over to the maintenance service groups to run the work schedule. The service groups decide to do work or give it to outside service providers.

The work is presented on paper schedules with 1-2 month intervals, with the paper work sent back to complete the work record in their internal
work management system to enable reporting. There is no accounting link, and the costs are manually entered based on provided sheets.

The scheduling, planning and execution by the service providers are monitored through those reports.

The work progress and finance monitoring, cost control, funding for additional corrective work and emergency work funding are done by the asset management, but in a complicated way with unclear accountabilities and information flow.

The same group prepares maintenance criteria, receives feedback and updates the manuals, but the process directions and requirements are not specified in any detailed documentation.

They include some economical and technical aspects in the prepared business cases to support financial evaluation for justifying asset replacement decisions.

Contingency plans for emergency conditions are not prepared, but the annual plan may contain some recommendations for critical plant.

There is a basic asset register based on sheets sent from site. There is no central registration of the plant on order and subsequent input of their data in the asset register, which is acknowledged and seen as a problem for a quick identification of available spares in a fault situation.

3.1.7. Tennessee Valley Authority

Transmission support group plans maintenance annually and transfers data on regular basis to service groups, which are fairly independent in their
work and the asset manager has poor control and overview of the progress of their work.

They also prepare maintenance criteria, monitor feedback and update the manuals as seen fit.

The maintenance work progress is monitored by each group and by the transmission support group and discussed in monthly meetings between the service providers and the asset manager. The maintenance work is done with no service level agreements.

There is a basic work management system as it does not include costs and has no links to the asset management software. There are no specific contingency plans for emergency conditions.

A separate asset analysis group does population and age statistics, failure investigations and failure statistics, asset condition investigations, and assessment of remaining life.

The results are used in another group to prepare a business case and recommendations for a refurbishment, modification or replacement of an asset. These recommendations contain some basic technical (failures, difficulties in operation, critical circuit assessment) and economical aspects for the relevant asset, but they are not based on any standard model as there is no detailed documentation on how to prepare a standard business case.

The registering of the assets is poor, and completed mainly by procurement and construction staff in the work management database (no separate
equipment database) based on order data, with asset serial numbers and location added later based on eventually-supplied field reporting sheets.

3.1.8. TransGrid

Asset management (called asset performance) covers the responsibility for asset strategies, asset performance and feedback on achieving targets, technical support and plant tendering, while other areas look after asset planning, design and maintenance.

Asset maintenance management is done through regional areas, which are responsible for:

- asset maintenance planning (annual maintenance plans and budgets, and monitoring work progress);
- asset maintenance (short-term work scheduling, work backlog control, workforce resource management to complete the submitted required work programme and basic reporting);
- asset maintenance support (short-term work analysis and confirmation, technical support, fault response coordination and subsequent individual fault investigation and coordination, review and recommended action to correct one-off plant fault issues raised during the year).

Project management and engineering design are two separate areas for the capital works programme but local area managers are ultimately responsible for the projects in their areas.

A separate group is responsible for all asset performance reporting and monitoring of reported trends against the assigned targets to maintain the impartiality in the overall process.
3.1.9. Powernet

One area of asset management (called assets) covers basically responsibility for asset strategies, asset performance, feedback on targets, benchmarking, asset replacement investment planning and business cases preparation, technical support and plant tendering, maintenance planning, budgeting and control, internal and external service providers management, system incidents and investigation.

The main components are primary plant, secondary plant, performance, maintenance, investment planning, and benchmarking.

Internal service providers perform 50% of asset maintenance, while the other 50% is done by an external company through a strategic alliance agreement.

Engineering design has been moved to a separate entity outside the network business, while the project management is in another separate area, but within the network business, and charged with liaison to the engineering design group.

System planning also resides outside the transmission network business in a separate company deliberately set-up by the government.

The same approach has been taken when it comes to organising the system control, ie by use of a separate company, in an attempt to ensure an independent control of the way the system and assets are operated. Regulatory, customer care and commercial marketing groups are in the process of merging into one area, as well as the finance, human resources and administration support group.
Capital expenditure for asset replacement is expected to rise significantly in the next 5-10 years because there are many major substations that are 50 years old.

Their standard approach in future will be to deal with the whole of substations circuits instead of only with the individual plant, as it eventually increases total costs and reduces reliability with the combination of old and new plant in the same circuit.

There are problems with preparation of asset replacement business cases as there is no formal framework in place. The exchange of information and data with network planning and system operations is difficult, especially feedback from asset management about the inclusion of asset condition and replacement plans into the network development plans.

It is acknowledged that there is a need to expand reviewed options for plant or substation retirements with different voltages and network designs, and to seek an input from engineering design, which is also proving difficult in the current organisational structure.

3.1.10. Hydro-Quebec

Hydro-Quebec is a company that covers the transmission and generation sides of the business, however this report only covers the transmission part of it.

The main characteristic of their transmission business is that there are four main regional operating areas, which own their respective assets and are accountable for their performance.
Therefore, they make the final decision on which maintenance and capital works they will execute in each financial year based on the recommendations they receive from their asset management and planning functions. Those functions operate as corporate departments and have supporting and consulting roles in the whole business process.

The following work is performed by the areas themselves: maintenance planning, annual budgeting and control of expenditure, management of internal and external service providers, and project management of the projects in their area. The maintenance work is done through a combination of internal and external service providers.

One area, ie the asset management department (called asset support), covers the responsibilities of network and asset strategies, maintenance policies, network and asset performance analysis, benchmarking, asset replacement business cases preparations, technical support, and plant tendering for the business. In addition, they support the areas in system incident investigations.

Engineering design has also been allocated to this asset support department to provide engineering and design work for the areas.

The system planning is a separate part of the business, as well as the system control, regulatory and customer care, and commercial marketing, finance, HR and administration groups.

Major issues that have been identified in their work are described in the following:

- No standard process and format in place for preparation of asset replacement business cases;
- Maintenance plan execution and practices differ from area to area;
• Basic and not very well documented asset registers and data collection, and input not properly controlled;

• Input of system and asset problems very much dependent on the areas, and there is no system in place to ensure data quality;

• Different format of performance monitoring in areas makes it difficult for the asset support to compare results and analyse the whole of the network;

• Exchange of information and programmes with network planning is difficult, especially with feedback from asset management on inclusion of the asset condition and its replacement plans into the development plans;

• There is no clear responsibility and accountability for the long-term view on coordination of development of the whole network and substation designs in the future.

3.1.11. HEP

The HEP, an electricity company, is also a fully integrated electricity business, ie it still covers the distribution, transmission and generation sides of the business, and is owned by the government as the only shareholder. This report only covers the transmission part of it.

The main characteristic of their transmission business is that there are six main regional operating areas, which own their respective assets and are accountable for their performance.

The reorganisation of their current structure includes discussion, in a much similar way to other utilities being operated as an integrated electricity business (involving generation, transmission and distribution) about the following main topics:
• various proposals are being discussed on how to split generation, transmission and distribution;
• future and roles of the system control centre and a market pool operator;
• how to split transmission and distribution parts of the business (at a zone substation level, transformer LV breaker or zone substation fence).

The main asset management issues active at the moment are the following:

• lack of funds for network expansion and asset replacements due to catch-up expenditure to restore the war damaged plant;
• there are no formal asset management process and procedure, and it depends too much on the individuals and their ad hoc links and relationships;
• too many meetings at technical level involve higher management levels, preventing spending time on the long-term plans and visions;
• a lot of investigations are late as there is an acute shortage of experienced engineers due to difficulties of such business to attract new staff;
• problems in coordinating budgets and plans for 6 different areas, and ensuring that the same maintenance practices are adhered to;
• how to adjust network development plans with the assessment of asset conditions and vice versa.

3.2. Comparative Study Summary

This comparative study has been prepared to show a summary of common issues and differences in the management of transmission assets after a review of a number of similar national and international electricity
companies. The study identifies problems and deficiencies that any new model must resolve.

A summary of the main points from the reviewed companies pertinent to the development of the proposed asset management model is given in the following paragraphs:

The areas of asset management and asset maintenance have now been clearly considered as an important part of the transmission business in all companies. While many have not compiled a complete model or completely understood the process and procedures required to fully integrating all asset management work, there is a general acknowledgment of a need for a complete model.

Therefore, they are all aiming to put a structure in place to cover all aspects of asset management functions and are devoting or planning to put significant resources into that work.

In general, maintenance service providers do more or less day-to-day scheduling, resource management, some degree of use of work management or maintenance management computer systems, monitoring and reporting status of work and costs.

An in-house service provider completed this directly through the internal work management system, and some do that also with the outsourced support. Some asset management groups meet their service providers more often than others to discuss work progress and problems, with such practice more prevalent in companies that do not use some forms of computer management systems.

System studies and planning for network enhancement are done by separate groups, generally not considered an asset management issue. Most companies do not recognise a formal requirement for a need to have asset management
plans and network development plans exchanged and cross-referenced on a regular basis.

Most companies also use the network development group to prepare asset replacement business cases for non-performing assets with information to be provided by various other groups, and making this area somewhat convoluted and unclear.

There is a vast array of organisational structures applied to cover asset procurement, data registering and ongoing data management for asset location and condition. Some companies have completely neglected that area, which makes it almost impossible to perform a proper asset management, particularly with regard to the long-term planning of their assets renewal.

Therefore, they need to resort to general population models and generic asset life expectancy assumptions. These lead to inaccurate predictions about the size and quantity of the coming asset problems, and represent unknown risks to the network operation and viability of business in the future.

A number of electricity companies are still gearing towards detailed computer based maintenance management systems, including common line and substation equipment databases, aiming to register their total asset database and to record maintenance costs against each element of their network.

Asset replacement strategies in the US are mainly based on individual asset performance, safety and security of critical circuits, and less on age, maintenance costs or replacement age profiles.

On the other hand, the UK utilities are spending a lot more of capital money (about 2-3% of their network asset replacement value) on asset replacement projects annually. The main reasons quoted are to avoid high
operational risks and subsequent possible large fines by rigid regulatory bodies their governments have imposed on them.

Some companies have attempted to register network critical locations in various formats, issued and updated usually by the system operations function. The register mainly defines the importance of circuits in the network on a scale of 1 to 5 at the various circuit levels. That could prove helpful for their network planning and asset management studies.

Some switchgear and transformer maintenance policies are set up in such a way that they recognise a difference between the new equipment and the equipment with 20 years or more in service.

Also, higher levels of maintenance are not automatic in some companies, with attempts to base them on the number of operations and various test results obtained during the maintenance (timing tests, contacts resistance measurements, gas content and electrical properties of oil).

Generally no serious contingency planning exist as apparently everything in the network is covered double or over, and has been caused by the capital overspending on assets to have a high network security, and to ensure no load loss occurs under any normally expected system fault conditions.

That is generally due to the fact that there is little knowledge about their assets (poor registering of assets and activities) and their assets current and long-term condition.
4. CONTRIBUTION AND ADVANTAGES OF THE RECOMMENDED INTEGRATED MODEL

The thesis has developed and documented a new asset management model and its process with a number of business functions and their procedures that are appropriate for a transmission business to implement and rely on to efficiently address the problems and deficiencies identified in Chapters 2 and 3.

The integrated model covers and defines roles for all business functions necessary for a successful performance of the asset management process in a transmission business, with the required integration of those functions through necessary cross-links and the required timely information flow and exchange for all of the functions.

The basic outline of the developed integrated model is presented in Chapter 5.

The framework in which the new model is developed is a general one. It is independent of specific organisational structure of any transmission company. This generality is achieved by expressing the framework in terms of required business functions and their roles that are to be fully accounted for in any implemented transmission organisational structure.

The model outline, process, relevant procedures and supportive documentation will be developed and described in more details in Chapters 6 - 15.
The thesis also contains a presentation and discussion of a developed, approved and completed business case for the replacement of a non-performing asset in Chapter 16.

The research outcome will enable transmission business companies to implement, use and continually improve the developed integrated asset management model and its process with the defined documentation for the business functions, necessary databases, procedures, production and use of various reports, maintenance working plans and asset renewal programmes.

The documentation describes strategy and policy intentions, defined process and procedures to implement them, and required initial and output documents to support the process.

The databases establish ways of recording details about assets and their characteristics, position in system, various requirements, actual actions, faults, and future plans.

The developed process provides details of all required initial documentation, necessary databases and data recording and reporting, procedures to perform the necessary work in a timely and correct fashion, and specifies working functions to perform those procedures or to provide prescribed inputs for other functions in the set time frames.

It also specifies all required output documentation that provide the information necessary to make correct, timely and effective decisions by all interlinked work functions in the asset management process.
The developed model provides the transmission company with a framework to enable proper and timely management of its transmission assets in various business areas.

The business areas include setting proper asset maintenance policies and regimes, execution of the prescribed policies through long-term asset maintenance plans, asset operational and financial performance monitoring, and an assessment of their operational and long-term suitability.

The model ensures that future long-term asset management plans are prepared for the asset renewal based on all aspects of the asset cost, performance, age distribution, regulatory legislation, environmental requirements and asset critical position in the system.

The model also includes a mutual and timely updating of relevant network development plans, asset renewal plans and asset maintenance plans.

The model process presents the transmission companies with a tool for proper management of the whole asset renewal and maintenance over a period of time in a planned and controlled manner.

The process enables the company to continually assess its future work and financial liabilities, and viability of the business, by knowing and reviewing the risks for adopting or not the recommended and planned actions to be followed in the future.

That will assist in understanding when and what action to take to limit the potential risks to the system and to the financial health of the company, and to realise any possible savings in long-term maintenance costs by arranging suitable plant renewals.
The process prevents the need to make a sudden and unplanned large commitment of capital and maintenance expenditures that the business possibly could not afford.

The developed asset management documentation gives the transmission company a transparent and effective vehicle to show to the internal and external stakeholders and other forces (board, insurers, regulator, industry, government, auditors, etc) that the company follows a responsible course of action in managing the assets under its responsibility.

Documented procedures ensure that the adopted course of action is justified, and then fully implemented.

It is clear that such a comprehensive approach to the area of asset management in the transmission business through the development, implementation and use of an integrated and dynamic asset management model is the right answer to the task that was set up for this research to yield the right outcome.
5. **ASSET MANAGEMENT MODEL**

5.1. **Recommendations for Any New Model**

The results of the critical review of the published literature and the summary of the asset management practices of the companies visited have been used to indicate the possible improvements or new areas of asset management process, functions and procedures that should be covered by any new model that aims to rectify the identified deficiencies and gaps in the current approaches to the asset management.

The results have also been used to define how the identified functions should be interconnected and aligned into an integrated model to provide a timely and complete feedback amongst themselves. That model should bring all the necessary information and options for opportunities and on time to the right people within the company for their consideration and proper decision making.

5.2. **Objective of This Work**

The pressures and constraints that are currently being imposed on all transmission business companies around the world as detailed in Chapters 1 and 3 have placed a clear emphasis on what their ultimate goals must be.

The companies are expected to continue delivering improved financial returns from their transmission electricity assets to all their stakeholders (that can include shareholders, government, public and employees in various countries) while at the same time maintaining or increasing the reliability of their assets in operation.
This represents a real challenge to the transmission businesses as they are forced to face challenges of a different kind from those in the past in a situation with ever ageing assets.

That is compounded by an environment of a reduction in a possible access time to the network for the same assets for maintenance and renewal works, as requirements for network utilisation and construction works, due to expansion of the network, increase.

The objective of the research and this thesis is to develop an answer to that challenge so that the transmission businesses can deal with the above mentioned situations in the best possible way.

While many others have not compiled a complete model or completely understood the process and procedures required to fully integrate all asset management work, there is a general acknowledgment that any final complete model and its process will have to integrate all the main areas of work and define necessary asset management business functions.

The new asset management model needs to achieve an environment where the functions in place ensure that:

- asset maintenance policies and plans are developed and implemented;
- all assets in service in the transmission network receive proper care according to those plans;
- the assets performance and their overall condition are continuously monitored and assessed while in service;
- assets are identified and highlighted where there are problems;
• the reasons for the problems are identified and optimal long-term solutions devised to address those problems for the benefit of the network, company and stakeholders;
• maintenance policies and plans are continuously reviewed and improved;
• inputs from various defined sources are continuously received and reviewed to respond properly and on time to achieve the best possible short-term and long-term outcomes for management of assets;
• all asset related activities are integrated so that their links and procedures achieve a timely and correct interchange of all defined information amongst the relevant functions in the asset management process.

It is the intention to show that this can be achieved through the implementation and continuous use of a comprehensive asset management model as developed, defined and proposed in this thesis.

5.3. Development of the New Model

The new model has been developed through a number of stages as outlined in the following:

a) identification of the mechanism of transmission asset management process in the electricity transmission business;

b) identification, definition and requirements of additions or improvement of the main work functions of the identified asset management process;

c) identification of the transmission business functions, their required links, and type of the necessary relations between them to cover the specified
work functions of the asset management process. That should not only include information they should provide to one another when required, but also requirements for the interactions to occur within the specified time and relations that have been developed in the asset management process;

d) using the outcomes of the above three steps, finalise an integrated asset management model that covers all required aspects of the identified asset management work functions and transmission business functions involved in the asset management process and linking of their required activities for all the assets used in the transmission network (lines, cables, primary and secondary equipment).

This linking amongst business functions will enable a continuous and complete exchange of information in a defined set of feedbacks at the prescribed times, achieving a desired dynamic framework.

5.3.1. Identification of Asset Management Process

The first step was to identify the mechanism of an asset management process in the transmission business and its functions involved if a successful management of the assets in the active service in the transmission network was to be achieved.

This process was wide and covered a large number of the transmission business functions that in some way influence how those assets in service are looked after and how their current and future operational, maintenance and renewal needs are being or will be met.
The following transmission business functions are necessary to the success of the developed asset management model and its process:

- asset management,
- asset owner,
- network planning,
- system operations,
- maintenance services,
- engineering design,
- project management.

The asset management process was identified as having two distinguished and boundary points during the life of the asset, and a number of activities in-between, as shown in Fig.5.1.

The boundary points in the asset life are:

- a start in a form of an asset acquisition;
- an end in a form of the asset disposal.
FIG.5.1: ASSET MANAGEMENT PROCESS IDENTIFICATION
The asset acquisition may be initiated through a number of different activities resulting in the requirements of new assets in the transmission network:

a) need due to new customers,
b) growth of the network causing loading to increase above the current asset rating;
c) increase in generation and network connections causing fault levels to rise above the current asset rating;
d) change in the planning criteria for the parts of the network that the current assets cannot match;
e) change in the operational requirements for the parts of the network that the current assets cannot match;
f) new requirements for the assets in service brought in by various government or statutory legislation that the current assets cannot satisfy (now or in the short or long periods);
g) failure of the current assets in service that could not be salvaged;
h) reduction in performance levels of the current assets;
i) increase in maintenance costs of the current assets;
j) deterioration of the asset condition that represents an unacceptable risk for the required operation of the network or to the cost for the company or other areas in the event of the asset failure.

Items a) to d) are generally accepted to be network growth issues and are dealt with through a network development planning process, which is not part of this research.

An asset management process for current assets in service generally deals with items g) to j), which is the focus of this research.
The items referred above as item e) and f) are dealt with by both of those two processes depending on the size of the problem and the assets those items would impact on.

The asset disposal may be initiated through a number of different activities that require the assets in service in the transmission network to be retired:

a) asset replaced through the above network improvement activities that cannot be used at another location (obsolete performance, too expensive to run due to high maintenance costs, too expensive to uprate to a required standard for other location);
b) asset replaced after the failure in service and cannot be repaired or the repair costs would be too high;
c) asset replaced due to deterioration or unsatisfactory service before its failure through an asset renewal project.

The above asset disposal options review is generally combined with other activities of an asset management process for transmission network assets in service (maintenance planning, network development, operational conditions, customer supply risks).

In-between those two boundary points, there are a number of other activities that are in some way relevant to the asset management process:

- inspection;
- servicing (maintenance);
- condition monitoring;
- diagnosis and repair;
- failure and repair or else (disposal);
- refurbishment (overhaul);
- modification;
- replacement with relocation or disposal.

Throughout the above process that transmission assets undergo during their lifetime, there is an obvious need to know one's asset inventories and their details as a basis to collect other information and to monitor the asset.

Therefore, it is a paramount requirement that there should be an elaborate data acquisition process to capture data about new assets, and to properly record work on current assets until their disposal.

That in turn creates the need for a number of databases to be set up in the company to enable the data recording and reporting.

5.3.2. Identification of the Process Main Functions

The high level process that has been identified as fulfilling all the requirements for a proper asset management role in a transmission business leads to the need for identification of the main work functions that are or should be fully covered in that process.

A specific approach towards achieving that need defines four steps to reach the required outcome:

- use of all identified areas in the transmission business that have any involvement in working with the current assets;
- interviewing those identified areas;
- setting up a series of workshops with those areas to determine their current involvement and opinion of other areas;
• prepare a summary to define all essential functions and their characteristics.

A summary flow-chart, as shown in Fig. 5.2, has been designed as a result of that investigation. The above approach has yielded a conclusion that the work functions need to encompass the areas of asset strategy and policy, asset owner's input, maintenance criteria, management of maintenance service providers, maintenance management, performance management, recording and reporting of assets and their activities.

There must be a procedure to ensure action is taken on the reported and obtained information of operational and maintenance problems and restrictions. Also, that changes and influences from network planning, input by other areas that deal with external factors, and planning of asset future role by asset owner, are covered.

Underpinning that process is the provision of ongoing support and improvement in the necessary information systems and decision tools, which are procedures in themselves and will be covered in this thesis.

The above findings about the identified work functions required for a complete asset management process are presented below in Sections 5.3.2.1 to 5.3.2.5, where the function requirements are described in more details.

These findings are based on the previously agreed understanding that the business functions must address the full scope of the asset management model and its process in a timely manner if the model to be set up by the thesis is to meet its expectations.
FIG. 5.2: MAIN WORK FUNCTIONS OF ASSETS MANAGEMENT PROCESS
5.3.2.1. Policy and Criteria Development

The work on policy and criteria for the installed assets includes the following activities:

- Preparation of new and improvement of current asset management and maintenance policy and criteria;
- Development of new requirements and procedures;
- Analysis and improvement of the maintenance policies and practices;
- Development of new maintenance techniques;
- Development and review of spares policy;
- Review of new regulations, network requirements and technologies;
- Development of reliability-centred maintenance analysis;
- Development of condition-based maintenance;
- Analysis of asset life cycle-cost and impact on policies and standards;

5.3.2.2. Information Systems and Databases

The roles of information system and databases supporting other functions of the asset management process are summarised in the following:

- Development and ongoing improvement of supporting asset information system and databases;
- Implementation and ongoing improvement in data acquisition procedures and organisation of asset database updates;
- Collection, maintenance and quality audit of asset database records;
- Assist with information system analysis and development and implementation of new features;
• Implementation and use of various decision-making and planning tools.

5.3.2.3. Maintenance Management and Support

Maintenance management and support require the work outlined in the following:

• Preparation of asset maintenance plans;
• Preparation of asset maintenance budgets;
• Management and monitoring of maintenance work progress and costs against the annual plan and budget;
• Establishment and management of Service Level Agreements with the service providers and monitoring of the work undertaken by them;
• Assessment of and remedial action proposals for submitted asset inspection and problem reports;
• Production of asset maintenance and asset performance statistics;
• Asset inventories management.

5.3.2.4. Asset Performance Management and Investigations

Asset performance management and investigations include the following activities:

• Monitoring and assessment of asset condition;
• Analysis of results of asset regular and special testing;
• Analysis and management of asset maintenance work history (cost and defect performance trends);
• Analysis and management of fault and defect data statistics;
• Investigation of assets with poor performance;
• Investigation of major asset failures;
• Provision of technical and specialist advice.

5.3.2.5. Asset Renewal Planning

The planning work for the asset renewals includes the following activities:

• Review and analysis of asset condition;
• Preparation and update of the Asset Management Plan;
• Review and coordination of asset renewal (repair, modification, refurbishment and replacement) and network development plans;
• Preparation and update of the Asset Contingency Plan;
• Implementation of recommendations from the Asset Management Plan;
• Preparation of asset renewal business cases;
• Capital expenditure approvals for asset replacements projects;
• Maintenance expenditure approvals for other major asset works;
• Management of asset repair, modification and refurbishment works.

There are also other inputs into the above work functions from the following areas that will have to be accommodated properly in the new model for the asset management process:

- input from asset manufacturers of the new and existing assets;
- input from various areas providing own internal knowledge, such as asset management, maintenance, construction, design, testing, etc;
- system planning;
- system operations;
- asset owner function groups with inputs and instructions on corporate, legal, financial, media, environment, energy regulator and network performance requirements;
- input from the other industry bodies and associations;
- outcomes of internal or mixed working groups and investigations set up in the company to achieve better returns on asset investments or to increase the safety and reliability performance.

5.3.2.6 Summary of Work Function Requirements

In summary, the complete model and its process will have to fully cover the following five main areas of the asset management:

- asset management process and procedures, which includes company’s strategy and policy at the high level, that will define how the organisation will deal with the asset management practice, organisation, resources, planning and implementation of strategy and policy, and actions on the results of the process;

- asset maintenance criteria and practices, maintenance work content, maintenance work cost identification and planning, improvement strategies in maintenance policy, and standard specifications for drawdown contracts;

- asset maintenance planning and implementation, annual work maintenance plans and budget and cost planning, service level agreements and contracts with service providers, work and cost performance monitoring of the providers, improvement of the efficiency and effectiveness of the maintenance work and process;
- regular reporting and analysis of asset maintenance and asset performance, and subsequent follow-up actions based on the prescribed guidelines, including feedback to update current maintenance policy documents and to correct the network future development plans;

- long-term asset management plans based on asset maintenance costs, performance, age distribution, environmental impact, regulatory requirements, critical position in the system, and future role in the network development plans.

It has also become obvious that the paramount areas that need to be covered first by a complete model are clear asset strategy and policy in the company with defined approach to asset management and identified work and business functions.

That should be followed by a definition of the process and procedures for all necessary activities to define roles and involvement of the business functions (maintenance and construction, asset management, network planning, design, operation, project management, procurement, finances) in the above main areas of transmission asset management

5.3.3. Development of Links Between Business Functions

To achieve a dynamic and integrated asset management model it is necessary to define all links between various business functions in the asset management process as defined above.

That should include requirements for individual steps and procedures in the interactions between those business functions in the asset management
process and the definition of the composition and timing of those interactions.

The collected data would be useless without regular and properly installed representations with relevant and timely information through a reporting process using an array of defined reports.

The reports are then analysed and reviewed by the proper personnel in defined responsible business functions to contribute to the company’s awareness of the asset current operations, performance and well being, and assessment and planning of its future condition and purpose.

Up-to-date knowledge of asset current requirements, its condition and performance (operational as well as financial), and its many future directions and expected purpose in the transmission network, as the overall system grows and subsequent operational needs change, are important and require continuous inputs throughout the asset management process.

These inputs form the basis of proper decision making required by all responsible business functions within their work framework about the asset current and future role in the transmission network and its operational and maintenance needs throughout its service life.

A complete and timely exchange of the feedback information about the network assets in service, its condition and reliability amongst the asset management, operational and planning business functions is the most important aspect of the overall mechanism for a proper functioning of the developed asset management model and its process.
The above mentioned activities must not only be fully integrated in an organisational sense, ie that all the work and relations are clearly defined and implemented, but they must all also have a known time component.

That means that all the defined interchange work links have a defined time lag in which the necessary users have to implement the transferred information into their work, and then provide their own feedback to the next group(s).

All the above need to be underpinned by a well-set up organisation of the transmission business and the use of engaged internal and external resources into an organisational matrix to cover all functions.

Any eventual matrix of an organisational structure for the transmission business must always aim to set clear responsibilities for various aspects of the defined asset management model and its process.

That should ensure that all parts of the organisational matrix have covered the defined and required structure, content and timeliness of links between the functions with their mutual responsibilities.

This work has been in parallel with work from Section 5.3.2, and using the same investigation process to firstly confirm the existing interaction between the current organisational groups.

The findings have been used to map out the current procedures and compare them to the requirements.

The identification of the gaps has allowed then to proceed and set-up implementation of the links in full according with the model process requirements.

All developed and defined required links between the relevant business functions with their contents, reviews required and their timing references
are presented with more details in Sections 5.4, 6.2.3, 6.4, and 7.3; and in Chapters 10, 12 and 13.

5.4. *Presentation of the Developed Integrated Model*

Asset management is an organised process within a company that needs to be implemented to ensure that there are proper documents, process and procedures in place.

They are to ensure sustainable delivery of a high service level of managed transmission assets at a reasonably low cost with assessed and known risks considered manageable and acceptable.

The level should ensure a performance of the transmission network that is acceptable to the company, market and regulator. Sustainable delivery must ensure long-term profitability of the company and long term-viability of the assets themselves.

The final integrated and dynamic asset management model aims to satisfy the above goals and requirements through its:

- proper business functional structure,
- fully dynamic and integrated process,
- completeness of its initial and output documentation;
- organisation of the full use and update of the developed documentation,
- definition of all aspects of the required works by having the complete process covered by an elaborate procedures matrix.
5.4.1. Integrated Model Structure and Initial Documentation

The model is based on two main activity streams defined in the Asset Management Policy to cover the above mentioned asset management requirements:

a) definition and execution of maintenance and repairs of assets in service, which is given a broad term of **asset maintenance management**;

b) monitoring of asset performance, assessment of condition, how critical is the asset position in network, and planning of necessary actions to respond to the identified asset problems (modification, refurbishment and replacement), which is given a broad term of **asset renewal management**.

The model begins with an asset management strategy statement for the management of transmission assets, which is presented in document Asset Management Strategy in Section 6.2.

It follows with a definition of aims and goals that the implemented asset management process needs to fulfil in the transmission business to achieve the above strategy statement, which is presented in document Asset Management Policy in Section 6.3.

The model is then further defined and developed in documents referred to as Asset Management Process Manual and Asset Management Procedures Manual.

The Asset Management Process Manual deals with the definition of the processes of the developed asset management model and its main functions (eg asset management, planning, maintenance, operations, etc) and defines
the necessary procedures and information flow for the developed asset management model and its process on a high level.

The Manual defines the initial documentation required for the process, required databases, required functions and their dynamic links and integration. It also specifies reports the above functions need to produce and use, the sequence and interconnection between the reports, how to perform the required reviews, and the output documentation providing information and directions for using these results.

The Asset Management Procedures Manual details ways of executing the process in the asset management model by describing the procedures following initial documentation, actions and interactions for the responsible business functions, update and use of the required databases, reports, and direction based on information contained in the outcome documentation, from the defined process.

The following main business functions are necessary to ensure the model is successful:

- asset management,
- network planning,
- system operations,
- maintenance services,
- engineering design,
- project management,
- asset owner.
Those business functions could also, but not necessarily, represent names of groups in an organisational sense, but they can be performed by a number of different groups in any set up of the transmission business structure.

The only important rule to follow to achieve the model benefits is to ensure that the adopted structure and its groups have clearly covered all main process work and business functions.

In that way, the required process and its procedures with the relevant documentation will be clearly accountable for the functions assigned to the set-up organisational groups.

The required responsible transmission business functions are described in more detail in Chapter 12.

The central focus is on an asset management function, which has to have its needs and responsibilities clearly identified and visible in any adopted business organisational structure.

It should also be given an overall coordination role for all asset management related activities in the business even when they are performed throughout any other area in the set-up structure.

The model simplified structure outline, incorporating a general asset management process, main functions involved, their interactions, required initial and output documentation with possible output results, is presented in a flow chart in Fig.5.3.

Fig.5.3 also shows links between the main business functions required for the process to succeed. The links and their content are explained in more detail in the thesis.
FIG.5.3: ASSET MANAGEMENT MODEL STRUCTURE
The most important links are to the:

- transmission network planning and its network development plans, which deal with all requirements for new network assets due to the development of the transmission network;
- system operations that provides ongoing information on changes in the way the network performs and operates;
- asset owner function arms of finance services and business development for general business guidelines.

It is important to reiterate that the new asset management model deals only with the existing assets in service in the transmission network.

The process to acquire new assets to cater for new transmission network developments is dealt with by the network planning function through a separate set of rules, and that process is not covered by this research and thesis.

The network planning work is influenced and determined by various factors, such as system growth due to more customers and more consumption, increases in load transfers and fault levels on the system due to such growth, and new requirements coming through from the regulators, new regulations and new standards.

The model does however make extensive use of network development plans to identify all aspects that may influence the way current assets should be managed in the course of the asset management process.
Initially, it is necessary to have the main policy documentation at the company’s level to cover an overall asset management approach within that company with regards to the management of its assets.

Therefore a number of documents have been prepared to cover the required areas, such as:

- Asset Management Strategy,
- Asset Management Policy,
- Asset Management Process Manual,

All the above documentation is to be discussed in more detail in Chapters 6 and 13.

5.4.2. Asset Maintenance Management and Documentation

Asset maintenance management is an organised process, as shown in Fig.5.4, to make sure that all installed equipment has adequate and up-to-date maintenance policies.

It also ensures that there are necessary instructions in place to transform those policies into the action, and on how to perform the specified maintenance.

That is followed by ensuring that those assets are properly inspected, checked, tested and adjusted as per those policies and instructions on a regular basis by dedicated and qualified maintenance service providers.
FIG. 5.4: ASSET MAINTENANCE MANAGEMENT PROCESS

AM - Asset Management
AMP - Asset Management Plan
SLA - Service Level Agreement
Provision must be made for specific procedures for emergency response and follow-up actions in the event of asset failures (effecting asset repairs or using prepared contingency provisions to assist in the event of asset failures that cannot be repaired on site).

Subsequent instructions are necessary to achieve proper handling of the replaced assets after the failed and non-performing assets are replaced with a new unit.

This process must include a procedure for the development and upkeep of service level agreements with the maintenance service providers.

The agreements should cover how the service providers will receive and execute the required maintenance work, specify ways to monitor and review performance of their work, and include a provision to accommodate regular auditing of their work management and maintenance work process, and their procedures.

The asset maintenance management also includes a role of maintenance optimisation, achieved by applying various maintenance analysis techniques to the results of the reports produced on asset maintenance work.

These techniques are used to analyse the assets' current and future short-term operational needs and maintenance history to assess the effectiveness and efficiency of the maintenance work and confirm the need and adequacy for the proposed maintenance work.
A number of documents have been prepared to cover all the issues presented above, which can be summarised as follows:

- relevant maintenance policies,
- maintenance instructions for work,
- requirements for maintenance servicing work,
- arrangements with maintenance service providers,
- asset generic contingency arrangements in the events of asset failures,
- asset maintenance programmes of all maintenance works.

Some of these base documents are maintenance documents, such as:

- Asset Maintenance Policy Manual,
- Asset Maintenance Servicing Manual,
- Asset Maintenance Instructions Manual;

while some are supporting documents, such as:

- Service Level Agreements,
- Generic Contingency Plans.

Others documents contain results, which are an outcome of the requirements in the above base documents, such as Asset Maintenance Plans.

All the above documentation is to be discussed in more detail in Chapters 7, 8, 10 and 15.
5.4.3. Asset Renewal Management and Documentation

Asset renewal management is an organised process that covers a number of important areas, shown with their inputs, outputs, and the information flow in Fig.5.5.

The process consists of:

a) asset information management;

The asset information management includes validation of the received data, audit of the data entry procedures, and a number of required reports for asset renewal management functions and procedures.

b) asset performance;

The asset performance includes monitoring of asset performance, testing an assessment of its condition and remaining life, assistance with asset failures and replacements, investigation of asset failures, and regular audits of the maintenance work and asset management working process and procedures.

c) future asset strategies;

The future asset strategies include analysing received reports, reviewing and assessing plant condition and its critical position in the network, and future service plans in order to estimate remaining useful, technical, economic and safe operational life of an asset.
Those strategies also cover an analysis of risk management assessment and criteria for necessary modification and refurbishment of assets in order to ensure that assets reach their designated lifetime.

The strategies also take into consideration the importance of the assets in the network, and the planned enhancements and additions of the network due to various system and external requirements.

That will assist in work to define any action for or with the asset in a defined timeframe, and planning of investments into renewals of assets that are currently in service in the transmission network.

A number of documents have been prepared to define the initial and output documentation covering asset assessment procedures that use the reports, their reviews, and the output results.

Some of these documents are considered initial documents, such as the Business Case Analysis Manual.

Other documents contain results, which are outcomes of the asset assessment procedures, and they are:

- Asset Management Plan,
- Business Case Studies,
- Special Contingency Plans.

These documents are discussed in more detail in Chapters 9 and 15.
FIG.5.5: ASSET RENEWAL MANAGEMENT PROCESS
6. **MAIN POLICY DOCUMENTS**

There is the need to firstly establish a framework for any new model by defining the main policy documents that will specify goals and aspirations for that development that will lead the development work towards the expected outcomes.

6.1. *Process of Developing the Framework*

The electrical supply industry is an asset intensive business, and the transmission business is not different in that respect.

Pressures from Government (Western Australia, Appendix 22.2), industry and external competition (through an open access regime for transmission assets) back in 1993, together with its own desire to achieve the industry best practice, placed a greater emphasis on the Western Power Corporation (WPC) and its transmission business (Appendix 22.3) to deliver significant improvements in both commercial and technical performances.

That also called for a continuous improvement of return from its assets, while maintaining and improving operational quality and reliability of the power supply.

To respond to these pressures in an organised, continuous and proper way, the transmission businesses must have ensured to have in place:

- a clear **asset management strategy** that sets out responsibility and accountability in the business for the management of its assets through an asset management ownership model;
• a defined **asset management policy** that sets out the commitment to the right process, procedures, supporting tools and planning of the necessary resources that will meet the short and long term requirements for its assets through an asset management functional model.

The objective of both the above asset management strategy and asset management policy is to ensure that:

• Plant performance meets current customer requirements;
• Plant capacity and condition will enable customer requirements to be met in the future;
• Plant faults can be rectified without jeopardising network security;
• Power supply is restored quickly after faults;
• Industry best-practice levels are achieved and maintained for the plant 'whole-of-life' operation costs and performance;
• Long-term business plans reflect operating and capital expenditures needed to renew assets in a timely and organised manner;
• Safety of employees, customers and public is protected;
• Environmental impacts are acceptable;
• Business can sustain long-term financial viability;
• Share holder value increases.

Asset management at the generic level is a set of business procedures concerned with developing, operating and maintaining the asset that delivers owner’s requirements.

It is about delivering the required standard of asset performance for the transmission business and its customers at the minimum overall costs while maintaining long-term asset upkeep and viability.
The transmission business in Western Australia first adopted an idea of asset management model development as a general approach to solve all the above issues in 1994.

That strategic decision was then followed in 1995 with a review of its assets performance and asset carer functions to reach a stage that will ensure proper custodianship for its existing assets in service.

It resulted in the establishment of a dedicated transmission maintenance group with the initial focus being to develop and implement a proper asset maintenance management of its primary assets, that was soon followed with a need to expand its role and embrace a wider asset management focus.

Many discussions then ensued on how to approach a development of an overall asset management strategy for all its transmission assets.

A variety of different available ways were explored during 1996 and 1997, including initial internal and external audits of asset management practices and comparing external studies to the internal developments.

Following the above work and presentation to the senior management, an initial asset management model was proposed and then implemented in the business during 1998.

The model, using and building on the experience of the initial model, was extended, with the implementation of the developed process and procedures, into a more detailed model across the whole of the transmission business during 1999 and 2000.
The following Sections 6.2 and 6.3 discuss the strategic principles of an asset management model as adopted by the transmission business, and describe how accountability for managing assets has been assigned throughout the business functions.

6.2. Asset Management Strategy

The first step in setting-up the required framework for the development of a new model for the transmission asset management is to clearly define the company’s asset management strategy.

6.2.1. Asset Management Ownership Model

The key feature of the asset management ownership model presented in Fig.6.1 is the separation of the roles of the asset manager and the service provider functions within the company.

In this model, the asset manager is accountable for policies and subsequent decisions about current and future roles of the asset, while the service providers are responsible for managing the resources that carry out activities on the asset, as defined and requested by policies and plans developed by the asset manager.

The basic tenets of that asset management ownership model are:

- Clear focus on maximising the value of the asset for the owner;
- Clear separation of responsibility for managing the workforce from responsibility for managing the asset;
*Asset Owner:* Business objectives, development and results; return on assets; shareholders value added.

*Asset Manager:* Asset planning; life cycle cost; condition and performance; utilisation.

*Service Providers:* Service contracting; service delivery; workforce planning.

**FIG.6.1: ASSET MANAGEMENT OWNERSHIP MODEL**

- Clear definition of accountabilities and relationships, with service level agreements in place between the “decision” and “action” functions.
- Contestability of all work performed;
- Development and implementation of the organisation, infrastructure and procedures to support the model process and functions.

The asset manager has an orientation to the long-term effects of the policies and decisions about the asset with a focus to optimise returns on investment against agreed satisfactory service and financial levels of the transmission network with the asset owner.
That involves optimisation of the network and asset development, utilisation, maintenance, upgrade, operation and retirement of the assets to support the asset owner’s strategy of maximising return from the asset and at the same time building shareholder’s value.

The orientation for the service providers is to build and operate a workforce for maintenance and construction work, with a focus on work service quality and excellence, culture of market competitiveness, and continuous improvement in their work.

6.2.2. Asset Management Strategy

Assets only exist to support the delivery of products and outcomes. Asset management is a structured process covering the whole life of an asset with the objective being to achieve the best possible match of the asset with the business needs.

Decisions about assets must therefore be integrated by linking the asset management process with the required business outcomes and programmes in all other transmission business areas.

The key features of the above asset management framework are:

- Link with business planning process;
- Service or output driven;
- Structured and systematic;
- Based on whole-of-life concepts.

The framework for our asset management strategy to try to ensure fulfilment of the above requirements is shown in Fig.6.2.
6.2.3. Asset Management Business Functions

The translation of the asset management ownership model into asset management business functions of the transmission business is shown in Fig.6.3.

These business functions clearly reflect the allocation of accountabilities to the asset owner, asset manager and service providers in line with the above asset management ownership model.
6.2.3.1. Asset Owner

The asset owner is accountable for the overall direction and long-term profitability and growth of the transmission business.

Its focus is on regulator and legislative issues, operational and financial performance targets, long-term business development, and subsequent business directions and instructions to other functions.

The asset owner also provides other essential services to support other areas of the business such as financial and budgeting management.
Therefore, the main areas included with the asset owner are:

- Business Development, providing overall business directions and requirements, including information from the energy regulator, government and local authority legislation, and open access policies;

- Finance Services, providing financial guidelines, budget planning and coordination, financial reporting and other general support.

6.2.3.2. Asset Manager

The asset manager is responsible for defining and enhancing the asset management process, its procedures and the relevant documentation.

This covers asset maintenance and operational strategies to achieve asset performance objectives, optimising the life cycle cost of the assets to maximise the value adding to the business, monitoring asset performance, managing relevant risks, setting asset and network standards, and planning long-term asset maintenance and capital fund requirements.

The decisions must be based on a life-cycle view of costs and performance, assessment of various identified risks to realise optimal capital and operating costs against minimum performance required, and achieving long-term viability of the assets and the business.

The specific focus on asset management enables the development of policy, process, and procedures for the enhancement, maintenance and operation of the current asset base in such a way to deliver defined network
performance and to maximise shareholder's value over the life of network assets.

This is an essential goal and requirement since there is substantial capital committed to the asset base and the need to maximise the regulated income derived from these assets if they are going to contribute to the economic profit of the business.

Three main business functions have been set up to carry out the asset manager role in the transmission business:

- Asset Management;
- System Operations;
- Network Planning.

Asset management is responsible for the overall asset management process and its policies, standards and procedures relating to the current assets in service, including lines, substations, cables, and primary and secondary plant and control equipment.

The asset management role is to manage performance and control maintenance of the installed assets in service, to initiate and subsequently to sponsor any approved asset renewal projects (modification, refurbishment and replacement).

Network planning is responsible for the planning criteria and standards guiding the performance, enhancement and retirement of the transmission system according to performance levels set-up by the asset owner.
They undertake operational and planning analysis of the network, ensure future capability planning, and are the sponsors of the resulting network upgrade, augmentation and expansion projects.

System operations are responsible for the organisation of proper functioning of the power system and the transmission network and associated assets to deliver supply to the end customer.

That includes responsibility for operational reliability, security and quality of electricity supply, coordinated and controlled access to the transmission assets, and for the day-to-day operation and stewardship of the power system control and data acquisition systems and equipment that supports their activity.

6.2.3.3. Service Providers

The service providers are accountable for the provision of all defined and requested maintenance and other service for the specified work documentation, for coordination of those works, and for providing those services cost-effectively and efficiently.

They have to deliver the products that are market tested for value and quality to the transmission business, and need to support the asset management process with proper feedback and innovation input about the work they perform.

Workforce management decisions regarding staffing, skills and productivity, union relations and bottom line margins are based on achieving flexibility, customer focus and strong cost and work management, with a view to maintaining or growing market share.
Any service provider, internal to the transmission business, which delivers services that are potentially contestable, must have those services tested against the external market from time to time.

That has to be part of its integral work process:

• by regularly obtaining comparative quotes for its work programme and practices;
• by competing for suitable external works having the potential to confirm itself and delivery of its services and also to deliver a non-regulated income to the business.

Three main functions have been set out to carry out the service provider role in the transmission business:

• Project Management;
• Engineering Design;
• Maintenance Services.

Project management is responsible for establishing project management processes, and providing project management, control and reporting services for all capital projects and major maintenance projects.

Engineering design is responsible for providing engineering solutions and input services needed by the sponsors (asset management and network planning) and project managers of capital and major maintenance projects to support the asset management process.
Maintenance services are responsible for providing all construction, maintenance and commissioning services on transmission assets in service (substations, primary plant, transmission lines and cables, protection equipment and AC and DC systems, land corridors).

6.3 Asset Management Policy

A formulation of an Asset Management Policy is a further important step towards achieving the objectives set out in the Asset Management Strategy.

6.3.1. Introduction

Asset management is a critical aspect of the transmission business as it impacts on the following core areas of the business:

- Maintenance and capital costs,
- Economic profit,
- Shareholders value,
- Operations service performance,
- Fulfilment of customer expectations and requirements,
- Safety of employees, customers and public,
- Protection of the environment.

Maintenance and capital expenditures for the maintenance, uprating and replacement of its transmission network assets directly affect profits, cash flows and the value of the business.

While excessive operating and capital expenditures on assets can lead to poor profitability, on the other hand the poor asset management process
may result in higher long-term costs and exposure to higher liability risks. It can also result in a failure to meet customer requirements, asset owner or regulatory service standards, and breach other legal or statutory obligations.

Transmission business will therefore be fully committed to the development, implementation and continuous update of such an asset management process that will ensure an effective and efficient maintenance of its existing assets and proper and timely planning of necessary resources to meet the long-term requirements for its assets.

The above mentioned asset management process and its required procedures can be specified through two main activity streams:

- definition and execution of maintenance and repairs of assets in service. This activity is given the broad term of asset maintenance management;

- monitoring of performance, assessment of condition, critical position in service, and planning of necessary actions to respond to the identified asset problems (through modification, refurbishment and replacement). This activity is given the broad term of asset renewal management.

This document provides a policy overview indicating how the transmission business should effect the above two management activities to ensure the ongoing performance and appropriate responses for the long-term requirements of its existing assets in service in the transmission network.

Development of the transmission network to cater for an increase in the load and thermal ratings, fault level increases due to new generation, and through the new customer connections is the sole responsibility of the network planning.
The results of their studies are given in a separate set of documents covering short and long-term network development plans for the load areas.

6.3.2. Asset Management Policy

The following rules have been adopted by the transmission business when dealing with requirements and application of asset management throughout the company, based on the above agreed strategy, to achieve the best results:

(i) Long term asset maintenance and asset renewal plans will be prepared annually for all assets to cover necessary asset maintenance servicing, repairs, refurbishment, modifications, and replacements, and they will be based on:
- asset age and condition;
- asset future role in the system and potential for obsolescence;
- probability of an asset failure and the consequences of such failure;
- physical and system environments in which the asset operates;
- realistic asset decay predictions and subsequent life-cycle costs planning;
- need to ensure the long-term financial viability of the business.

(ii) Investment in the existing asset infrastructure will be based on the need to:

- maintain defined reliability and quality of supply to customers;
- reduce servicing and operating costs;
- extend the economic life of equipment;
- increase return on assets;
- ensure safe operation of assets;
- meet regulatory and environmental requirements.

(iii) All proposals for major expenditure on assets will be prepared on a consistent basis using the standard project approval process.

(iv) Asset maintenance will be completed for each type of equipment to:

- achieve minimum maintenance costs;
- ensure the condition stays within acceptable limits;
- operate it at an acceptable level of risk;
- meet required performance targets.

Their maintenance plans will take into account the overall life cycle plan of the assets, including renewal and disposal plans, and will employ world class methodologies for its implementation.

(v) Risk exposure will be identified through due diligence programmes, asset audits, analysis of performance history and other specialised risk analysis projects. Critical assets will be identified by a standard risk management procedure and classified into different risk categories to place resources where they are most needed. All risk types will be periodically assessed and will include:

- statutory infringement risk;
- ownership cost risk;
- service performance risk;
- customer impact risk;
- community impact risk.
Special contingency plans and emergency response strategies will be developed for all additional significant risk situations and cross-referenced to other relevant existing asset generic or special contingency plans or plans for emergency situations in the organisation.

(vi) All asset management work will be carried out in accordance with relevant legislation and national standards and guidelines (including occupational health and safety, environment and employment). Internal policies will be developed to interpret and support external legislation and guidelines where necessary.

(vii) Information systems will be developed and maintained to enable:

- proper registration of assets;
- recording and management of asset procedures and activities;
- provision and reviewing of asset performance statistics;
- quality of management decision making;
- improving the competitive capabilities of the business.

(viii) Key performance indicators (KPI) for the company’s key results areas will be defined, measured and reported to system operators, system planners and asset managers on a regular basis. KPI trends will be reviewed with asset maintenance providers and internal and external technical specialists on a regular basis in a bid to achieve continuous improvement of policies and practices.

(ix) All field workers, internal and external, must be trained to national competency standards for all work required for constructing, operating, maintaining, testing and commissioning all transmission assets.
Core skills and knowledge will be retained within the transmission business to enable the efficient and effective management of transmission assets, and to provide a knowledge platform when:

- seeking opportunities for private sector participation and involvement in the management and maintenance of the transmission assets in order to achieve the most cost effective and technically viable solutions;
- arranging continuous internal and external auditing of the asset management and maintenance work practices to ensure compliance with relevant policies and procedures and to identify opportunities for improved performance.


The Asset Management Process Manual is a document intended to outline all aspects of the adopted asset management model and to briefly present the characteristics and requirements of those aspects for the adopted model to be successfully implemented and operated.

Other documentation and instructions have been prepared as part of the overall model documentation that defines and sets out details of all the functions, their roles and requirements, and other tools and procedures to enable them to complete their defined tasks.

6.4.1 Asset Management Documentation

The asset management process requires initial documentation for the implementation and upkeep of the asset management model, and output
documentation with instructions on dealing with obtained results and initiating follow-up actions as shown in Fig.6.4.

The model specifies documentation defining all necessary activities, responsible groups to perform those activities, databases and reports the responsible groups need for performing their task successfully.

It also includes the format and content for the expected outcomes of their activities.

The documentation is presented in Chapters 6 to 16.

6.4.2. Asset Management Functions and Their Responsibilities

The asset management functions that are required to support the asset management model and its process and procedures have been identified, defined and linked according to the developed asset management model.

This area is presented in Chapter 12.

6.4.3. Asset Management Databases

For proper asset management, it is necessary to keep records of all installed and spare transmission assets, maintenance and repair activities performed on them, and about asset failures.

That is achieved by establishing, updating and using a number of adequate databases and procedures to ensure they receive a proper acquisition and recording of the data they require.
Asset Management Plan | Asset Maintenance Plan | Asset Renewal Plan

Asset Maintenance Management Documentation
- Maintenance Policies Manual
- Maintenance Instructions Manual
- Maintenance Services Manual

Asset Renewal Management Documentation
- Business Case Analysis Manual
- Special Contingency Plans
- Network Development Plans

Generic Contingency Plans | Service Level Agreement

FIG.6.4: ASSET MANAGEMENT DOCUMENTATION STRUCTURE & INFORMATION FLOW
The acquisition and recording procedures ensure that all relevant data for transmission assets is collected and reviewed, and that information is entered in databases in a timely and correct manner.

Databases to record necessary information for transmission assets can be split into two different database types, one detailing asset data (asset information registers) and the other detailing asset activities data (asset activity registers).

The following databases are defined as the asset information registers:

- Transmission Plant Management System (TPMS);
- Transmission Lines Management System (TLMS);
- Transmission Ratings Information System (TRIS);
- Transmission Lines Geographical Information System (TLGIS);
- Transmission Protection Equipment System (TPES).

The following databases are set up as the asset activity registers:

- Transmission Plant Allocation System (TPAS);
- System Operation Disturbances Database (SOD);
- Notice of Intended Works Database (NOIW);
- Mincom Information Management System (MIMS);
- Network Development Plans Summary Database (NDPS).

The TPMS, TLMS and TPES databases are also used as asset activity registers as they include records of asset failures that are registered against the respective registered asset records.

More details on these databases are given in Chapter 11.
6.4.4. Recording of All Assets and Their Data

All assets need to be recorded together with all their data, with procedures in place to ensure that the relevant data is collected and entered correctly and in a timely manner.

Their records are generally contained in several relevant asset databases.

The data range from initial technical data during the planning and approval process, through the asset tender and purchasing data during its acquisition, to their installation, commissioning, operation and storing.

More details on the recording of data are given in Section 13.1.

6.4.5. Recording of All Asset-Related Activities

All activities related to the network assets need to be recorded for further reviews. They consist of maintenance works, outage plans, protection operations, system incidents and future replacement plans.

All maintenance activities (preventive, corrective, emergency and major works) are recorded to enable reviews of the efficiency and effectiveness of total asset maintenance work.

That will in turn enable further reviews of asset maintenance performance through various reports that will assist in determining number and type of unplanned repairs and their costs.

In addition, every corrective, emergency and major maintenance work, requiring special access to the assets in-between regular maintenance intervals, is reviewed in detail and assigned a corresponding proper failure code to enable recording of failures.
Recording of asset outages, protection operations and system disturbances allows for accounting of all asset-related incidents in the network to assist in further reviews.

Keeping records of all future asset replacement plans allows the coordination and optimisation between asset renewal, asset maintenance, and network planning activities.

More details on the recording of data about asset activities are given in Section 13.2.

6.4.6. Recording of All Asset Failures

All maintenance work completed on assets, in addition to their regular and planned preventive maintenance, is deemed to have originated from an asset failure, and is recorded using the above analysis of the maintenance work.

That will in turn enable further reviews of asset performance statistics through various reports explained later in this document and will assist in determining the number and type of asset incidents and asset failures.

More details on the recording of data are given in Section 13.3.

6.4.7. Asset Management Reporting

A number of reports and reporting procedures have been set-up to ensure that transmission assets with poor performance (operational, financial and technical), that present or future action (eg refurbishment or replacement) are identified.
A procedure has been defined to ensure that these assets, once identified, are dealt with in a correct and timely fashion, and the proposed actions are listed and properly documented.

More details on these reports are given in Chapter 14.

6.4.8. Review of Asset Maintenance

There is a need to assess the progress of asset maintenance on a regular basis using maintenance work statistics between asset management and service providers, as specified on a monthly basis.

The main focus of the review is to highlight all high-cost repair items and to identify recurring asset problems.

It is used to determine adequacy of maintenance policies, maintenance services and maintenance instructions for the maintenance work, and other asset renewal works to assess the success of current remedial actions in progress.

The review also includes an optimisation of the current asset maintenance plan by assessing impact of changes in current and future asset projects on planned maintenance and renewal works and making necessary changes in priority of the future work requirements.

More details on this review are given in Section 13.4.1.

6.4.9. Review of Asset Performance

There is a need to assess performance of the assets using the performance statistics on failures, emergencies and fault and forced outages on a regular
basis between asset management, service providers, network planning and system operations on a three-month basis or as required.

The main focus of the review is to highlight assets with poor performance.

The review also includes an overview of current and future asset projects, to assess their impact on the identified items and their planned works, to be able to determine requirements for future actions.

More details on this review are given in Section 13.4.2.

6.4.10. Benchmarking

In the course of the transmission business it is very important to have a close comparison of asset maintenance and management processes, procedures, practices and resulting performance indicators, with those of other national and international transmission businesses.

Therefore, it is necessary to subject the business to the benchmarking studies with companies in similar businesses.

The studies will basically compare asset base, operating and maintenance results, asset performance, and asset maintenance and management procedures of the participants with a goal being to produce an industry average and highlight industry best practices in the particular area of the transmission business.

The outcome of the benchmarking is used by the individual participants to identify improvements needed in a variety of their maintenance and asset management activities and tasks, and how they could be improved.

More details on the benchmarking are given in Section 13.4.6.
6.4.11. Review of Asset Maintenance Plan

This review has two main phases. The first phase is when the plan is in preparation, and the second one is during its execution.

In preparing the plan, the asset management needs to consult initially with network planning, system operations and the asset owner (finance and business development) to ensure only necessary work is included in the plan for the next period.

The plan is then discussed with maintenance service providers to ensure they have available resources and time. The service providers also confirm the cost estimates for the planned activities.

The progress on execution of the plan (work progress and financial result indicators) requires regular reviewing between the asset management and the maintenance service providers on a monthly basis.

The review should also include an assessment of asset performance indicators and inputs from the service providers on possible improvements towards progress in the asset maintenance procedures by recommending corrective actions as necessary.

For more details on that review see Section 13.4.3.

6.4.12. Review of Service Level Agreements

The service level agreements need to be reviewed regularly between the asset management and the maintenance service providers.
The review should include the status and trends of the agreed and monitored performance indicators, and propose further improvements to the process as required and agreed.

More details of the review process are discussed in Chapter 10.

6.4.13. Review of Network Development Plans

There is a need to assess future network development plans on a regular basis between the asset management and network planning to determine the impact of these activities on the current and future planned asset maintenance activities and asset renewal projects.

The system operations and asset owner functions might be taking part in some reviews, but should be informed of all review outcomes.

More details on this review are given in Section 13.4.4.


The asset management plan needs to be reviewed at least annually following the process detailed in Section 13.4.7 to assess viability of all registered items, i.e. if they are still required in full, partial or at all, or if their planned timing is still relevant.

The review shall also determine if there is a need for additions, taking into the account results of reports and their reviews.

The results of the review are used to update the asset management plan, to request changes in the network development plans, or to revert to updates of asset management documentation.
6.4.15. Review of Asset Management Process Performance

There is a need to measure the success of the used asset management process to assess whether it meets the company's key performance indicators for technical and financial performance.

Therefore it is necessary to perform regular reviews of those indicators, as detailed in Section 13.4.8, and to audit the relevant documentation and procedures to confirm whether:

- Performance of the assets is satisfactory;

- Maintenance, repair and replacement costs are satisfactory;

- Performance versus costs ratio is acceptable;

- The relevant documentation and procedures are being used.

6.4.16. Review of Asset Management Model

The asset management model itself needs to be the subject of reviews, which should be carried out by internal and external audit services following the process given in Section 13.4.9.

These reviews should be used to confirm that the model, its process and associated procedures are sound and well documented, and comparable to the appropriate models used in similar industries around the world.

The reviews should also identify areas for further improvements or refinements.
6.4.17. Review of Asset Owner Requirements

The results of all the above reviews must be presented to the asset owner informing him of the condition and performance of the asset, and how the initial set-up requirements for the network assets are being met.

This opportunity is used to gain knowledge about the latest trends in the asset owner areas of asset management, and to quickly assess their impact on the overall asset management process.

This review must also include a report on the use and suitability of the adopted asset management model and its process, and the appropriateness of the issued documentation to support it.

More details on this review are given in Section 13.4.5.

6.4.18. Development Work

All of the above reviews and their results, participation in the above and other future benchmarking studies, information gathered internally from asset management reports and reviews and externally from other companies and through industry bodies are then used to initiate different development work as necessary in the areas of:

- asset management model and its process;
- the model procedures and working arrangements;
- use of new equipment and technologies;
- new maintenance policies and practices;
- long-term use of various assets currently in service;
- update of network planning criteria;
• review of network operational and contingency requirements;
• requirements for internal and external resources in numbers and skills.

The reviews are generally completed by internal working groups, but can often include external specialists, expert companies, relevant industry bodies and university departments, and manufacturers of the equipment used in the transmission business.

More details on the development work are given in Section 13.4.10.


A number of procedures have been defined and implemented to create the working environment for the developed integrated asset management model.

The procedures are described in detail in the Asset Management Procedures Manual that is presented in Chapter 13.
7. REQUIRED MAINTENANCE DOCUMENTATION

There needs to be substantial documentation for planning, scheduling and execution of the asset maintenance works as a solid foundation to be able to continue with higher level activities of asset management based on the wealth of information produced by the proper maintenance process.


The Maintenance Policy Manual defines the frequency (periods) and different levels of maintenance for all transmission primary and secondary assets, ie substations, lines, cables and primary and secondary plant.

The substations include substation sites, fences, buildings, alarms, lights, water and electricity connections, telephone connections, security systems, fire detectors, fire extinguishers, water sprinkler systems, etc.

The lines include all types of transmission and sub-transmission lines (steel-tower type, wood-pole type, concrete-pole, and metal-pole types).

The cables include high voltage oil filled and XLPE (cross-linked polyethylene) insulated type underground cables.

The primary plant includes circuit breakers, current and voltage transformers, surge arresters, air-cored and oil-filled reactors, power transformers, capacitor banks, disconnectors, earth switches, earthing compensators, etc.
The secondary plant includes protection relays, DC supplies (batteries and battery chargers), communication equipment, system control and data acquisition equipment, etc.

Their maintenance policies cover basic instructions for each maintenance level (ie areas or parts to be targeted), and tests required prior, during and after the maintenance work with broad pass or fail criteria for each required asset test.

The maintenance levels for the plant usually include an inspection prior to the expiry of a warranty period, one to three time-based maintenance work levels, one to three levels of plant normal and fault operations, and condition assessment based on plant testing maintenance levels.

These maintenance work levels start with a simple site inspection with basic checks, and finish with a detailed site servicing activity, which can sometimes consist of a full disassembly of the asset, and survey and service of its major internal components.

The maintenance levels for transmission lines include air-borne and ground visual inspection patrols, ground and helicopter washing, conductor condition test, fly-by thermovision measurements, climbing and tightening up the hardware, etc.

A separate set of prescribed activities is in place to enable control of lines and plant environmental surroundings, generally known as the vegetation control policy.
The maintenance levels for transmission cables include physical ground checking of the cable routes, oil pressure monitoring and insulation integrity testing.

Each of the time-based levels has its own frequency and scope of work. The time-based maintenance is supplemented where possible with asset condition and a number of operations in service (e.g., a number of mechanism operations, number of fault operations, condition of oil and insulation, thermographic survey results, etc).

The sequence of various levels is also specified, and as a general rule the higher level includes the lower one’s work content.

This document also describes routine inspection and patrol requirements for substations and lines. For example, inspection visits to substations on a regular basis are used to check on the general condition of the plant and to detect any physical damage (e.g., holes in the fence, plant emitting loud noise, oil leaks, etc).

All of the above activities are translated into the maintenance standard tasks with their respective frequencies, and are linked to maintenance standard jobs that contain details about maintenance service provider, type and amount of expenditure expected, personnel skills required, and the equipment and materials necessary for the work.

A number of important factors must also be taken into account when planning timing, scope, and maintenance task contents for all of the above maintenance activities:

- government land department die-back regulations for certain areas;
- seasonal ground access restrictions;
• landowners’ access and stock management concerns;
• cultural heritage areas of indigenous people;
• farming work cycle access restrictions for country areas;
• federal and state work and safety legislations;
• local government noise policies;
• traffic access restrictions for metropolitan or country areas;
• various local government and neighbourhood time and access restrictions for metropolitan or country areas;
• asset owner’s requirements stemming from open access and technical code rules and agreements with the energy regulator.

A layout of typical asset maintenance policy manual is given in Appendix 22.4.


The Maintenance Services Manual contains individual asset specific maintenance work specifications, which are detailed, hands-on, step-by-step servicing instructions to be used by the maintenance crews of the service providers when performing the required maintenance tasks.

The service instructions are usually pertinent to the particular type and model of equipment by a specific manufacturer, even the relevant plane might have been delivered in the number of instances.

The instructions prescribe:

• skill levels for maintenance staff for various maintenance levels;
• work content and sequence of the work steps;
• parts, tools and equipment necessary to successfully execute relevant maintenance tasks;
• tests and measurements to be performed prior to and after the maintenance work, with acceptable test results to confirm that the work has been successfully done.

All the above servicing requirements are also translated into the maintenance standard jobs in the maintenance management software system with the following indications:

• required maintenance service provider,
• servicing requirement levels,
• accounting denomination for the proper registration of the expenditure,
• breakdown of the estimated cost (labour, material, services, equipment) for the completion of the necessary maintenance job,
• expected duration of the activity.

The maintenance standard job contents and details are usually compiled from a variety of sources:

• manufacturers’ maintenance servicing manuals and instructions;
• supplements from extensive in-house experience in maintaining the particular equipment;
• input from other utilities;
• advice from the service providers;
• information presented at the industry bodies and forums (eg CIGRE, users’ workshops, etc);
• feedback information from various failure investigations;
• feedback from outcomes of various benchmark studies.
All of the above information needs to be reviewed every time a new plant type is introduced into service in the transmission network. This ensures a timely update of the existing documentation or a preparation of the new documentation necessary to enable proper care of the newly introduced asset.

7.3. *Asset Maintenance Instructions Manual*

The Maintenance Instructions Manual contains guidelines on how to handle the diversity of asset maintenance activities performed by a variety of internal and external service providers (see Appendix 22.5).

It also defines involvement of various other business functions of the asset management process (asset management, operations, planning, etc).

Below are some examples to illustrate how these instructions help with the maintenance work for some of the most important areas:

7.3.1. *Lines and Cables Maintenance*

These guidelines are prepared to assist in the management of maintenance of transmission cables, lines and line structures.

The guidelines are important to state the roles, responsibilities, and the work content of the main functions in the asset management model used for lines and cables maintenance work.

The maintenance groups cover all internal and external maintenance service providers that could be used in the course of the required line and
cable maintenance works, such as line maintenance, insulator helicopter washing, line patrols, vegetation clearing, etc.

The information gathered on line patrols is recorded on standard report sheets and entered in the Patrol Summary Report identifying common defects by grouping them and nominating their span or pole numbers.

The Patrol Summary Report with associated defects must be promptly returned to the maintenance services supervisor for the assessment, recording, and scheduling of the required repair work.

The management of the repair work is discussed in the procedure for handling fault reports in Section 7.3.4. The outage application and approval process is described in detail in the procedure for access to plant in service in Section 7.3.6. The issuing of work orders for the maintenance works to the responsible service providers is covered by the procedures detailed in Sections 7.3.7 and 7.3.12.

7.3.1.1. Planned Work That Requires Outage

All planned works that require an outage are coordinated and scheduled by the works scheduler. That work is planned from preventive maintenance regime and remedial work identified in the previous work completion reports and regular patrol inspections collected over time but not assessed as urgent at the time of the work or patrol.

The maintenance groups make the necessary outage arrangements within the outage block (usually within one-week period) for the work.

The work scheduler issues work orders and job tickets to the maintenance groups once approvals for required plant switching are received.
All defects and irregularities found during line maintenance work are to be recorded by the maintenance groups on standard report sheets.

Appropriate work orders must be raised by the work scheduler to cover corrective actions done during the maintenance work.

If a minor defect is found, it can be corrected immediately by the maintenance groups. They must lodge any outage extension requests for that work with the switching operator and inform the work scheduler.

If other defects are found and assessed they will lead to high repair costs not budgeted for, they are referred to the asset maintenance management for approval before the work proceeds.

It is imperative that the requested outage extensions, once approved, are immediately advised to the work scheduler, so that any other outstanding work on the transmission substation plant in the affected circuits can be attended during the same outage if possible.

Upon completion of work, the maintenance groups report the work outcome on the job ticket, with a summary sheet if necessary, and return the ticket for a prompt work order closure and for input of new work requests if additional work is required.

7.3.1.2. Planned Work That Requires No Outage

All planned line works that require no outage are controlled by the maintenance services supervisors who arrange for work orders on existing maintenance account codes to be issued regularly as per the agreed lines maintenance criteria.
The work orders are to be closed by the maintenance groups as soon as possible after the work completion.

7.3.1.3. Remedial Work That Requires Immediate Attention

All detected defects posing an imminent threat to the public, personnel or continuity of supply or problems found in need of remedial work within the next five working days are considered urgent, and require immediate attention.

The maintenance groups should arrange for an adequate urgent outage directly from system operations.

A separate urgent maintenance work order number is to be created to capture repair costs.

For faults caused by the public there is the need to use special insurance related project and account code numbers when issuing work orders for later analysis and insurance claims.

Work on other urgent defects that did not receive immediate outage approval is to be referred to the respective maintenance services provider who will arrange an outage through outage process as soon as practical.

If the repair costs for the necessary repair work are expected to be high, the maintenance services superintendent will refer the work request to the asset maintenance services management for review and approval before the work can proceed.

If the approval is given for the remedial work to go ahead the work order will be issued promptly.
7.3.1.4. Emergency Breakdown Work

If the maintenance group is called by the SO to attend an emergency breakdown, all details of the breakdown and the corrective action taken must be recorded as soon as possible after the work completion.

A separate work order number is always created for all major incidents to capture incurred costs.

The maintenance group called in for a line emergency breakdown or advised about an imminent line outage needs to urgently notify the work scheduler about the outage who will assess if any other outstanding work could be executed during that unplanned outage.

If possible, the work scheduler will arrange for further contacts and work orders as necessary.

7.3.1.5. Other Remedial Work

During the outage arranged for any particular remedial or emergency work, it is possible that an opportunity might present itself and needs to be taken to do other outstanding remedial work.

If so, a separate work order is to be raised later by the work scheduler to cover the other work performed.

If the other work alleviated the need for another scheduled outage, the maintenance group must forward a notification to the work scheduler as soon as practical, who will advise system operations officers to update the outages database.
7.3.1.6. Feedback on Status of Work

If the work cannot be completed as planned, and the date change is more than four weeks, the maintenance service provider must report the change to the asset maintenance management.

They will decide whether to accept the change, cancel the work altogether, or seek rescheduling of the work.

Where the activity associated with a job has finished, but all the requested work has not been completed, a new work request must be raised to cover the outstanding work from the original work order.

The maintenance service provider or the work scheduler must raise a new work request within one week of the completion of the original work order, and inform the asset maintenance management accordingly.

7.3.1.7. Environmental Issues

In the event of any environmental incident that has caused an environmental damage or has the potential to cause damage, pollution or conflict of interests, the environmental group must be informed immediately for:

- advice on immediate clean-up,
- assessment of environmental damage impact,
- preparation of any remedial works,
- to deal with local publicity on the incident,
- to activate the State Emergency Service if necessary,
- to notify and liaise with all relevant authorities.
Any other received Patrol Summary Report with reference to environmental issues must be copied and sent to the asset environmental service management with the action recommended or already undertaken.

Also, any issue concerning vegetation control and general line corridor and substation easement maintenance activities is to be referred to asset environmental service providers for the necessary follow-up action.

7.3.1.8. Asset Management Issues

The asset maintenance services management staff need to refer any asset fault or asset problem perceived to be a possible generic issue to the asset management for a further investigation and cross-reference to the development, asset management and maintenance plans.

All accepted recommendations from a report on a serious or major fault are to be included in the Asset Management Plan for future reference.

7.3.2. Substations Maintenance

The guidelines are prepared to assist in the management of maintenance of transmission substations and associated plant items.

The guidelines are important to state the roles, responsibilities, and the work content of the main functions in the asset management model used for substation maintenance work.

The maintenance groups cover all internal and external maintenance service providers that could be used in the course of the required substation
maintenance works, such as switchgear maintenance, remote alarm checks, water flooding systems testing, etc.

The information gathered during substation and plant inspections is recorded on standard inspection sheets, and entered in the Q/T Report identifying common defects by grouping them and nominating their circuit and equipment identifier.

The Q/T reports are prepared separately for each substation, using the Q/T report book at the particular site, and a copy remains at the site to indicate that the defects have already been reported. It also serves as a reminder for the next inspection to check if the defect has been addressed.

The Q/T reports with associated defects must be promptly returned to the maintenance services supervisor for the assessment, recording, and scheduling of the required repair work.

The guidelines follow the steps and flow of activities, and make use of other instructions, as described in Section 7.3.1 in the guidelines for lines and cables maintenance.

7.3.3. Emergency Breakdown Response

The transmission business needs to ensure there is a coordinated and effective response for breakdowns of its primary and secondary plant (transmission lines, substations, protection, etc).

The response includes necessary activities, communication procedures and service standards required to successfully initiate and organise emergency repairs and to address any environmental issues that might arise.
A guideline has been developed to answer the above needs based on the principle that when a fault occurs, the SO will firstly ensure safety, attempt to restore supply second, and then decide on the urgency of repair.

The priority is to address key issues immediately, namely the safety of the public and other equipment, and restoration of customer supply.

During that decision making process, the operational staff are free to contact and consult any asset maintenance or asset management personnel as deemed necessary or to nominate them to coordinate the repair activities.

If the repair work needs to start immediately, SO staff will contact the relevant maintenance service group by using their listed contact pager number. The maintenance service group, once contacted, will arrange for the necessary work.

There is a standard response time, but a quicker response procedure is applied when the power supply has not been restored to special risk customers (large mine, smelter, single town supply, hospital).

The maintenance service group shall immediately contact the asset management in the event of major plant incidents or environmental issues. These are briefly explained below:

- For primary assets, major plant incidents include transformer trip, major circuit breaker damage, plant explosion, plant fire, major line damage;
- For secondary assets, major plant incidents include panel and equipment fires, failure of multiple assets in a single incident, high voltage surge entering a panel, equipment failures over multiple sites, major pilot failure, failure of a secondary equipment coincident with a major primary plant failure;
Environmental issues cover equipment major oil spills, damage to property, damage to crops, trees in need of major trimming, bush fire, fire caused by conductor, cable oil loss, explosion with effects outside substation fence.

The maintenance service group will, when contacted, identify the group being mobilised, confirm that the SO have been informed about the incident and have sanctioned the need for the after-hours emergency repair work, and whether the supply to the special risk customers has been affected.

The supervisor of the group that will attend the repair shall also advise the name and mobile phone number to enable contact of operational staff as necessary. The supervisor is also to report on the work progress at least every two hours, or as necessary, to the operational staff.

In the event that initial investigation on site reveals that a new service group is required, the site supervisor will call on that new group via their relevant pager number, and advise the operational staff.

The initial supervisor remains the coordinator on site until the new group supervisor arrives and receives necessary briefings about the problem. When the new supervisor takes over the site problem, the SO staff must be informed.

7.3.4. Handling of Fault Reports

When any party finds a problem in the field with substation or line asset, the normal procedure is to fill out a Query/Trouble (Q/T) report from the book on the substation site.
This will indicate to all those who visit this site later that the problem has been identified and reported for some action to be taken.

There are two possible sources for this reporting:

a) When the internal maintenance service provider staff during their inspection or maintenance work raise the Q/T report, the report will be assessed by the respective engineering officer or maintenance supervisor, and entered into the database in the form of a work request.

   A work request is a simple means of flagging within the database that a problem has been identified. All relevant information must be entered, eg. job priority and recommended date for work, scope of work and approximate duration.

   The work scheduler will convert this work request into a work order when the recommended scope of work and costs are approved;

b) When the Q/T report is raised by other staff (districts, operations) or external contractors, the report shall be sent to the internal service provider maintenance superintendent, who will immediately assess it or allocate it to the appropriate area for an assessment.

   After that, the procedure described above in a) is applied.

In both cases, the service provider officers assessing and entering the work request are free to contact asset management personnel for any additional information or assistance required.

A copy of the received site Q/T report is to be held by the workscheduler, with the work request number written on the report top for later ease of reference.
All work requests that need design or engineering input (refurbishment, modification), require significant expenditures, or need a decision on the choice of service providers as reviewed and approved by the asset management staff.

That approval will be given either in writing or by stamping work requests in the database.

The work scheduler is to approve minor work requests directly.

The work scheduler will apply to the SO for an outage to access and repair the relevant plant, and approval for the outage is given in a form of a switching programme number.

Once approved, the work scheduler prints job tickets with any relevant additional information to the maintenance service provider staff or to nominated external service providers.

7.3.4.1 Jobs for Which an Outage is Required

All work requests that require an outage need to be converted into work orders with a switching work order for the switching outage, in order to receive a switching programme number.

Once the SO accept work orders requesting outages, only they have the ability to alter estimated dates (by moving switching work order scheduled dates in their database holding notice of intended works).

All other work orders linked within the outage work order block will then move automatically in as block (see Section 7.3.6. for more information on the outage procedure).
7.3.4.2. Jobs Not Requiring an Outage

Maintenance service providers can alter work order start and end dates to meet their other commitments and smooth their workload pattern for the jobs not requiring outages.

7.3.4.3. Feedback on Status of Work

If the work cannot be completed as planned with the dates changing by more than four weeks, the service provider is to report the change to the asset maintenance service management to decide whether to accept the change, or seek other way to reschedule or cancel the work.

Where the activity associated with a job has finished, but not all of the requested work has been done, a new work request must be raised to cover the work not done from the original work order.

The service provider or the work scheduler must raise the work request within one week of the completion of the original work order.

7.3.4.4. Completing Work Orders

Once the job has been completed, the personnel will complete the work order ticket within one week and without waiting for late bookings, and send it to the work scheduler, who will complete the work order in the database.

It involves entering the work results, actual completion date, and mandatory completion remarks on the actual work performed.

Finally, the associated initial report for the completed job is sent back to its originator to complete the feedback loop.
7.3.4.5. *Work Request Priority Coding*

The type of maintenance work that is being undertaken must be identified to enable further analysis of actions taken on the assets and the type of interruption the fault has caused. Therefore every individual task must abide by the identification rules given below:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency work on plant that has failed in service</td>
<td>T1</td>
</tr>
<tr>
<td>Emergency work on plant (call-out, or within 2 weeks) for plant that has not failed in service</td>
<td>T2-T5</td>
</tr>
<tr>
<td>Work on plant during the next maintenance</td>
<td>T9</td>
</tr>
<tr>
<td>Work on plant to be done this financial year with outage</td>
<td>T6, T7&amp;T0</td>
</tr>
<tr>
<td>Work on plant to be done anytime with outage</td>
<td>TA</td>
</tr>
<tr>
<td>Work on plant to be done anytime without outage</td>
<td>TB</td>
</tr>
<tr>
<td>Work on plant to be on the requested date</td>
<td>T8</td>
</tr>
</tbody>
</table>

The same values must be used in WOs raised for switching (a separate WO is always required for switching where the required work needs an outage).
7.3.5. Obtaining a Replacement Plant

This instruction provides a guideline for a situation where there is a problem reported on a substation plant that requires the plant replacement.

A Q/T report must be issued to record a problem with the plant, which shall be forwarded to the asset management and should indicate that, subsequent to the plant assessment, the plant needs replacement. It should also suggest when this should take place.

The asset management issues a request for a suitable replacement plant to the plant inventory group using a standard form, which also indicates the urgency of the request and what to be done on the replaced plant.

The inventory group reviews the current stock in custody (spare, surplus and project plant) for the availability of a suitable replacement unit, and discusses possible replacement scenarios with the relevant engineering design sections (eg for protection design, substations design, etc).

When the final decision is made, and the replacement unit is available from the stock in custody, the plant inventory group will confirm this via a standard allocation sheet form. If the allocated plant requires replenishment, the group will arrange for the order and purchase of the new plant.

Depending on the urgency, the replacement can be done in three ways:

- inclusion of the requirement on the next tender,
- extension of an existing order,
- immediate direct purchase from any supplier.
If the allocated replacement plant is sourced from the stock that belongs to a current capital or maintenance project, the relevant project manager's approval is required prior to its use. The plant group is to order a unit for replacement for the project immediately.

If the allocated unit is of a different type from the one being replaced, substation and protection design changes are required. The asset management will send a request for change of the design and drawings to the engineering design via a standard memo with a work order to cover this work cost.

When the design change is completed, and drawings and material lists are updated, the design group sends a PEA form with all necessary drawings to the construction service provider with a work order for their action and expenditure. A copy of that form is sent to the asset management.

The service provider will then schedule the work with the other relevant groups according to the advised urgency. The main service group will also timely inform all other groups required for the work of the work schedule, and then coordinate the work programme with them.

The responsible site construction officer issues a PPRF form for each replaced plant item (one copy each to the plant group, surplus store and one attached to the unit itself). All replaced units are to be returned to the surplus store unless differently specified in the PEA form.

The plant inventory group will perform or arrange for an assessment of the returned plant condition to define any need for further repairs or modifications and obtain the cost estimates for that work. This information
will be used in asset management with other knowledge about future needs for such assets to decide on the future use of the plant.

The procedure for return of the replaced plant and its assessment is detailed by a separate guideline in Section 7.3.10.

**7.3.6. Access to Plant in Service**

There is a need to have a clear procedure for obtaining access to the transmission network from system operations (SO) such that all necessary planned and emergency maintenance work can be carried out on transmission primary and secondary equipment.

Such a procedure has been developed and implemented as explained further in this Section. The procedure is supported by an automatic and dynamic interface link between the maintenance works database (MIMS) and the operational databases for notice of intended works (NOIW).

That interface enables daily interchange of up-to-date information between both databases that is vital for each of them to perform their tasks.

Both databases are detailed in Sections 11.2.1 and 11.2.4.

**7.3.6.1. Lodging of Notices of Intended Works for Planned Works**

The maintenance work for all transmission primary and secondary assets is scheduled and coordinated through six-week work plan intervals. The items of plant are grouped together to minimise the number of outages (eg. substation plant at each end of a line is grouped with the associated
transmission line outage). The outage work order blocks (WOB) are created as a result of such planning. The WOBs are defined as a grouping of work orders (WO) raised against all assets with links to the facility that has a switching WO raised against it.

The WOBs are headed by a switching WO, as every outage requires an approved switching programme. The switching WO is a notification to system operations that an outage is requested for the associated list of plant for the required maintenance works.

The WOBs are automatically loaded overnight from MIMS into the NOIW via a special interface link. The WOBs appear in the NOIW as awaiting an acceptance format that requires a load system study and allocation of a switching programme number by the SO.

The six-weekly works programme is regularly issued to the service provider groups by the work schedulers to enable them to plan appropriate resource capabilities for the scheduled work. From this interaction with the maintenance groups, resource availability is determined and WOBs are finally confirmed.

The individual responsible service provider groups negotiate with the SO on the detailed commencement and completion outage dates for their respective work.

All changes to the switching work order commencement and/or completion dates should be finalised by the workscheduler six weeks in advance. This provides the SO with six weeks to accept the NOIW request, conduct the load studies, review and write switching programmes, and to confirm final network outages.
Once an outage WOB comes into the six-week notification period, all decisions about the commencement and completion dates, switching programme numbers etc. is the sole responsibility of the SO.

When the six-weekly works programme indicates that some maintenance groups are not fully utilised, the workscheduler will check if there is any outstanding work in the current backlog of maintenance works. If the work exists and it could be inserted into the six-weekly works programme, but it requires an outage, the work scheduler will consult the SO first. If the outage looks likely, they will submit the new outage WOB to the SO for acceptance and approval via the standard NOIW link.

When the outage WOB needs to be moved as the switching outage is cancelled or rescheduled, all work orders associated with this WOB will move automatically in both databases. That minimises need for a manual intervention and also keeps the outage WOBs intact.

7.3.6.2. Processing of Notice of Intended Work

The outage WOB can be obtained and reviewed, cancelled, accepted or confirmed by the SO through their NOIW System. All parties can view the six-weekly works programme in MIMS. All outages for the next week will be confirmed by the SO by every Tuesday evening.

The work scheduler will finalise the next week work programme every Wednesday morning and print all work order tickets to appropriate maintenance groups by 1pm Wednesday.
This will give the maintenance groups at least two full working days to plan work and to make accommodation and travel arrangements for the following working week. It is generally expected that outages would be confirmed by the SO even earlier, especially where they involve special arrangements for travelling and accommodation for the affected maintenance groups.

The SO can instruct appropriate maintenance groups directly whether the outage is to proceed, and can reschedule outages, with notification given to the affected maintenance groups. Indication that an outage is confirmed by the SO is given with the assignment of a switching programme number. (The outage is then confirmed and will proceed pending any emergency). If an accepted NOIW or approved outage is cancelled or re-scheduled, the SO will inform the affected maintenance groups with a reason and an alternative date if possible.

The works scheduler and the maintenance groups then need to reschedule the cancelled work, and try to schedule any other outstanding work for that time to make use of allocated resources.

The maintenance groups can correct minor defects during any outage. If an extension to the outage is needed to accommodate this defect work then a request is to be lodged with the SO by the maintenance groups and the completion date for the outage changed accordingly.

If the request is rejected by the SO, the maintenance groups report the defect via a standard Q/T report as described in Section 7.3.4.

All cancelled work will move automatically into the maintenance work backlog and will be resubmitted to the SO for work at a future date.
One switching work order number can be used for work on various items of plant or for multiple work on one item of plant when the work happens within a week by use of split tasks.

If a part of the work in the outage WOB of the initially planned work is postponed, and moves into the future for more than a week, a new switching work order number needs to be raised to request that new outage.

7.3.6.3. Emergency Breakdown Work

Should the failure or deterioration of equipment result in a fault or a forced outage, the SO shall assess the situation and decide if the repair needs to proceed immediately based on how critical that equipment is for the continuity of supply.

If the SO decide that some repair work is immediately required, the emergency situation call-out procedure shall be followed as described in Section 7.3.3.

The mobilised maintenance group attending to the emergency breakdown takes the necessary corrective action as agreed with the SO and asset management under the emergency switching programme number provided by the SO.

The maintenance groups need to record the action taken straight after the work completion through a Q/T report, which will result in a subsequent creation of separate work orders for the repair work and switching as described in Section 7.3.4.

Such emergency repairs may also affect some of the previously planned scheduled outages, in which case the following rules shall apply:
• If the concern is with security of the network, the SO must inform the work scheduler or affected maintenance groups that the scheduled outages will not proceed, and the SO are to provide alternative dates, or

• If resources attending to the emergency repairs result in the scheduled work not proceeding, the appropriate maintenance groups will inform the work scheduler and the SO to arrange alternative dates so that the missed work can be completed.

7.3.6.4. Interface Between Both Databases

The interface link between both databases, MIMS and NOIW, operates overnight on a daily basis and transfers information pertaining to each job in each outage work order block correctly, resulting in an automatic and reliable interchange of information.

7.3.7. Definition of Maintenance Work Categories

Generally the maintenance work can be divided into two categories:

• Preventive maintenance work;

• Corrective maintenance work.

There is an important additional category, being an outcome of a business case analysis, which is related to major works required on the asset. They are recommended as the most cost-effective solution for an item that has
exceeded its useful life or its performance has been found to be unsatisfactory. That category is:

- Major works (major repair, modification or refurbishment on the asset after obtaining a maintenance fund approval).

7.3.7.1. Preventive Maintenance Work

This work is planned in detail with its scope and frequency and the work party, and it is scheduled well in advance and always catered for in the work budget. It is subdivided into two major groups:

- Routine maintenance is a short duration work, with visual inspections, alarm testing, basic lubrication regimes and minor part replacements (e.g., fuses). The work is represented with maintenance standard tasks (MST) and linked to maintenance standard jobs (MSJ) with known service provider and agreed costs. The work does not normally require outages and therefore, it does not require switching access MSTs.
  
  Examples of this work are line patrols, substation rounds, alarm checks;

- Servicing maintenance is a work of longer duration that mainly requires an asset outage for the work to be performed, but some work can be done under "live work provisions". That work is also represented with MSTs and linked to MSJs for the known service providers with agreed costs. It will also require switching access MSTs for the work that will involve outages or live works that need access permits.
  
  Examples of this work are maintenance of circuit breakers and lines, injection of relays.
7.3.7.2. *Corrective Maintenance Work*

This category is subdivided into three major groups:

- **Emergency (unplanned) maintenance.** This type of work occurs with no warning at random when equipment fails, or is just about to fail and is immediately taken out of service. It is generally in situ work, but it can develop to off-line work. The timeframe is unknown.
  
  Examples of this work are:
  
  - Car hits a pole;
  - Lightning strike that damages set of discs;
  - Pole top fire that causes a line trip and requires an immediate attention;
  - Voltage transformer explosion;
  - Power transformer failure and trip.

- **Deferred (1) (planned) maintenance if corrective action is taken in same financial year.** This type of work can be deferred for a limited time until maintenance resources are available or system access is arranged but it cannot wait until the next preventative maintenance or the next financial year. Examples of this work are:
  
  - First oil pressure alarms;
  - Large oil leaks;
  - Significant contacts overheating.
Deferred (2) (planned) maintenance, if corrective action can be taken in the succeeding financial years. This type of work occurs in the same way as deferred (1) work, but does not require action in the same financial year. It can be scheduled for the next preventive outage or the next financial year.

Examples of this work are:

- Small oil leaks;
- Insignificant contacts overheating.

7.3.7.3. Major Works

This type of work is always planned and budgeted for in the maintenance budget. It is classified as major work on plant types or line hardware that needs a business case and maintenance funds project approval. It involves the technical and financial business case before the work can proceed.

The work is subdivided into three groups:

- Overhaul (planned and budgeted). This is generally a long duration work requiring in situ dismantling of plant and equipment, but involves no design changes or assembly modifications. The outage duration can be extremely variable dependent on further work found during dismantling and inspection.

Examples of this work are:

- Refurbishment of transformers (preservation of life expectancy);
- Refurbishment of CB's (preservation of life expectancy);
- Sylgard spray of insulators (preservation of life expectancy).
• Modification (planned and budgeted). This type of work usually requires a long outage time and is usually performed off-site with the removal of equipment to a workshop area, and involves design changes or assembly modifications.

Examples of this work are:

- Design related changes to non-performing circuit-breaker operating mechanism and its control circuits;
- Change of line dampers with a different type because the original type is not performing to expectation;
- Change of line fitting type because original types are not performing to expectation.

• Remedial (planned and budgeted). This is generally associated with condition monitoring processes and asset performance analysis, carried out off-site, and involves repairs or assembly modifications. The item may remain in service until it is removed for work purposes.

Examples of this work are:

- Whole items of plant returned to the workshop for major planned repair;
- Transformers rebuilt in factory due to failure risks;
- Replacement of small quantities of line wood pole/structure (aged asset);
- Replacement of significant portion of battery banks;
- Changing insulator clamping because as the current one has been worn out.
A number of codes have been set-up for use when raising and issuing work orders to enable setting up annual budgets and monitoring of expenditure throughout the financial year for all maintenance activities per maintenance type and per maintenance service providers.

The maintenance activity type code consists of:

♦ responsibility centre (primary or secondary assets);
♦ activity type (preventive or corrective or major works).

7.3.7.4. Coding Maintenance Activities Type

The responsibility centre codes used for the account code in work orders are defined for maintenance of the primary and the secondary assets.

Separate activity codes are to be used to form an account code in the work orders as per listed preventive, corrective and emergency, and major works maintenance activities in the following manner:

Primary Assets-Preventive
Lines: patrols, maintenance, washing, vegetation, corridor and easement works, pole testing, replacement of poles after pole testing, pole treatments, TVI from lines, cables work.

Substations: building, fence, lights, cleaning and gardening, insulator washing, routine inspections, thermographic inspections, graffiti removal, environmental activities and remedial work.
Equipment: switchgear, batteries, chargers, oil testing; CT/VT/SA, earthing & switchboard testing; replacement of plant after plant testing, routine maintenance, warranty inspections and work, condition monitoring, contingency planning.

Secondary Assets-Preventive
Preventive maintenance: testing, inspections.

Primary Assets-Corrective & Emergency
Overhead line repair work, cable repair work, switchgear repair work, plant replacement after failures.

Secondary Assets-Corrective & Emergency
Relay repair, replacements of relays after failures.

Major Works
Modification, refurbishment.

7.3.7.5. Coding Maintenance Service Providers

There is also the need to identify responsible maintenance service provider work groups for specific work by using codes for all the individual internal and external service providers in the work order management system as shown in examples below:

- switchgear work;
- electrical insulation testing;
- lines maintenance work;
• lines washing works;
• line corridors environmental work;
• relay works;
• electrical controls work;
• gardening and other civil works,
• construction work,
• specific maintenance work by external providers.

7.3.7.6. Work Orders for Cancellation of Site Work

When site work is cancelled in the last moment due to bad weather or system constraints, a special work order needs to be created to cover the non-working hours.

The work order is raised against the asset on which the original work was planned, and from the relevant cancellation standard job.

7.3.8. Formulation of Asset Maintenance Plans

MIMS corporate database is currently used to schedule and execute the maintenance planned for all transmission plant and equipment. It has no facility to create readily available summary of the maintenance plan in a format suitable for discussion and optimisation purposes.

A procedure has been prepared to achieve the output format necessary by using the data from the MIMS replication database and running a series of MSA queries.
7.3.8.1. Planned Preventive Scheduled Maintenance

Maintenance plan in this category is assembled using the requirements listed in the following categories:

- planned preventive work requests,
- maintenance standard tasks as per the maintenance policies for all primary and secondary assets;
- upfront defined planned major works activities;

Most of this maintenance comes from the first and second categories, which need to be converted into the work orders by the works scheduler when they are due for execution.

The third category exists in the form of a work order with an attached cost estimate for the budgeting purposes.

The works scheduler then combines the workload of all maintenance services providers and outage requirement plans to schedule the work.

7.3.8.2. Planned Corrective Maintenance

This is maintenance undertaken to correct effects of known equipment failures or other asset unacceptable situations.

Maintenance in this category for primary and secondary assets consists of the requested corrective works planned for the following period, and it is compiled from the following areas:
• Work requests raised throughout the previous periods and planned for work in the next period;
• Work orders not completed in the previous period and rescheduled for the next period;
• Work orders raised for future known repair work to be done in the next period.

The above work requests need to be converted into the work orders by the works scheduler when they are due for execution, and scheduled for work together with the other work orders above.

7.3.8.3. Unplanned Preventive Maintenance

This is maintenance based on plant condition feedback, and usually initiated as a result of some type of trigger mechanism (eg number of operations, number of trips, fault levels, level of measured activity, etc) or a knowledge of the condition of an item from routine or continuous testing and monitoring.

Maintenance in this category for primary and secondary equipment is listed in a separate group and forecast from a knowledge of the current asset population under that type of monitoring and expected trends in the deterioration of the condition of the equipment.

7.3.8.4. Unplanned Corrective Maintenance

Maintenance requirements in this category for all assets are predicted by using lists of unplanned corrective works that appear in the current year,
and are based on the type and trends in asset failure statistics for the current and future asset population.

7.3.8.5. Emergency Maintenance

This is work that needs to be undertaken after major failures, or maintenance work required on an urgent basis to avoid possible serious consequences, and to make a situation safe before or after failures in the current year.

The forecast is prepared based on the knowledge of incidents occurred in previous years, trends in asset failure statistics, and from condition assessments presented in the Asset Management Plan.

7.3.8.6. Maintenance Optimisation

Once the first cut of the maintenance requirements for network assets in the next planning period is completed, the requirements need to be assessed and prioritised against several other asset activity plans and records.

It will ensure that final maintenance plan is based on a total view, ie it represents an optimal schedule for the required maintenance of the network assets.

These plans and records are:

- asset management plan and its planned activities for asset renewals and replacements;
- network development plans and their planned asset upgrades and replacements;
- asset operational requirements and critical position in the network;
- asset maintenance, operating, and failure history in the previous period.

Corrections in work or work priority are made for the assets listed in the original-cut plan that are to be actioned through any of the above plans or had no maintenance and operating problems in the previous period.

It is important to emphasise that this procedure is also regularly applied to the maintenance review meetings during the year, see Section 13.4.1.

Once the optimised asset maintenance plan is completed, it is then used for the preparation of budget estimates in the forthcoming financial years for which the maintenance plans are valid, as described in Section 7.3.9.

7.3.9. Preparation of Asset Maintenance Budgets

The work identified as required and forecast throughout procedures defined in Section 7.3.8 needs to be converted into the expected expenditures for future years in a proper accounting format.

MIMS has currently no facility to create readily available estimates summary to prepare the expenditure forecast for the budgeting purposes.

A procedure has been prepared to achieve the necessary outcome format by using the data from the MIMS replication database and running a series of MSA queries.

The final budget requirements are prepared by following the procedure explained below, which are then presented to the asset owner sub-functions for the review and endorsement.
7.3.9.1 Estimates

The method used to obtain budget estimates depends on the type of the required maintenance. Where the work is planned in advance and the typical costs are well known the total costs occurring in a financial year can be calculated with reasonable accuracy.

However, budget estimates for maintenance undertaken to correct failures, or where a failure is anticipated, are based on considerations such as typical expenditures in recent years and their trends, and the condition of the plant.

The actual maintenance expenditure can also be influenced quite considerably by many unforseen events, so significant discrepancies can occur between actual expenditures and the budget provisions.

For example, unusual weather conditions, such as violent storms, can lead to expenditures in excess of the budget provision, where on the other hand unseasonably heavy rains at intervals during the summer can lead to significantly reduced maintenance expenditures as less-than-usual insulator washing would be required.

Maintenance expenditures are charged to a number of specifically defined maintenance activity account and maintenance service provider codes, and the corresponding budget estimates are prepared for each of the account and service provider codes (see Appendix 22.6).

For the purpose of expenditure monitoring, the account codes have been grouped into various maintenance categories, such as planned, preventive, corrective etc. in accordance with Section 7.3.7.
7.3.9.2. Budget Estimates for MST Initiated Work

These budget estimates are produced through the use of Maintenance Scheduled Tasks (MST), which are appropriately linked to the Maintenance Standard Jobs (MSJ) in MIMS database.

All necessary details to produce those estimates, including estimated costs, of the activities undertaken on each type of equipment, are recorded in MSJs, which are “triggered” at the defined intervals for each item of the equipment via the MSTs.

That creates a work order for the work required at the right time in the year.

The tables identify activities initiated by MSTs. The forecast expenditure for each of these activities and their corresponding account codes is obtained by adding into one sum the estimated cost of all MSJs that will be triggered by the MSTs during the financial year for which the budget is prepared.

The required budget data from MIMS are obtained through an MSA query that has been created to extract appropriate details of MST initiated work during the relevant financial year from the MIMS replication database, its output saved in an Excel format.

A suitable spreadsheet format has been created to assist with converting the estimates produced as described above into the format required by financial services for company budgeting purposes.
7.3.9.3. Budget Estimates for Non-MST Initiated Known Work

There is the need to budget for the expenditure in future financial years for previously recorded works required on assets that could not be done at the time and has been postponed to be done later and budgeted based on the estimated costs for that work.

In these instances, start and finish is approximately known in the future financial years, and work requests and work orders are created to indicate that period and a likely cost requirements for execution of the works.

The estimated costs of these work orders are summarised per defined cost code categories to indicate future total expected expenditures, and are included in the future financial years budget estimates.

Examples of the type of work where this approach is appropriate are:

- Non-urgent and postponed maintenance work that will still involve significant expenditures, and cannot be funded from budget provisions in the current financial year;

- Condition-based and postponed maintenance works;

- Known corrective maintenance works.
7.3.9.4. Budget Estimates for Non-MST Initiated Unknown Work

There are a number of instances where expenditure in future financial years is uncertain and can only be based on the past expenditure, trends of the past expenditure, and other factors specific to each class of expenditure.

Examples of the type of work where this approach is appropriate are:

- Emergency Maintenance Work

The budgeting for this type of work is done by assessing the previous years expenditure and probability of future failures in the coming years due to ageing and poorly performing asset families, and reviewing asset replacement plans in development and asset management areas.

- Corrective Maintenance Work

The budgeting for that type of work is done by assessing the previous year expenditures and probable expected expenditure due to ageing and poorly performing asset families, and by reviewing asset replacement plans in development and asset management.

That is then adjusted by reviewing possible surplus that can be expected in preventive maintenance area due to non-execution of all planned works due to various factors (system outage cancellations, other asset failures, project variations, resources shortages, etc) using the previous years experience.
• Condition Monitoring Initiated Maintenance

The budgeting for that type of work is done by assessing the status of operational statistics for the monitored assets, by analysing annual reviews of ageing and poorly performing asset families, and by forecasting the quantity of assets that might need replacement in that year.

7.3.9.5. Provision for Budget Estimates for Unknown Work

Such budget requirement provision for future years in the budget planning is achieved through the use of so-called “dummy” work orders in the budgeting software system. They will not be used for actual works and no costs will be charged to them.

Any actual required work when initiated requires individual work orders to be created for the specific work, with costs charged to the same account code as previously budgeted through the “dummy” work orders.

It is important that the originators of the required maintenance work in the future place sufficient information in the extended description of the budget work orders or work requests.

In that way the scope and importance of the work is clear to budgeting personnel, who do not have technical background and detailed knowledge of the requested work.

This will enable a quick assessment of priorities in the likely event that pruning of the budget provision is required, through the cycles of the maintenance plan optimisation and budget negotiation process with the asset owner and other business functions.
An MSA query has been created that extracts appropriate details of all work orders and work requests initiated for work from the MIMS database and produces a report based on this data and access to the MIMS replication database.

Another spreadsheet has been created to assist with converting the cost estimates for the maintenance work orders produced as described above into the format required by financial services for the company's standard budgeting procedure purposes.

7.3.10. Removal of Assets from Service

The instruction details the procedure and responsibilities applicable when primary plant assets need to be removed from a substation site due to a project or maintenance-related activity.

It explains the relevant activities and flow of information related to the movements of plant from the substation site to the workshop store, its assessment, any required upgrade or repair actions, and then transfer to the store or somewhere else as defined in an issued instruction.

7.3.10.1. Initial Procedure after Removal of Assets from Site

A Primary Plant Return Form (PPRF) is mandatory for all items of the replaced primary plant that are to be sent from the substation site to the plant central workshop store.

The form must be prepared and one copy attached to the removed plant (other copies to be sent to the store directly and to the plant inventory officer in asset management).
The transport to the store is to be arranged by the service provider performing the work as part of the capital or maintenance project under which the plant has been removed.

Once the plant identity has been confirmed, a visual inspection of the plant item is to be carried out by the relevant workshop staff, and a report prepared to indicate its current condition.

The prepared report, signed PPRF form, and a delivery advice form are then sent to the plant inventory officer in asset management.

7.3.10.2. Assessment in Asset Management

Following receipt of the above information with the PPRF form, the asset management plant officer determines whether the whole item of the plant can be re-used in the future for new projects, or could be used as a strategic spare.

7.3.10.3. Returned Plant Required for Future Use

When the returned plant is required for re-use, it shall be returned to the store in "fit-for-use" condition. The following procedure shall apply:

- Asset Management requests the maintenance services to detail the scope of work and provide the cost of any refurbishment and testing required to be carried out prior to the plant being returned to store and the estimated residual life of the plant after refurbishment;
- If asset management determine that the advised costs are too high, the plant shall be considered unsuitable for reuse and procedure for disposal in Section 7.3.10.4 shall apply;
If the advised costs for refurbishment and testing costs are acceptable, asset management will issue a request to maintenance services to complete the work on the plant as required;

Following refurbishment and receipt of acceptable test certificates (when applicable), asset management will arrange for stock numbers, residual values and store location to be created through the custody stock store coordinator and transmission accounting officer;

Asset management will confirm acceptance of the refurbished plant to maintenance services and provide them with the applicable stock numbers, store locations and account codes.

Maintenance services will arrange for the transport of the plant to the custody store, with the transport costs booked to the project or maintenance work order under which the plant was removed from site.

If this is not possible because the project or maintenance work order is closed, a standard general plant account code is to be used;

Asset maintenance will issue a set of approved test certificates (where applicable) to the maintenance service provider for its commissioning.

7.3.10.4. Returned Plant not Required for Future Use

When returned plant is not required or is deemed unsuitable for future use, the following procedure shall apply:

Asset management offers the surplus plant to the maintenance service providers as a source of spare parts;

If the plant is required for spare parts, the maintenance service provider will advise asset management accordingly and assume full responsibility for the plant;
If the plant is not required for spare parts, asset management will obtain an approval from the management to dispose the plant and issue an instruction to the workshop accordingly;

- Asset management will ensure that the record of the final status of the returned plant is updated in the relevant asset databases.

7.3.11. Identification of Assets

The identification of network locations together with individual equipment items attached to those locations is provided via the MIMS function equipment tracing review windows.

The procedure is called fitment (addition) and defitment (removal) of an individual item of plant to an installation position.

That provides a record of the current and past history of all the individual network asset installation locations and plant attached to those locations for current planning of the maintenance work and future analysis.

When identifying an item of plant, the installation position equipment profile needs checking to determine the following:

- the installation position exists on the equipment component profile;
- a fitted equipment reference is required, or a tracing action is allowed for the nominated installation position.

When maintaining equipment tracing with a work order, the item of equipment entered on the work order is the costing equipment. The MIMS database provides the facility to review and reset the existing maintenance
tracing schedules for each installation position entered, which is that of a tracing action of fitment, defitment or rebuild in situ.

Both batch and online capabilities are provided for reporting:

- where the equipment has been traced;
- what equipment is currently fitted to the installation position equipment;
- all equipment that has ever been fitted to the installation position;
- what equipment is currently held in store for the nominated stock code.

7.3.11.1. Equipment Tracing

Both individual physical plant item and individual installation position need recording to enable future reporting of item maintenance history in MIMS.

The installation position remains unchanged, regardless of the physical item that may from time-to-time be fitted to and defitted from the installation position.

Equipment number information can be further refined by the use of:

- component codes - indicating the various major items making up the equipment number;
- modifier code - indicating the location of a fitted equipment where more than one of a fitted equipment is part of an equipment number.
7.3.11.2. Main Mechanisms

The main mechanism of the equipment tracing facility includes:

- **Equipment Register (ER):** A file holding the static information on individual equipment is subject to tracing. A flag on the file indicates whether the equipment is subject to tracing. Information that is held about individual equipment varies depending on the type of equipment. The individual equipment is identified by its equipment number.

  It should be remembered that equipment tracing applies only to those items of importance and high value that maintenance personnel have determined to have sufficient impact to warrant tracing.

Therefore, the following apply:

- only equipment recorded in the equipment register as being traceable is subject to equipment tracing,

- all members of an interchangeable group must be registered to enable MIMS to adequately trace history without indicating errors.

- **Equipment Tracing File (ETF):** A file holding, in chronological sequence, a series of references to other documents throughout MIMS that have some action for the equipment. These documents include:

  - purchase orders;
  - work orders;
  - store credit requisitions;
  - store requisitions.
The ETF is simply a chronological record of these actions, and their records in MIMS then provide complete and valuable information on the life-cycle of the fitted equipment. Fitment and defitment of fitted equipment to and from an installation position can be done without a work order.

❖ **Equipment Group Identifier (EGI) File:** A file is used in common with other modules and holds a profile of installation positions for reporting 'holes' and double fitments. The EGI file plays a part in maintaining the accuracy of the tracing information to enable reporting all fitment work orders and all equipment classified as currently fitted.

❖ **Relationship of Equipment Numbers to Stock Codes:** When registering an item of equipment in the ER, a stock code can be assigned to it. This allows the choice of equipment assigned to the stores for control purposes. If the equipment is to be traced in and out of stores (issue requisitions and receipts), the equipment number must be recorded.

❖ **Reporting Mechanisms:** A series of reports to either ensure the accuracy of tracing information or to present a comprehensive maintenance history of an item of fitted equipment.

❖ **Operating Statistics Profile (OSP) for Equipment:** One of the critical items of information about the life history of fitted equipment is the OSP log that the fitted equipment achieves when fitted to equipment and operating. These following statistics are measured:

- for each fitment incidence, the amount of work done on each fitment (until it is defitted or rebuilt in situ);
- total accumulation for the life of the fitted equipment.
It should be noted that the various types of operating statistics (hours, tonnes, kilometres etc) used in MIMS are user-defined, as well as all the maintained statistics for each piece of equipment.

In order for statistics to be recorded against an item of equipment, the OSP for the equipment needs be set-up to define the statistics to be recorded and how those statistics are to be recorded.

### 7.3.12. Use of Work Order Management

This procedure is prepared for the work order management module in MIMS, and to assist with the creation of work orders and population of the necessary fields in the module work orders.

It is important that all the necessary fields indicated in this instruction are populated, because this is essential for the success of later reporting and future analysis of asset performance from the work orders history.

The work order number is automatically generated by the system, and the user’s default set-up (this can be overridden by manually selecting a work order prefix).

The originator identity is recorded through the user’s pay number that will appear automatically.

The work order brief description is required, but the use an extended description field is optional.
The correct plant location or actual plant unit details must be entered into the equipment details field, and the work group code into the appropriate responsible work group field.

The originator’s priority is entered by choosing a proper code from the selection table in relevant instruction in Section 7.3.4. A work request number is to be entered where appropriate.

The work order and maintenance types must be selected from the appropriate asset management instruction in Section 7.3.7.

The component code for affected asset, where applicable (eg. CT for current transformer), component modifier code (phase) where appropriate (eg. R for red phase), and planners priority are selected using codes from the appropriate instruction in Section 7.3.7.

The cost centre account and project number details, where applicable, are added. The work driver, work cause, and plant type mode are then selected.

It is possible to create a number of individual tasks through the task tab window, with their own start and finish dates, as long as they are in between the start and finish dates entered for the main work order.

When closing a work order, whether it has been completed or cancelled, completions date, completed by, completion type code and completion remarks are entered through the completion tab window.
7.3.13. Expiry of Asset Warranty

All new plant requires warranty inspections after expiry of their warranty period, so they can be checked for deficiencies or problems and report back to the supplier to have them rectified.

There is the need to have regulations and requirements for general checking of asset condition prior to expiry of their warranty.

In addition, some plant (circuit breakers, power transformers, instrument transformers, disconnectors, earth switches and capacitor banks) requires work and testing before a final acceptance certificate can be issued to the relevant plant supplier.

Therefore, an instruction for the execution of that activity is required.

The control of warranty requirements is achieved by using warranty MSTs on all relevant equipment, to ensure that the work order for the warranty work is triggered and scheduled, and that the relevant maintenance providers execute the scope of warranty work.

The provider will also check if there were any problems reported for that piece of equipment in the past.

For all simple equipment that needs no site work, if no problems have been recorded during the warranty period through the Q/T reporting system, the warranty inspection work order in MIMS is closed immediately to change the equipment status to be out of warranty (eg surge arresters).
If there were problems, a standard form should be filled and sent to asset management for further action based on the following information:

- if there are no more outstanding jobs, ie all work has been completed, the end date for the warranty work order is changed to one year from the date of the last completed repair;

- if there are still outstanding jobs, change the work order end date to the planned end date for the last repair.

The above information is required to enable asset management to return the manufacturers' bank guarantees for the plant under warranty after expiry of the plant warranty period, by releasing or not releasing the final acceptance certificate.
The scope of the generic contingency plan documents is to cover transmission asset failures resulting from consequent or independent coincident events, and to provide a comprehensive response to such failures where they take the transmission system outside the boundaries of normal planned operational risks.

The events can be caused by:

- Environmental sources such as lightning, fires, earthquakes, cyclones, birds, trees;
- Human sources such as vandalism, accidents;
- Malfunctioning of other equipment, explosions of adjacent plant and failure of protection systems.

The generic contingency plans ensure that every major transmission asset in the network can be suitably replaced, and the power supply restored, in the timely and coordinated manner to manage reliability and security risks on the system in the meantime.

Major transmission assets include transmission lines, cables and primary and secondary plant.

These plans cover the whole network and are designed to cater for all events considered reasonable operating failure risks.

They should not be mixed with special contingency plans sometimes developed in addition to the generic plans and tailored to cover possible increased failure risks for a specific asset(s) in a limited timeframe.
The generic plans also do not cover system-wide catastrophic emergencies such as multiple coincident events or disaster events as a result of a source of risk that is considered well beyond normal operating risks as explained in Section 15.4.

For example, the essential N-1 contingency substation planning criteria has covered the majority of power transformers in the South-West Integrated System (SWIS) substations of WPC. The criteria mean that substations operate in a manner that will allow the loss of one piece of plant in the substation without introducing the need for a load shedding.

The introduction of special contingency planning, as described in Section 15.4, with the development of a plan using a concept of Rapid Response Spare Transformer (RRST) (spare mobile unit on moveable platforms that can be brought to substation sites within 8 hours), has allowed the use of the modified N-1 requirement through use of 1% and Normal Cyclic Rating (NCR) criteria.

The criteria mean that there is a small time window in a year when N-1 criteria will not be met if a fault occurs in that time window. Such rare situations have been accepted, as the risk for a failure occurring exactly in that window is small, and the RRST can be brought to the substation quickly. In that way, such arrangements bring a lot of capital outlay savings, due to a significant postponement of the long-term requirements for new transformers.

For substations that cannot be operated in the NCR manner, a further consideration is required. The most common circumstances that can cause the need for further considerations are those in which:
- Substation capacity is no longer covering load demand with the loss of plant;
- There is an increased chance of loosing two pieces of plant at a substation;
- The consequences of loosing one piece of plant are unacceptable.

These circumstances could often arise in network due to:

- Preceding unrectified failures at the substation;
- Transformers experiencing extreme operating conditions (such as multiple close through faults due to automatic re-close function of the switch);
- Substation is the sole supplier to sensitive loads;
- Plant has been identified in the Asset Management Plan as being susceptible to a failure.

Asset identified in the need of further consideration beyond the scope of the generic contingency plans will require a special contingency plan.

The generic contingency plans are ‘live’ documents and require a regular, at least annual, review of their contents to ensure they match the evolution of the network. The plans are based on the current Network Planning Criteria and System Operation Requirements, and are generally valid for one year from the date of issue.

Examples of generic contingency plans that cover eventual failures of the transmission assets and provide a framework for a proper response and the management of such incidents are given below.
8.1. Emergency Management Plan

The Emergency Management Plan is implemented when a specific level of emergency has been initiated.

The Plan outlines the responsibilities of the key officers involved in the emergency response management, and the recommended action guidelines.

The Plan is based on the responses required for specific events of the graduated levels of severity with four levels of emergency.

The purpose of the actions in responding to each of the identified and defined emergency event levels is to:

♦ Minimise damage and loss of electricity supply to customers;
♦ Be consistent with the safety of the public and employees;
♦ Ensure that management, customers and other stakeholders are kept informed of the status of impending or actual emergency situations;
♦ Ensure that stakeholders are made aware of any special requirements in a timely and organised way;
♦ Enable coordination and communication with other operational groups.


There is a need for close cooperation in such emergency situations between the transmission network and other components of the electricity supply chain, ie the distribution networks, retail, generation, marketing, and often even external parties.
The form and structure of this plan is based on agreed principles, as there are generally many common elements in the above parties' separate plans.

In some cases, it is expected that these individual plans will be required to operate in parallel, with all actions coordinated by the nominated common emergency coordinator.

The plan will not be initiated for all events occurring on the network part of the system. Mobilisation for normal breakdowns will be managed by the existing call-out system as presented in Section 7.3.3.

The SO control centre monitors the situation, and in conjunction with other involved or affected parties, decides when to initiate an emergency. It is expected that emergencies will be declared when it becomes clear that the normal procedures for handling general breakdowns will not be adequate.

It should be noted that this plan has been developed as basis to enable the transmission business to manage specific categories of emergencies in its network on a high level, but its purpose is not intended to describe how the business functions actually responds to each individual event.

\textit{8.1.2. Emergency Management Plan Levels}

It should be noted that the level descriptions are a guide only. The final decision on the level of emergency will be made through consultation among the incident controllers of the affected parties, and a decision taken on which party will take the lead and nominate the emergency coordinator for that particular event.

- Level 1 is an internal warning level and may be initiated when such conditions occur that are likely to affect customers, employees, other
stakeholders and business performance within 24 hours for events which might still be managed by normal contingency planning. This level involves communications with internal business stakeholders only, with the responsible officer for initiating this level of emergency being any of the senior system operations controllers on duty.

- Level 2 is an alert level and will be initiated when conditions occur with a strong possibility of affecting customer supply, business performance or normal customer related activities, or employee or public safety and wellbeing within 24 hours, and could be handled by normal contingency planning. This level involves communications with both internal and external stakeholders, with the responsible officer for initiating this level being the head of system operations control. Contacted officers are expected to be ready for a possible level 3 or 4.

- Level 3 will be initiated following conditions that have had, or are having, a significant effect on supply to customers business performance or normal customer-related activities, or employee or public safety and wellbeing. Significant effects on supply to customers include multiple feeder outages, less than 10,000 customers without supply, customers without supply for less than four hours, restoration of supply requiring significant coordination of information and resources. The responsible officer for initiating a Level 3 is the Manager System Operations.

- Level 4 will be initiated following conditions that have had or are having a major impact on supply to customers, business performance or normal customer-related activities, or employee or public safety and wellbeing. Major effects on supply to customers include major bulk supply loss, greater than 10,000 customers without supply, customers without supply for more
than four hours and restoration of supply after a major and/or prolonged outage. The responsible officer for initiating a Level 4 is the CEO Transmission or his delegate.

Each area within the transmission business is expected to identify its own role in the execution of the emergency plan, and to develop their local emergency response plans for each individual type of event.

These local plans must be consistent with this main plan, and should allow each area to respond effectively to each event.

The areas of responsibility and various actions required by the relevant officers (for each position or area of responsibility) from the actual organisational areas of the transmission business for each level of emergency are contained in the local plans.

8.2. Primary Plant Failure Contingency Plan

The purpose of this document is to ensure that there is a contingency management plan to cover consecutive or independent coincident events resulting from catastrophic failure of items of the primary plant.

The plan is intended to ensure that all major primary plant items in the system can be suitably replaced in the timely manner needed to manage reliability and security risks on the system.

Major plant covers power transformers, saturated reactors, circuit breakers, current transformers, voltage transformers, and surge arresters.
This is essentially a planning document on a tactical level. The contingency arrangements are a high-level risk treatment view of the approach that the transmission business should take to address catastrophic plant failures.

They are not intended to give details about the arrangements for its implementation and execution of response on an operating level.

The more detailed operating response arrangements are developed as a follow-up to the Primary Plant Contingency Plan with asset management and asset maintenance service providers that will execute the plan.

Whether the contingency plans are activated or not will depend on circumstances and system conditions at the time. There may be a better risk management strategy or a different level of risk accepted on the day.

The decision to activate a contingency response is one for system operations and asset management, and may involve activating the transmission call-out procedure only, or the emergency management plan.

A set of plant restoration times is derived from consideration of the network planning and system operations criteria. The plant restoration times are not targets in themselves, and typically much shorter times will be achieved.

The restoration times are intended to provide a recommended timeframe for the risk management decision making and a framework for developing the tactical and operating contingency arrangements as a response to the event.

The Primary Plant Contingency Plan is only a ‘living’ document. The contingency arrangements contained in the plan need to be reviewed regularly, to ensure that they are current, and need to be matched to the evolution of the transmission network and the power system.

A typical layout of such plan is given in Appendix 22.7.
8.3. Secondary Plant Failure Contingency Plan

The purpose of this document is to ensure that there is a contingency plan to manage consecutive or independent co-incident events resulting from failure of items of the secondary plant. The plan deals with an emergency response in the event of such catastrophic failures.

The plan generally identifies secondary equipment generic types and their locations, with possible modes of failures, and then specifies action to be undertaken and by whom when the failures actually occur.

The form of response is generally an immediate replacement with a similar or a better item identified previously, to recover the operation.

Any better arrangement for the particular failure is considered an activity outside the scope of the plan, although the plan needs to be updated with any outcomes of the later review that might improve the responses at the next failure situation.

8.4 Lines and Cables Failure Contingency Plan

This document is prepared to deal with an emergency response in the event of a failure of transmission lines and cables. All transmission lines are susceptible to structural damage from extreme environmental conditions, accidental collisions or deliberate vandalism.

Historically, most of the failures have occurred in remote sections of transmission lines in country areas, and due to their locality, there is a loss of supply until the required resources and correct materials are organised.
In the metropolitan areas where materials and resources are more easily accessible, the response time and restoration of supply is faster.

This manual is intended as a guide to the construction of emergency structure(s) in the event of any structural damage to a lattice tower or steel pole transmission line to bypass/prop the damaged section quickly. This will ensure that any loss of supply is kept to a minimum, and the area is made safe and allows for the damaged line to be restored in the normal fashion.

On completion of repairs to the original line, the emergency line can be removed with minimal damage to the surroundings.

For wood-pole transmission lines, the failed structures will be replaced with like structures using normal construction techniques. An emergency transmission line structure must be easily transported, erected and dismantled, without complex aids.

Environmental changes must be kept to a minimum, and the time-consuming work of the placement and removal of foundation elements is to be avoided or at least minimised.

The manual is intended to cover the concept and features of the emergency repair structures. It is not intended to address every possible aspect of the restoration for a failed transmission line.

The techniques for terminating the ends of the failed line sections and connecting the recommended bypass will vary, and must be tailored to suit the individual field requirements.
9. **BUSINESS CASE ANALYSIS MANUAL**

There are a number of asset linked characteristics and working issues that need to be considered in a business case analysis when a proposal recommends any required action for the targeted assets.

The assets taken up for such analysis are sourced from the assets listed in the relevant parts of the Asset Management Plan that have been previously identified and highlighted as a non-performing asset.

The calculations of the relevant risk factor for each of the relevant components referred to in Sections 9.1.1 to 9.1.17 are given in Section 9.2.

The composition of the risk matrix, an analysis of the risk matrix calculation, and a guide for the use of recommended risk limits and special constraints in assigning a risk ranking for the asset condition and required recommended action are also given later in Sections 9.3 and 9.4.

Finally, a summary of possible business case outcomes and basic rules to assist asset management decision-making on a future action or work required for an asset, being subjected to the developed business case analysis and achieving a certain risk ranking, is presented in Section 9.5.

9.1. **Main Components**

The asset management integrated model presented in this thesis has defined seventeen main components that must be included in the preparation of an asset business case analysis that covers all relevant issues.
These components are described below, with relevant comments about the allocations of their priorities, their associated weighting factors, risk factor evaluations and cost implications as appropriate.

9.1.1. Age

The current age of the asset is taken into account, but it is not an overarching contributor to the asset performance, and is therefore given a low-weighting factor of two.

The risk factor is calculated from its current age versus the expected end age.

9.1.2. Frequency of Failures

The frequency of asset failures is given a high-weighting factor of four, as the failures influence network performance, increase maintenance costs, cause loss of supply and revenue, reflecting badly on customer satisfaction.

The risk factor is based on the number of failures per unit per year.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

9.1.3. Condition

The condition of units can be a significant factor, which can lead to long-term failures and uncertainty for the units’ future performance.

The risk factor is based on the amount of additional maintenance work required in excess of regular preventive maintenance, and is given a medium-weighting factor of three.
9.1.4. Environmental/Regulatory Requirements

Normally the plant is sufficiently well designed to avoid any significant impact on the environment, therefore its weighting factor is rated at medium three.

The risk factor is based on the effects of any possible release of gas into the atmosphere or oil into the ground.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

For example, introduction of a new obligatory government regulation, or where a particular asset is situated on a sensitive area for environment (new noise-level legislation, underground water catchment).

9.1.5. Maintenance Costs

The asset maintenance costs are a significant portion of the company’s maintenance expenditure, and therefore are given medium-weighting factor of three.

The risk factor is based on the ratio of total asset maintenance and repair costs for the asset compared with the costs of a new asset of the same or similar characteristics.

9.1.6. Replacement Costs

A proposal may be to replace the defective units with a new model that requires very little attention. It needs weighting versus repair or refurbishment to continue in service through an economic analysis. Such
0.1.7. Competency of Employees

The skills to repair or completely refurbish the affected unit within the company and using its own work force are assessed, as this could significantly influence any final decision. A medium-weighting factor of three is assigned.

The risk factor is determined from analysis of the available skills.
There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

For example, the required internal skills to attend the relevant asset no longer exist, or the asset is based in a location that is extremely difficult to reach.

9.1.9. Availability and/or Cost of Repair Services

The skills to repair or completely refurbish the affected unit external to the company are also assessed, and will influence any final decision. This is given a medium-weighting factor of three.

The risk factor is determined using a combination of factors described previously in 9.1.7.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

For example, the external skills to attend the relevant asset no longer exist, or the asset is based in a location that is extremely difficult to reach.

The assessment of risk for both areas described in Sections 9.1.8 and 9.1.9 should also review the factors listed below:

- difficulty in obtaining spare parts;
- remote locations of the units in question;
- difficulty in arranging access to the units;
- low success rate on previously tried refurbishment and modification activities;
- high cost of the rework required;
future changes in environmental legislation with regard to a handling of the plant that contains various substances.

9.1.10. Safety of Employees

The unit in question may pose a risk for the crew performing work on adjacent circuits as it may operate under fault conditions with insufficient security to guarantee safe operation. Therefore, it is given a high-weighting factor of five.

The risk assessment is based on the probability that failure could lead to incidents with severity depending on its duration, and the size and type of an area that could be affected by the asset failure.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

9.1.11. Safety of Public

Equipment failure may present a direct risk to the public. That risk could be in the form of flying debris or exposed live conductors. It may not always be possible to mobilise a crew in sufficient time to quickly restore customer supply, thus leading to hazards in the general public domain. Therefore, it is given a high-weighting factor of five.

The risk is assigned on the probability of an incident occurring, possible impact on public, the incident duration, and the size and type of public areas that could be affected by the asset failure.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.
9.1.12. Safety of Adjacent Equipment

There is a real risk associated with suspected units having to operate under fault conditions as adjacent equipment could be damaged by flying debris, further exacerbating the consequences of failure. It could further release contaminated particles into the atmosphere. This is therefore given a high-weighting factor of four.

The risk is assigned on the probability of an incident occurring and the incident possible effect on the plant could be affected by the failure.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

9.1.13. Obsolete Design

Sometimes units are designed with inherent design imperfections, poor tolerances, etc, causing failures (eg jamming of operating mechanisms), but generally they perform their duties as required.

There is an issue where equipment upgraded to a new standard cannot provide the full benefits as other units further in the chain are still obsolete in their functions (eg protection current transformer feeding a new electronic relay). This is given a low-weighting factor of one.

The risk is assigned on the probability of an incident occurring, its possible duration, and the impact of the plant failure on other plant in the chain that could have their functions affected.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

Any loss of supply from affected circuits has consequences on quality of supply. It could cause complete loss of supply for a protracted period, depending on the ability of the system to temporarily feed customers from alternate sources. This is given a high-weighting factor of five.

The risk is assigned on the probability of an incident occurring and its duration, and the type and size of the area affected by the plant failure.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

9.1.15. Impact on Customer

Any loss of supply could lead to a long and disruptive loss of supply, sometimes to sensitive load areas. There could be significant production time lost in mine site operations and disruption of power supply to the commercial customers and the general public, and is therefore given a high-weighting factor of five.

The risk is assigned on the probability of an incident occurring and its possible duration, and the type of customer(s) that could be affected by the plant failure.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.
9.1.16. Impact on the Company

A loss of supply to customers could have a significant effect on the company’s business, and therefore is given a high-weighting factor of five.

The risk is assigned on probability of an incident occurring, possible duration, cost to restore to original condition, and the amount of revenue that could be lost by the plant failure.

Some of the possible effects are:

- lost supply over a significant period means significant loss of revenue;
- replacement and repair of equipment under emergency situations is costly, particularly if another adjacent plant has been damaged;
- relationship with customers would suffer, an important consideration in the open access and increasingly competitive environment existing today.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan is required.

9.1.17. Ability to Manage the Renewal Process

It is important to manage the renewal process through adequate equipment condition assessments and long term planning to replace equipment under risk over a period of time in a controlled manner rather than be failure driven. It is therefore given a high weighting factor of five.
A prudent business takes action to limit the potential risks to the system and to the financial health of the company and to realise any possible savings in long-term maintenance costs by arranging suitable plant replacements.

It will prevent the need to make a sudden and unplanned large commitment of capital and maintenance expenditures that the business could possibly not afford at the moment and in the future.

Even in a case where such financial means might be made readily available, there is a high probability that executing such unplanned works on time would not be possible due to the following factors:

- the lack of immediate availability for required quantity of necessary equipment;
- the lack of engineering design resources;
- the lack of construction and commissioning resources;
- the inability to gain sufficient access rights to the system for the required work programme.

It is important to emphasise that many other company’s work areas also compete for the same financial and human resources above, in an already stressed and heavily loaded transmission network.

The areas include regular maintenance works, ongoing network expansion construction works, approved and planned asset renewal programmes, response to and repair of failures, access restrictions due to seasonal system load curves, seasonal system access limitations, and daily system and customer switching operational requirements.
The best way to avoid the above problems is to use the asset management model that ensures an on-going assessment of the network and its equipment performance and condition.

Then there is a process for the implementation of necessary network operational arrangements to ensure the secure supply and safety of operational staff, and plan the recommended works for improvements.

It continues with the efficient planning of renewal programmes (long-term budgeting, timely project approvals, ordering new equipment, new engineering designs, system access planning, securing working resources).

The risk for individual components is assigned on the probability of incident numbers, their direct and indirect costs, possible time and cost to restore to the original condition, and difficulties arranging an adequate replacement.

There is a special constraint where the risk factor of 5 is assigned, and an immediate action plan in some form is required.

The final risk ranking for the business case is assigned after an overall risk assessment of the asset reviewed in the business case analysis.

The selection of an adequate course of action within a certain timeframe, to deal with the ranked risk, is also necessary.
9.2. Calculation of Business Case Component Risk Factors

The defined business case components, Section 9.1, need to have their risk factors calculated based on the information pertinent to the individual factors as presented throughout Sections 9.1.1 to 9.1.17:

9.2.1. Age

The risk factor in relation to age is formed on the basis of the asset current and expected life as given below:

- Up to 1/3 of its expected life: 1
- Up to 2/3 of its expected life: 2
- Up to its expected life: 3
- Reached its expected life: 4
- Beyond its expected life: 5

9.2.2. Frequency of Failures

The risk factor in relation to frequency of failures is formed on the basis of the asset average number of failures as given below:

- Less then one per 4 years: 1
- One or more per 4 years: 2
- One or more per 3 years: 3
- One or more per 2 years: 4
- One or more per year: 5
9.2.3. Condition

The risk factor in relation to asset condition is formed on the basis of the repair maintenance costs required in addition to the costs to do preventive maintenance work, as defined by its maintenance regime:

No corrective maintenance extra to preventive 1
Corrective maintenance up to 15% of preventive 2
Corrective maintenance 15-30% of preventive 3
Corrective maintenance 30-50% of preventive 4
Corrective maintenance over 50% of preventive 5

9.2.4. Environment and Regulations

This risk factor is based on possible effects that any new regulations, asset failures, or its operation might have on the repair and operation of those assets with regard to environmental impacts.

The risk is formed on the basis of the impact that asset will have on its environmental regime and type of its operation as given below:

No practical impact 1
Small impact 2
Medium impact/visible to public 3
Significant impact/Semi regulated 4
Catastrophic impact/Regulation 5
9.2.5. Maintenance Costs

The risk factor in relation to maintenance costs is formed on the basis of the total incurred costs for all necessary maintenance works versus the asset replacement costs as given below:

<table>
<thead>
<tr>
<th>Total annual cost/replacement cost</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>1</td>
</tr>
<tr>
<td>2%</td>
<td>2</td>
</tr>
<tr>
<td>3%</td>
<td>3</td>
</tr>
<tr>
<td>4%</td>
<td>4</td>
</tr>
<tr>
<td>5%</td>
<td>5</td>
</tr>
</tbody>
</table>

9.2.6. Replacement Costs

The risk factor in relation to replacement costs is formed on the basis of a preparation of a net present value spreadsheet and its assessment as summarised in the following:

<table>
<thead>
<tr>
<th>Difference between replacement and continuous operation</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5%</td>
<td>1</td>
</tr>
<tr>
<td>5-15%</td>
<td>2</td>
</tr>
<tr>
<td>15-25%</td>
<td>3</td>
</tr>
<tr>
<td>25-50%</td>
<td>4</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>5</td>
</tr>
</tbody>
</table>

9.2.7. Spare Parts Availability

The risk factor in relation to spares parts availability is formed on the basis of the quantity and location of spares available as, given below:
Plenty of spares available 1
Spares are scarce 2
Spares from the manufacturer from shelf 3
Spares from manufacturer on order only 4
No spares available 5

9.2.8. Competency of Employees

The risk factor in relation to competency of employers is formed on the basis of maintenance crews that can perform the work, as given below:

Any crew can do it 1
Some crews can do it 2
One crew can do it 3
One person can do it 4
No one can do it 5

9.2.9. Availability and Cost of Refurbishment Services

The risk factor in relation to availability and cost of services is formed on the basis of available providers and their locations who can perform the work, as given below:

Locally available service, many providers, or low cost 1
Locally available service, one provider, or medium cost 2
The service available in other states, many providers, or medium cost 3
The service available in other states, one provider, or high cost 4
The service available overseas with high cost, or not available 5
9.2.10. Safety of Employees

The risk factor in relation to the safety of employees is formed on the basis of impact that the asset failure can have on employees, as given below:

- Equipment contained, no external impact possible 1
- Equipment has parts under pressure that can burst 2
- Equipment can fail internally, moderate impact on close distance 3
- Equipment can fail externally, high impact on larger area 4
- Equipment can fail catastrophically, very high impact on larger area 5

9.2.11. Safety of Public

The risk factor in relation to the safety of public is formed on the basis of impact that the asset failure can have on public, as given below:

- Any defect contained, no impact on supply 1
- Any defect contained, small impact on supply 2
- Any defect contained, moderate impact on supply 3
- Some impact outside confined area, high impact on supply 4
- Significant impact outside confined area, very high impact on supply 5

9.2.12. Safety of Equipment

The risk factor in relation to the safety of equipment is formed on the basis of the impact of the asset failure on equipment, as given below:

- Equipment is contained, no external impact is possible 1
- Equipment has parts under pressure that can burst, plant nearby of limited value 2
Equipment can fail internally, medium impact on close distance, plant nearby of medium value 3
Equipment can fail externally, a possible high impact on important plant nearby 4
Equipment can fail catastrophically, a high impact on important plant nearby 5

9.2.13. Obsolete Design

The risk factor in relation to obsoleteness of the asset design is formed on the basis of assessment of the asset as given below:

As new type 1
Almost identical to new type 2
Moderate old 3
Very old 4
Completely outdated 5


The risk factor in relation to impact on supply is formed on the basis of assessment of consequences to supply when asset fails as given below:

No impact on supply, immediate restoration 1
Small impact <1 MVA, quick restoration <1 hr 2
Moderate impact <10 MVA, slow restoration <1 day 3
High impact <25 MVA, long restoration <1 week 4
Very high impact >25 MVA, protracted outage >1 week 5
9.2.15. Impact on Customer

The risk factor in relation to impact on customer is formed on the basis of assessment of impact when asset fails as given below:

No impact on customer  
Small or transient impact on customer, no affected load  
Moderate impact on customer (a few hours), <1 MVA  
High impact (1 day), 1-10 MVA, production partially affected  
Very high impact, >10 MVA, production significantly affected

9.2.16. Impact on Company

The risk factor in relation to impact on company is formed on the basis of assessment of impact when asset fails as given below:

No impact on system or supply  
Small or transient impact on system, minor loss of supply  
Medium impact on system, some loads lost, supply maintained  
High impact on system, supply area affected, large loads lost, a sensitive load lost  
Very high impact on system, large supply areas lost

9.2.17. Ability to Manage the Process

The risk factor in relation to the ability to manage the asset renewal process is formed on the basis of assessment of how the impact of the asset failure can be dealt with, as given below:

It can be easily managed, spares in store (<50K/year)
Low impact, equipment in store (<150K/year) 2
Medium impact, equipment available 3-6 months (<250K/year) 3
High impact, equipment available 6-12 months (<500K/year) 4
Very high impact, equipment delivery difficult or over 12 months (>500K/year) 5

9.3. Assessment of Risk Matrix

The above seventeen risk categories with their weighting of risk, the risk range, special constraint nominations, and total weighting risk and special constraint numbers are presented in the following risk matrix.
<table>
<thead>
<tr>
<th>Category</th>
<th>Weighting</th>
<th>Risk</th>
<th>Weighted Risk</th>
<th>Special Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>2</td>
<td>1-5</td>
<td>2-10</td>
<td></td>
</tr>
<tr>
<td>Frequency of Failures</td>
<td>4</td>
<td>1-5</td>
<td>4-20</td>
<td>*</td>
</tr>
<tr>
<td>Condition</td>
<td>3</td>
<td>1-5</td>
<td>3-15</td>
<td></td>
</tr>
<tr>
<td>Environment/Reg.</td>
<td>3</td>
<td>1-5</td>
<td>3-15</td>
<td>*</td>
</tr>
<tr>
<td>Maintenance Costs</td>
<td>3</td>
<td>1-5</td>
<td>3-15</td>
<td></td>
</tr>
<tr>
<td>Replacement Costs</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td></td>
</tr>
<tr>
<td>Spare Parts Avail.</td>
<td>3</td>
<td>1-5</td>
<td>3-15</td>
<td>*</td>
</tr>
<tr>
<td>Competency of Empl.</td>
<td>3</td>
<td>1-5</td>
<td>3-15</td>
<td>*</td>
</tr>
<tr>
<td>Avail. of Repairs</td>
<td>3</td>
<td>1-5</td>
<td>3-15</td>
<td>*</td>
</tr>
<tr>
<td>Safety of Empl.</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td>*</td>
</tr>
<tr>
<td>Safety of Public</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td>*</td>
</tr>
<tr>
<td>Safety of Equipment</td>
<td>4</td>
<td>1-5</td>
<td>4-20</td>
<td>*</td>
</tr>
<tr>
<td>Obsolete Design</td>
<td>1</td>
<td>1-5</td>
<td>1-5</td>
<td>*</td>
</tr>
<tr>
<td>Impact on Supply</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td>*</td>
</tr>
<tr>
<td>Impact on Customers</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td>*</td>
</tr>
<tr>
<td>Impact on Company</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td>*</td>
</tr>
<tr>
<td>Ability to Manage</td>
<td>5</td>
<td>1-5</td>
<td>5-25</td>
<td>*</td>
</tr>
</tbody>
</table>

**TOTAL RISK FACTORS**  
MIN 64-MAX 320  
MIN 0-MAX 13
9.4. Risk Ranking for the Business Case

The risk ranking is an assessment of the impact of the analysed business case on the transmission business operational or financial performance if a project recommended in the business case does not proceed.

For example, a high risk ranking indicates a project with significant impacts on the business strategic results, and that there is a high risk the expected performance in the areas affected by the project will not be achieved if the particular project does not proceed.

The weighting risk range, number of special constraint limits, and the resulting risk ranking allocations are given in the Table 9.1.

<table>
<thead>
<tr>
<th>Weighted Risk Range</th>
<th>Number of Special Constraints</th>
<th>Risk Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-128</td>
<td>0</td>
<td>Low Risk</td>
</tr>
<tr>
<td>128-229</td>
<td>1-3</td>
<td>Medium Risk</td>
</tr>
<tr>
<td>230-320</td>
<td>&gt;3</td>
<td>High Risk</td>
</tr>
</tbody>
</table>

**TABLE 9.1. RISK RANKING ALLOCATION**
9.5. Summary of Business Case Outcomes

There are number of possible outcomes for the action to be taken as a response to the above business case analysis and the resulting risk ranking, and based on the combination of individual factor assessments.

These outcomes can be grouped into two main categories:

- There will be no need for work on the asset itself, but an update of the existing documentation or preparation of some new documentation will be required:

  (a) update of maintenance policy (eg. vary maintenance frequency);
  (b) update of maintenance services (eg. remove and grease more parts);
  (c) update of maintenance instructions (eg. repair minor line failures 'live' in service);
  (d) update of generic contingency plan (eg. keep more 330kV circuit breaker spares);
  (e) preparation of a special contingency plan to cater for asset failures for a specific period of time (eg. rapid response mobile switchboard in the case of failure of indoor metal clad oil insulated switchboards until they are replaced).

- The asset in question will require some kind of work within the options listed below. They will be added to the list of ‘Asset Future Projects’ and maintenance or capital funds approval will be sought within the timeframe recommended for the specified work:

  (a) refurbishment on site or in a workshop;
(b) modification on site or in a workshop;
(c) major repair on site or in workshop;
(d) replacement of several units to create a source of spare parts;
(e) relocation to less important or less demanding locations in the network over a period of time;
(f) replacement over a period of time and disposal.

A set of useful rules has been developed to assist in the decision making on which course of action to undertake for an asset after determination of its risk ranking, as indicated in the introduction of Section 7.5.

The rules make use of the assessment done on its individual risk matrix components, and are given in Sections 9.5.1 to 9.5.3.

During these deliberations, an important part of the review is to comply with the necessary links and information exchange to network planning, asset owner and system operations, as many aspects of work in those areas influence the final decision.

9.5.1. Low Risk Ranking

The 'Low Risk' ranking indicates that, although some problems exist with the asset operational or financial performances, the impact of its failures if it continues in service will be reasonably small.

If the problem is traced to the failure of different parts of the plant, but failures do not impact network performance, plant servicing level can be adjusted during its preventive maintenance work without varying its maintenance frequency.
If the failures do impact network performance, it will be necessary to vary plant maintenance frequency.

If the failures are caused by a small number of parts, a dedicated repair or modification task may be organised to rectify or replace the identified parts. That would be mostly done in situ, but sometimes it could be arranged in a workshop but only depending on the costs and practicality of work on site and possibilities of transport to the selected workshop.

Additionally, if the assets in question are to be dealt with in some way or replaced through some other asset renewal or planned development programmes, no action might be taken, depending on the action extent or timing in those programmes.

9.5.2. Medium Risk Ranking

The ‘Medium Risk’ ranking indicates that significant problems exist with the asset operational or financial performances, and that there could be some impacts to the network performance if the problems are not treated properly within a certain timeframe.

In most cases those problems can be addressed through an advanced repair or modification programme, on site or in a workshop, where the work cost and practicality will determine the final outcome.

In a situation where there is a lack of parts for such work arrangements, or the work would be very costly or impractical, a partial removal of some units to create a source of spare parts is recommended.
In a situation where there is a lack of skilled resources for the execution of such work, relocation to other less demanding or important locations should be implemented.

An important part of the above analysis should be to review the expected need for further required service of those assets at their locations. In the case where the individual assets will be removed in a relatively short time by another project, consideration of other options would be appropriate.

That would mean arranging a variation to generic contingency plans, change in the spare holdings policy (increasing the number of whole spare plant units), or developing and implementing a special contingency plan.

9.5.3. High Risk Ranking

The ‘High Risk’ ranking indicates that the asset in question presents a significant problem to the operational or financial performances of the network. There could be some serious impacts to the business or even in the wider arena where the transmission business operates if the identified asset is not treated properly within a short timeframe.

The options would most likely be to arrange a detailed refurbishment programme and to restore the condition and functions of the targeted asset as closely as possible to its original status.

That could be organised internally, if the skilled workforce and appropriate refurbishment plant exist, or with the original or a substitute manufacturer.

In any case, it should be noted that it is expected that the asset functions will be restored to a level such that the asset will be sufficiently
operational for the reasonably long time, at least until such time that the asset is scheduled for removal from that site.

If this is not feasible, the next step is to define and execute a modification programme to restore the asset condition to the sufficient level that would be satisfactory for the asset expected service life and performance.

That would normally include significant the manufacturer’s input and assistance, being the original or a substitute manufacturer.

In the case when the above work options are not feasible, technically or financially, it is expected that the asset replacement would become the only possible outcome.

In the final recommendation, a vital element would be the contents of the current and future network development plans, in the form of the upgrade or retirement of the transmission substations or lines in the period action is recommended for the assets in question.

Such feedback to the original business case recommendations could then force a change in the scope and timing of the business case action, or the business case recommendations would initiate changes of the planned actions in the development plans.

Further financial and operational reviews with the assistance of the asset owner functions (business development and finance services) will define which course of action will finally be taken (changing the asset renewal or network plans) that will represent an optimal network solution.
10. **SERVICE LEVEL AGREEMENTS**

The service level agreements (SLA) are agreed relationships between the asset management (AM) and asset maintenance internal service providers (ISP) on how to execute their roles and perform their assigned work for the asset owner in the set-up of the asset management. The developed documentation for their relationship is presented below.

10.1. **Purpose and Policy Statement**

The SLA needs to have a statement with intentions for its purpose and policy as presented below.

10.1.1. **Purpose of Agreement**

The purpose of the SLA is to define the relationship, scope and services of the required works, and service levels to be provided during the service works between asset management and internal service provider.

10.1.2. **Policy Statement**

The SLA is a binding agreement established between the above two internal parties in the company.

However, the SLA is designed to be activity and performance based, and not a lengthy prescription of a relationship.

The key elements of the SLA are:
(i) definition of the service to be provided;
(ii) methodology to be used to measure and acknowledge the success of the performance of the scope of service;
(iii) the remaining elements provide direction for the administration of the agreement.

10.1.3. Desired Attributes of the Relationship

The SLA is the documentation of an agreement for a business relationship between AM and ISPs. It defines the expectations and behaviours that are desired between those and other relevant involved groups.

The success of the SLA will depend upon the demonstration of specific attributes and behaviours by the parties. These are:

(i) trust and mutual respect;
(ii) complete sharing of information and an open book relationship;
(iii) acceptance of accountability;
(iv) all parties to act as a single team;
(v) all parties to treat the business as their own, in that they are cost conscious, take responsibility, and continually seek to add value to ensure the success of the company;
(vi) all parties to focus on and take pride in meeting or exceeding the commitments and targets listed in this SLA;
(vii) competent personnel capable of meeting their responsibilities;
(viii) sound communication practices;
(ix) decision making that is timely and exercised within the limit of appropriate authorities;
(x) confidentiality to be maintained with regard to sensitive issues;
(xi) all parties to endeavour to be adaptable and innovative;
(xii) good performance to be recognised, and performance not meeting expectations to be addressed;
(xiii) all parties to continuously learn, develop and improve themselves and the business.

10.2. Scope of the Agreement

The agreement needs a scope to define the relevant areas to be covered.

10.2.1. Relevant Assets

ISP performs the agreed services on the assets defined in the SLA.

10.2.2. Services to be Provided

ISP provides maintenance, construction, operations, logistics, input into the performance improvement activities, and other auxiliary services as defined by the SLA. These services will be provided to the standard levels as defined by the SLA.

The services include the provision of sustained strict housekeeping standards such that the material condition of all the assets is maintained.

Where subcontractors are employed to undertake some, or all of the services, then the services provided by the ISP will include the letting, administration and management of these subcontracts.
ISP will notify AM of all incidents and situations that have the potential for significant safety, environmental and cost consequences. This will be in accordance with the incident-reporting policy and set-up procedures in the SLA.

10.2.3. Re-work on Services Provided

Re-work is defined as the action taken on a non-conforming product so that it will fulfil the specified requirements.

Should any re-work be required, it will be executed as appropriate to the performance requirements established as part of the agreement.

Reporting and analysis of re-work will be in accordance with the Policy in the SLA.

10.2.4. Qualifications of Personnel

The personnel that will be used to perform the required work programme will be properly skilled and allowed improvements as shown below:

(i) statutory requirements-the statutory requirements for the certification of maintenance personnel shall be met as required by regulation;
(ii) on-going competency training-ISP shall ensure the competency and on-going training of personnel assigned to perform the services as defined by the SLA to ensure that the SLA defined policies are followed;
(iii) relationship with other parties-ISP will ensure the same standard for any subcontractors whom they may use in the works under the SLA.
10.3. **Performance Management**

There needs to be a defined area of performance management to ensure its monitoring and success.

10.3.1. *Performance Measures*

The SLA shall define the performance measures that will be used to monitor the success of the SLA.

Performance against this SLA will be monitored monthly.

This monitoring will include a comparison of the actual amount of services provided with the forecasted services.

Forecasts of cost and other key performance measures will be provided by the ISP, and shall be updated on a rolling quarterly basis.

The outcome will be presented in the agreed form of a report to be compiled and distributed by ISP to AM.

10.3.2. *Budget and Cost Accounting*

AM and ISP shall agree on the scope of services and the associated budgets that will be contained in the SLA.

A procedure to deal with emergent work, and a process for the draw-down of the reserved funds, will be clearly identified in policy documents referenced to in the SLA.
The ISP will ensure that all bookings are made to the correct codes, in accordance with policies defined by the SLA, to allow tracking of actual expenditure against the agreed budget.

This same requirement applies to all other service providers supporting the work undertaken by the ISP.

10.3.3. Acknowledgment for Services

A feature of the SLA shall also be that meeting or exceeding agreed SLA performance targets should be acknowledged.

This will include how to arrange for extra compensation over and above the agreed payments for exceeded targets in performance monitored by the SLA that are identified to be due to improvements in the work by the ISP.

10.3.4. Need for Improvement

Not meeting performance targets will result in discussion between AM and ISP senior management to resolve the issues and agree on prompt actions to achieve the targets and restore the relationship agreed in the SLA.

10.4. Continuous Improvement

Further benefits are achieved by ensuring that there is a dedicated activity of continuous improvement included in the SLA procedure.
10.4.1. Periodic Review

The participating parties will normally meet monthly to review actual the actual performance against performance targets as defined by the SLA.

There will be an annual review to examine the effectiveness of the agreement and to agree on future changes to the SLA.

10.4.2. Revisions

This SLA is a living document, and it is expected that this document will be used as a tool to facilitate the success of the agreed relationship, and will be revised as necessary during its use by submission from both parties.

10.4.3. Performance Improvement

In accordance with the attributes agreed in this SLA, both parties will actively and genuinely pursue the identification and implementation of all process changes in work and procedures that can improve their performance and reduce costs.


11. **REQUIRED DATABASES**

It is essential to have in place adequate and easy to use databases with proper data acquisition procedures for recording assets themselves and asset management activities.

The acquisition procedures ensure that relevant information is collected and correctly entered in the databases in a timely manner.

This is essential, as that initial procedure is then followed up by other procedures, using the data and analysing and assessing asset performance and the success of the asset management process itself.

Databases that have been defined and are currently in the use for assisting with the management of transmission assets can be split in two main types, asset information registers and asset activity registers.

The database set-up is shown together with the specified flow of information in Fig.11.1.

11.1. **Asset Information Registers**

11.1.1. **Transmission Plant Management System**

The Transmission Plant Management System (TPMS) is an asset register database for the transmission primary equipment.

It holds the following asset information: specification and order details, manufacturing type and model, design and technical characteristic details,
other details about each individual unit and its components, and the unit current and previous locations history.
It also serves to record asset failures against the asset items.

11.1.2. Transmission Lines Management System

The Transmission Lines Management System (TLMS) is an asset register database for the transmission lines and cables.

It holds the following asset information: specification and order details, construction type characteristic details, length and number of structures, structure details, assembly details of conductors and insulators, and the unit current and previous line identifiers history.

It also serves to record asset failures against the asset items.

11.1.3. Transmission Protection Equipment System

The Transmission Protection Equipment System (TPES) is an asset register database for the transmission protection equipment.

It holds the following asset information: specification and order details, manufacturing type and model, design and technical characteristic details, other details about each individual unit and its components, testing, setting and maintenance requirements, and current and previous locations history.

It also incorporates an asset activity function as it registers all protection equipment operations and relay failures against the asset items.
FIG. 11.1: REQUIRED DATABASES AND INFORMATION FLOW
11.1.4. Transmission Ratings Information System

The Transmission Ratings Information System (TRIS) is an asset register database for all current carrying transmission assets (e.g., transmission lines, circuit breakers, connections, etc).

TRIS holds the following asset rating information: limits for thermal and short-circuit fault currents, overloading and time curve characteristics, details of the ancillary components and conductors used to join major assets, climatic loading characteristics.

TRIS also contains relevant software rating calculations and diagrams to determine maximal plant loadings in different seasons and network arrangements.

11.1.5. Transmission Lines Geographical Information System

The Transmission Lines Geographical Information System (TLGIS) is an asset register database that contains details of routes and locations for all installed major transmission assets (lines, cables and substations).

It holds details of the asset geographical routes and locations as defined by their Geostationary Position System (GPS) coordinates.

It also assists in the project and maintenance work by displaying other transmission asset information for transmission lines, cables, and plant in the substations. The information is drawn from relevant initial sources, being one of the above asset register databases.
11.2. Asset Activity Registers

11.2.1. Mincom Information Management System

The Mincom Information Management System (MIMS) is an asset activity database that defines and tracks all maintenance activities for the transmission assets.

It holds the following asset information:

- asset hierarchical structure and cross-reference links details,
- details of individual locations,
- details of individual plant items,
- details of the assets fitted to the individual location,
- asset generic technical standard type denominations,
- required standard maintenance levels,
- required maintenance and testing activities,
- required maintenance and testing frequencies (trigger dates),
- standard job templates and their costs (standard fees).

The database also collects a history of maintenance and repair activities, outstanding maintenance work with its cost, and planned future schedules.

MIMS is a corporate information system with many modules, of which the following are predominantly used in the asset management process:

- asset register,
- asset maintenance scheduling and work management,
- operational statistics,
- condition monitoring,
- spare parts lists, and
- logistics.

11.2.2. Transmission Plant Allocation System

The Transmission Plant Allocation System (TPAS) is an asset activity database that tracks the movement of major substation plant assets between their active and passive services and records allocation of assets to be used for various capital and maintenance projects and maintenance tasks.

TPAS holds details of the nominated capital and maintenance projects and maintenance work activities, with technical details of the allocated assets.

It lists storage item codes, prices, quantities, delivery schedules, and specification and item denominations for the allocated and stored units.

It also contains other information about the current level and future requirements of strategic spare levels, surplus stock and project items, to allow a proper management of existing and future stocks for requirements of transmission substation assets.

11.2.3. System Operations Disturbances Database

The System Operations Disturbances (SOD) database is an MSA database that records all disturbances on the transmission network involving loss of supply or the opening of a circuit breaker.
The outage might happen suddenly without warning due to faults causing protection to island that part of the network, or an outage will have to be arranged immediately as the disturbance poses threat to the transmission network (security, public safety, other plant integrity, etc).

Therefore the disturbances are split into two categories:

- a fault disturbance, where a fault is caused by an uncontrolled and sudden incident;
- a forced disturbance, where the plant is switched out of service prior to its failure to rectify a problem.

Details of the disturbances include details of the time of the disturbance, the time that supply was restored and the time that the plant was returned to service, as well as the amount of load lost due to both the undervoltage caused by the fault (where applicable) and the amount of load lost.

Additional information includes relay flags, circuit breakers tripped, as well as the percentage of affected major customer loads.

The database is used to provide information on faults and forced outage incidents in the transmission network to asset management by a defined report on those incidents, but it is also used for reports to other business functions not covered in this thesis.

To assist in the reporting of activities, each disturbance is assigned a CIGRE incident category, a cause, and details of the plant affected (usually the plant involved in the fault).
Weather conditions and the type of fault (i.e. forced/fault, with/without interruption, auto-reclose) are also recorded to assist in further incident investigation and analysis.

### 11.2.4. Notice of Intended Works Database

The Notice of Intended Works (NOIW) database is a major planning tool used by system operations to coordinate, plan and approve transmission network circuit outages, and the related activities.

#### 11.2.4.1. Purpose

The purpose of the database is to control access to the network items to ensure that system security is never compromised, the risk of outage impacts is considered, and relevant contingency plans are formalised.

Each item is part of a transmission network circuit, normally taken out of service for the item maintenance activities, by the maintenance service providers’ work schedulers via an interface to MIMS.

Each circuit outage is given approval by the SO based on the following required characteristics in the outage request:

- Circuit to be taken out;
- SO switching program number;
- dates and times for an outage;
- required permit type;
- description of work;
• operational impact (OI);
• points of isolation (POI);
• recall time if required;
• circuits to remain out overnight.

11.2.4.2. Points of Isolation

NOIW with a valid switching programme number includes Points of Isolation (POI) that will ensure that the described circuit is disconnected from all possible sources of supply.

These points must have visible break points and must be locked off and fitted with a danger label.

Depending upon the type of work activities being carried out, the vehicles and other equipment being used, and safety clearances required for that work, the POI can and do change from task to task of the overall maintenance work performed during the same outage.

The POI is a network, system, personnel and public safety related issue, and is given the highest priority when assessing and determining the POI access for each job.

11.2.4.3. Acceptance and Approval

The work orders used from MIMS are either switching or asset-work based.
The switching-based work orders are fixed once they receive approval from system operations through the MIMS and NOIW interface link, and they are allocated a switching outage programme number.

The asset-work related work orders can be rescheduled by the maintenance service providers at all times, with timely advice to the SO when they impact in any way on the outage programmes and related switching work orders.

Therefore, it cannot be stressed strongly enough that at all times, the system operations and service providers need to communicate with each other to coordinate outage WOB moves within the NOIW database.

This communication process is the most fundamental element in ensuring that the aligned MIMS-NOIW procedures for coordination of maintenance work and outages on the network are successful.

To support the quality of that coordination, there should be an attempt to agree switching and asset-work based work orders for all known asset maintenance work between the SO and maintenance service providers for the next seven weeks.

11.2.4.4. Global Moves

As defined in Section 11.2.4.3, when MIMS and NOIW have accepted and approved switching work orders, only the SO personnel can change the outage dates through the NOIW database.
If a date change is requested by the maintenance service provider, and subsequently agreed upon by the SO, the system operations will use the Global Move function of NOIW-MIMS interface link to move the entire outage WOB by a set duration.

That action ties all the asset-work based work orders related to a single outage to the outage WOB, and will ensure that all those asset-work based work orders are correctly moved together in MIMS.

When the original content of outage WOB work is analysed by the SO, it might be necessary to split the switching work order across multiple switching tasks.

Those will optimise circuit outages in steps as per the plant required to be worked on during each stage of the requested outage.

The split switching tasks have the same identifying switching outage number, but use unique sub-split keys to identify each split task.

Further to those splits, it may be necessary to make provisions to exclude any holidays, free days and weekends, when maintenance service provider staff will not be available to perform.

When an outage record is postponed, all work orders are essentially deleted and from the active link and placed into a spare area.

The concept of the spare area allows identification and rescheduling to a new date of all the maintenance works that have been cancelled, postponed
or deleted by system operations in NOIW at the times when initially requested, planned, approved or being executed.

11.2.5. Network Development Plans Summary Database

The Network Development Plans Summary (NDPS) database is a major planning tool used by network planning to coordinate, plan and approve transmission network development projects and other related activities.

It contains the most important information about all proposed future network development projects and assets involved, with a clear indication which project is in conceptual, developed or firm stages, and an approximate time frame for each project and the assets that will be affected or replaced (see Appendix 22.8).
12. **REQUIRED RESPONSIBLE FUNCTIONS**

The asset management process and procedures defined by the developed integrated model require a number of specific business functions that must be accounted for in an organisational business structure for a successful operation of the asset management model.

These business functions have to perform their specified roles with prescribed duties in the defined time frames through a series of defined reviews and through the related activities prior to and after those reviews, as presented in Chapters 6, 7, 13 and 14.

The business functions are described in Sections 12.1 to 12.7, with their interaction links and supporting documentation presented in Fig. 12.1.

### 12.1. Asset Management

Asset management produce asset missions and strategies for assets currently used or about to be used in the transmission system. They monitor the performance and ageing process of the operating transmission assets.

They analyse asset fault and failure statistics, review maintenance costs and ratio of preventive to corrective maintenance work, and use the proceedings of those reviews to update asset maintenance policies.

They initiate and organise generic high level asset investigations and testing programmes to assess the condition of the assets in the transmission network based on the results of the above statistics.
They also initiate follow-up studies on asset generic faults to assess the asset condition and to determine the remaining life of the asset.

All of the above to confirm the validity of the present asset strategy and process and the subsequently implemented maintenance policies, instructions and maintenance service standards. This is to ensure the are always relevant against the network performance levels and development plans as set-up by the asset owner.

Any policies, instructions and service standards found inadequate are promptly adjusted.

Asset management is also responsible for ensuring that the plant and equipment purchased and installed meet the plant performance standards set by the asset owner, network planning, and system operations.

It has or engages plant specialists for line and substation assets to provide expert technical advice and guidance to asset management during plant condition assessment and to maintenance service providers when reviewing possible actions during maintenance and repairs of assets.

This includes liaison with manufacturers, industry bodies and other authorities as necessary.

Asset management also has an overall co-ordination role for all asset management related activities that are performed by other areas in the transmission business.

That includes the revision and update of the Asset Strategy and Policy documents and other asset management model supporting documentation (contingency plans, policy and instruction manuals, etc).
FIG. 12.1: INTERACTIONS BETWEEN BUSINESS FUNCTIONS & DOCUMENTATION
12.2. *Network Planning*

Network planning is responsible for setting system and network planning criteria necessary to meet the network and system performances as set-up by the asset owner, as required by the electricity regulator and the customers, and defined by legislation and standards.

Subsequently, they define the plant performance standards necessary to achieve the required system and network performances.

They use the above gathered information to prepare future network development plans to cater for load growth, new connections, and for the replacement of plant not meeting anticipated fault levels or thermal rating requirements.

They provide input into the assessment matrix of critical plant in service based on system reliability studies and availability of circuits due to the future development works in the network.

They are also responsible for the timely regular update of all long-term network development plans, using information from the asset maintenance and asset renewal plans, prepared and issued by asset management.

12.3. *System Operations*

System operations are responsible for the day-to-day operation of the transmission system and use of system and network assets in the best way to deliver the transmission business product to the customers.
That includes responsibility for system stability, network operation reliability, and security and quality of the power supply.

They also provide an assessment of how critical the transmission lines; substations and their circuits are to the operation of the network, and for the overall system reliability from an operational viewpoint.

They therefore play a pivotal role in the setting of priority and risk parameters that provide another significant input into assessment and decision making procedures about the asset future of the asset management model process.

They are also responsible for coordination and optimisation of the long-term system requirements that determine an outage access to the transmission network as requested by the internal or external service providers for the asset works.

It includes asset maintenance works; asset repairs, emergency access interventions, planned asset renewals, and network expansion projects.

That means influencing timing of the works that need to be undertaken on the same equipment, and ensuring that these requirements are reviewed in a timely manner as a part of the asset management process.

12.4. Maintenance Services

Maintenance services are responsible for providing electrical and mechanical trade skills for maintenance services according to details
specified in the Asset Maintenance Services and Asset Maintenance Instructions Manuals, and governed by the Service Level Agreement rules. They undertake plant investigative repairs, modification and upgrade trials, and provide appropriate feedback to the asset management for the requested work including scope of work, required timeframe and cost estimates. They are responsible for monitoring preventive maintenance work practices and instructions, for proposals to modify and update the above Manuals, with the aim of improving the overall preventive maintenance efficiency.

They are also responsible for the first call response to effect the urgent repair of major faults, for handling of minor maintenance projects, the planning and running of daily maintenance activities, and for providing maintenance data from their activities for relevant databases,

They use the maintenance management computer system for planning; scheduling and updating of maintenance activities using work requests and work orders.

12.5. Engineering Design

Engineering is responsible for providing engineering solutions and other advisory services in the area of design, drafting and cost estimating for repairing and renewal of faulty and failed assets.

That is followed by provision of the necessary installation designs, based on the recommended renewal and major maintenance projects.
They also perform a project management role for minor works requested by asset management from their maintenance and capital works programmes, and when required following the failure of assets in the active service.

12.6. Project Management

Project management is responsible for the establishment and management of planned asset replacement projects arising from approved capital project recommendations to replace assets according to asset renewal programmes.

They provide an important input into the business case proposals for asset replacement projects by advising realistically achievable timeframes for the prosed renewal project works.

They perform cross checks for the collateral and mutual influence of other ongoing and future planned projects to enable the proper execution of the recommended renewal projects.

They also obtain and provide necessary cost estimates for the recommended scope of renewal project works.

12.7 Asset Owner

The asset owner plays very important role in the adopted developed model as many initial requirements for the goals and targets of the asset management stem from the owner inputs. Some of the inputs are internally driven, while others are based on external factors.
Asset owner generally provides those inputs through the requirements for desired network operational and financial performance and the business overall performance targets.

These inputs are conveyed to other business functions directly or through two sub-functions, business development and finance services. Both sub-functions are discussed in Sections 12.7.1 and 12.7.2.

12.7.1. Business Development

Business development provides inputs to other business functions based on the asset owner instructions, and taking into account the following external factors:

- government and its regulators;
- legislation and regulations;
- company's board of directors;
- external customers;
- financial market conditions;
- external competition, etc.

12.7.2. Finance Services

Finance services assist with all financial matters determining the future fate of network assets to ensure that the proper accounting and financial tools and practices have been applied to the preparations of asset business analysis cases and their subsequent recommendations for any action on the network assets.
They manage and update the short and long-term financial business plans to reflect the short and long-term capital and maintenance expenditures necessary for the upkeep, renewal and replacement of assets, as their life is expended, and the transmission network is growing.

That is based on internal and external financial factors supplied by the business development and obtained from the asset owner and other financial and business sources.

They are also responsible for analysing requests for maintenance and capital funds from various business functions for the works and projects they recommend.

The finance service needs to relate those requirements to the level of costs determined that the business can afford, to ensure the ongoing financial viability of the business.
13. REQUIRED PROCEDURES

It is necessary to ensure that all information relevant about the asset itself and about assets related activities is recorded into the defined and set-up asset databases.

That will enable analysis of asset operational and financial performances, and subsequent assessment of asset condition, by using developed and defined reports presented in Chapter 14.

There will be further reviews and an exchange of information between asset business functions as defined in the asset management process.

There are also other developed procedures to ensure that obtained results are reviewed, discussed, and information is exchanged between relevant functions, and that the resulting action is implemented across the transmission business functions in an organised and timely fashion.

These activities can be therefore divided into the following four main groups:

➢ recording asset details;

➢ recording and analysing asset activities;

➢ recording asset failures;
reviewing and exchanging output information obtained from the previous three groups, and determining and implementing the resulting action.

13.1 Recording of Asset Details

An initial part of data recording is to identify and record the assets themselves to form the basis for all their future records and reporting.

13.1.1 Primary Plant

Asset management has the responsibility to ensure that all installed transmission primary equipment is registered in TPMS, with basic information copied into MIMS to enable maintenance requirements to be set-up as per Section 13.1.4, and for the quality and accuracy of the recorded information.

The TPMS update starts when the plant procurement group places an order for the purchase of plant.

The responsible officer inputs specification and order details, type and model of plant, and technical characteristics of plant (e.g. rated load and fault currents, rated and operating voltages, transformation ratios, etc).

When the plant is tested and delivered, and factory acceptance test certificates are made available, the responsible officer enters plant serial numbers for the relevant specification, item and order numbers.
When the individual items of the plant are installed and commissioned to start their operational service, maintenance service provider commissioning officers supply details of the plant serial numbers and relevant locations (substation circuit number and phase) to the asset management that updates the relevant location details for the installed assets.

13.1.2. Lines and Cables

Asset management has the responsibility to ensure that all new transmission lines and cables are registered in TLMS, with basic information copied into MIMS to enable maintenance requirements to be set-up as per Section 13.1.4, and for the quality and accuracy of the recorded information.

The TLMS update starts at the point when the engineering design starts the transmission line design and construction.

The responsible officer then inputs specification and order details, line design and construction type details (length and number of structures, structure details, electrical assembly and type and model of conductors and insulators), and other technical characteristics of the line (eg rated load and fault currents, rated and operating voltages).

When the line is constructed and all its poles are numbered, the responsible officer enters line segment and pole number details from the site inspection certificates available.

13.1.3. Secondary Equipment

Asset management has the responsibility to ensure that all new transmission secondary equipment is registered in TPES, with basic information copied.
into MIMS to enable maintenance requirements to be set-up as per Section 13.1.4, and for the quality and accuracy of the recorded information.

The TPES update starts at the point when procurement group places an order for purchase of the equipment.

The responsible officer inputs specification and order details, type and model of plant, and its technical characteristics (e.g., time and recording function settings, rated and fault currents, operating voltages, transformation ratios, etc).

When the plant is tested and delivered, and factory acceptance test certificates are made available, the responsible officer enters plant serial numbers for the relevant specification, item and order numbers.

When the individual assets are installed and commissioned to start their operational service, maintenance service provider commissioning officers supply details of their serial numbers and relevant locations (substation circuit number and line denominators) to the asset management that updates the relevant location details for the installed assets.

13.1.4. Asset Maintenance Requirements

Asset management has the responsibility to ensure that all transmission assets added to the transmission network (lines, cables, primary and secondary equipment) are promptly and correctly set-up in MIMS. That allows for the definition of their maintenance requirements and planning and execution of their required maintenance, and enables registration of all asset-related activities.
These records need to indicate all assets that require particular preventive activities (warranty control, inspections, checks and maintenance) by entering the necessary requirements from the maintenance policy manual.

The update starts when an asset is reported as operational and established in TPMS, TLMS or TPES. The responsible officers will assess details of the installed asset and identify it in the maintenance policy manual. If it differs from anything in the current list, a request is issued to the responsible function to add it to the list and determine its new schedules with the maintenance service provider.

Once all maintenance requirements information is obtained and determined, it is programmed and entered into MIMS. That includes a number of maintenance requirements, their maintenance levels and frequencies, links to relevant standard jobs, details of warranty requirements, and maintenance costs.

The entered requirements information is used by the maintenance service provider work schedulers to plan the required works, coordinate with system operations through the use of outage management procedures, and to submit to the provider maintenance crews for the work execution.

13.1.5. Asset Ratings

Asset management is responsible for ensuring all new transmission current-carrying assets (lines, cables, circuit breakers, current transformers, busbars, transformers and connections), registered in TPMS and TLMS, are defined in TRIS with their current rating characteristics, and for the quality and accuracy of the recorded information.
The update starts when an asset is recorded as operational in TPMS and TLMS. The ratings officer will assess all normal and fault ratings information available about lines, cables and plant, and update the relevant information in the database.

This would include thermal and fault currents, overloading and time characteristics from the results of its type and routine tests, details of the ancillary components used to join the plant, its conductor and winding details, and various climatic loading curves.

Asset management will then arrange for or perform necessary rating calculation programmes to determine the load and fault current rating capabilities of the asset in its particular location; taking into the account local climatic (temperature variations, wind), load (load profiles) and soil conditions (soil type, flooding).

13.1.6. Asset Geographical Locations

Asset management is responsible for ensuring geographical location information for new transmission major assets (lines, cables and substations) registered in TPMS and TLMS is recorded in TLGIS, and for the quality and accuracy of the recorded information.

The TLGIS update starts at the point when a project is approved to establish a new substation or construct new line or cable. The responsible officer inputs necessary project and basic location details, which are later updated as more information from the site measurement become available.
When the individual items of plant are installed and commissioned, and they start their operational service, the responsible officer will obtain those required additional details by arranging necessary substation site and line and cable route inspections and measurements.

13.2. Recording of Asset-Related Activities

An essential part of information flow is the recording of data about all related activities happening to and with assets to finally enable control of asset condition, performance and future destiny.

13.2.1. Asset Maintenance Works

The following details are recorded by maintenance service providers in MIMS for all maintenance work done on transmission network assets:

- facility identifier (line name, switchyard circuit and phase details);
- type of asset (manufacturer name and asset type description);
- asset serial number;
- description of the fault;
- work request details (when fault reported, what work is required; its cost estimate, work priority assessment);
- details of corrective action taken;
- work order number;
- repair crew identification code;
- corrective action type;
- time of repair;
- cost of repair;
- success of repair work (cancelled, completed or partially done);
- outstanding work required.

That will enable analysis of the maintenance work done through production of various reports explained in Chapter 14, and it will assist in identification of incidents.

That is in turn used to determine incident characteristics to identify which incidents were faults and failures of the transmission assets, as to further analyse the asset performance:

13.2.2. Network Outages

All network outages and the requirements for future outages are recorded by system operations personnel in the NOIW database explained in Section 11.2.4 to enable coordination, planning and safe execution of the required maintenance and other works on the transmission network assets.

The maintenance service providers apply for an outage via two methods to record their requests for required circuit outages into NOIW database:

- via interface link from MIMS to NOIW system where the interface program is run daily to create, update and delete the NOIW and MIMS records (generally preferable method);

- manually in an emergency where a relevant form is sent to the SO who then manually enters the required information into NOIW.
It is the role of the SO controllers and maintenance service provider work schedulers to synchronise both databases as they become “unsynchronised”, when daily changes to the work and the outage requirements arise.

The work schedulers, who operate and run the maintenance work database, have the final responsibility in validating and monitoring all asset-based work orders, where the SO controllers have the ability to globally move individual and multiple switching work orders for required outages in the NOIW database.

It must be stressed that at all times the system operations personnel and the work schedulers need to communicate with each other to coordinate outages, as this communication process is fundamental element in ensuring that the maintenance work and related outages procedure is successful.

13.2.3. System Operation Disturbances

Often a disturbance occurs in the transmission network that causes an outage of a part of the transmission network, which becomes non-operational, with or without loss of supply to any customer.

That outage might happen suddenly without warning due to some other faults causing protection to isolate that part of the network, or an outage will have to be arranged immediately as the disturbance poses some kind of a threat to the transmission network (public safety, plant integrity, etc).

All such network disturbances, where a part of the transmission network has become non-operational, need to be recorded by the system operations
control centre officers in the System Operation Disturbance database with all the necessary details as defined in Section 11.2.3.

13.2.4. Protection Operations

Every time a disturbance occurs in the transmission network that requires a protective action for that relevant part of the network, one or more protection relays will operate.

These immediately localise the source of the disturbance and limit the impact of that system disturbance as quickly and as much as possible on the overall operation of the transmission network.

All such network incidents, where a part of the network protection equipment has been called into operation, need to be investigated by asset management. The results are then recorded with all the necessary details in the TPES database with information about the appropriateness of the relay operation and subsequent action taken.

13.2.5. Primary Plant Allocations

Asset management is responsible for ensuring all the transmission primary plant that are currently not used in the system (eg units on order, in transit, in repairs, on testing or in spares custody stores) is properly accounted for and registered in the TPAS database. It is also responsible for the quality and accuracy of the recorded information.

The update starts when the new plant is ordered, or when an operational unit already recorded in TPMS is released from service on site.
The responsible officer will obtain all necessary details from the purchasing officer for the new equipment or use details from the received Primary Plant Return Form (PPRF) received upon release from the service of an existing equipment to make a record of its status and location.

Appropriate documentation is then sent out to the relevant parties to advise them of the necessary details about the asset for their work, or about necessary action they need to perform (allocation sheet, repair request, testing request, transport request, disposal notice, etc).

13.2.6. Secondary Equipment Allocations

Asset management is responsible for ensuring all the transmission secondary equipment currently not used in the system, eg units on order, in transit, in repairs, on testing and in stores are properly accounted for and registered in TPES, and for the quality and accuracy of the recorded information.

The update starts when the new secondary equipment is ordered or when an operational unit already recorded in TPES is released from service on site.

The responsible officer will obtain all the necessary details from the purchasing officer for the new equipment or use details from the received Relay Return Form (RRF) received upon release from the service of an existing equipment to make a record of its status and location.

Appropriate documentation is then sent out to the relevant parties to advise them of the necessary details about the asset for their work, or about
necessary action they need to perform (allocation sheet, repair request, testing request, transport request, disposal notice, etc).

13.2.7. Network Development Plans

It is the responsibility of network planning to record all development activities for the future network requirements dealing with transmission network assets in the Network Development Plans Summary database as defined in Section 11.2.5.

They need to subsequently make any changes and adjustments to those records promptly, as their planning work progresses, and corrections in targeted assets or timing of the works become necessary.

13.3. Recording of Asset Failures

Asset management is responsible for ensuring failures for all assets currently used in the transmission network are properly accounted for and registered in TPMS (for primary plant), TLMS (for lines and cables), and TPES for secondary equipment, and for the quality and accuracy of the recorded information.

The failure records are based on information produced by a number of reports on primary plant and line activities from various databases explained in Chapter 11.

Transmission asset failures are recorded to enable the analysis of asset faults and failures, and type and history of those defects. It is also necessary
to understand the mechanism of the defects, so it is important to enter all data in a correct and a consistent manner.

13.3.1. Event Definition and Data Requirements

There is the need to define events before the actual event recordings are effected, as is presented in the two defect definitions below:

A- Fault is the state of an item characterised by its inability to perform a required function, which can be due to the event of failure of the item itself (Trip) or to requirement for the forced outage to deal with the item (Emergency). This excludes scheduled and planned corrective outages.

B- Defect is an imperfection in the state of an item, which increases the probability of failure of itself or another item, but can be addressed at a later time through scheduling of planned corrective outages.

There is also a need to define data to be captured before the actual event recordings can be done, as is presented below:

- Line, line segment or circuit identifier;
- Date of incident;
- Component identifier;
- Comments on failure, possible cause, deterioration rate and trend;
- Consequence;
- Inspection procedure (global, routine, detailed);
- Technique used (visual, diagnostic, analysing samples);
- Comments on work done or to be done, conclusions.
13.3.2. Initial Reports

There is a need for a number of initial reports about asset activities in the transmission network to produce information that will be analysed to determine event types, and used later for updating asset failures databases.

13.3.2.1. MIMS

Only the maintenance activities on transmission assets (line, cable, primary plant and secondary equipment) to rectify defects, completed separately from the regular preventive maintenance work (requiring special access to the asset between regular maintenance intervals), are counted as failures, and need to be recorded as such.

An asset corrective maintenance work report is produced from the MIMS maintenance work database (see Appendix 22.9) to identify only such maintenance activity (corrective, emergency, major works).

The report is then analysed and reviewed, and relevant incidents are assigned proper failure codes according to the tables in Section 13.3.3.

13.3.2.2. TPES

A report is produced from the TPES database (see example in Appendix 22.10) to indicate all incidents that required operation of protection relays.

The report is then analysed and reviewed to identify all the relevant incidents, ie. the ones that have been caused by the asset failures.
The review outcome is then compared and cross-referenced to the above report from MIMS for incident type consistency and event data quality.

13.3.2.3. SOD

A report is produced from the SOD database (see example in Appendix 22.11) to indicate the fault and forced outages that had occurred in the network while operating the power system due to various incidents.

The report is then analysed and reviewed to identify the incidents caused by the asset failures themselves.

The review outcome is then compared and cross-referenced to the above two reports from MIMS and TPES for incident type consistency and event data quality.

13.3.3. Recording of Failures

The final step in achieving the availability of all asset information for future analysis, is ensuring that all asset failures, determined from the above reports, are properly coded and recorded in the respective databases for primary plant, lines and secondary equipment.

These records will represent all events that have caused incidents that are asset related, and represent asset intervention beyond its normal preventive maintenance regime works.
13.3.3.1. TPMS

The TPMS database is used to record failures of the primary plant according to the coding guidelines shown below. The failure code 1 consists of three characters and the failure code 2 consists of one character.

### Failure Code 1

1. The first character will identify the type of outage:

<table>
<thead>
<tr>
<th>First Character</th>
<th>Type of Cause</th>
<th>Reference in SOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>F — Forced Outage (Trip)</td>
<td>Faults that cause loss of supply.</td>
<td>Fault Outage.</td>
</tr>
<tr>
<td>E — Forced Outage (Emergency)</td>
<td>Faults that do not cause loss of supply but require an emergency outage to repair the plant.</td>
<td>Forced Outage.</td>
</tr>
<tr>
<td>M — Corrective Planned Outage</td>
<td>Defects that do not cause loss of supply. Plant is OK to stay in service until an outage is arranged.</td>
<td>Planned Outage, but before its next Preventive Maintenance.</td>
</tr>
</tbody>
</table>

2. The second character will identify the type of activity:

<table>
<thead>
<tr>
<th>Second Character</th>
<th>Type of Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Violent, explosive, type of failure.</td>
</tr>
<tr>
<td>M</td>
<td>Unit is repaired on site after failure.</td>
</tr>
<tr>
<td>R</td>
<td>Unit is removed from site after failure.</td>
</tr>
</tbody>
</table>
3. The third character will identify the type of end result:

<table>
<thead>
<tr>
<th>Third Character</th>
<th>Type of End Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Leave Blank)</td>
<td>Discarded.</td>
</tr>
<tr>
<td>R</td>
<td>Returned to site after repair.</td>
</tr>
<tr>
<td>S</td>
<td>Returned to store after repair.</td>
</tr>
</tbody>
</table>

Failure Code 2

The failure code 2 consist of one character that will identify the cause:

<table>
<thead>
<tr>
<th>Character</th>
<th>Type of End Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Insulation</td>
</tr>
<tr>
<td>O</td>
<td>Oil</td>
</tr>
<tr>
<td>M</td>
<td>Manufacturing Error</td>
</tr>
<tr>
<td>D</td>
<td>Design Error</td>
</tr>
<tr>
<td>C</td>
<td>Internal Component</td>
</tr>
</tbody>
</table>

A typical record would look like this, **FRR/I**, meaning a forced outage (trip of relays involved) of a plant caused by an insulation problem. The plant is removed from the site, repaired, and subsequently returned to the site to be put back into service.
13.3.3.2. TLMS

The TLMS database is used to record failures of the lines and cables according to the coding guidelines shown below. The failure code 1 consists of three characters.

Failure Code 1

1. The first character will identify the type of outage:

<table>
<thead>
<tr>
<th>First Character</th>
<th>Type of Cause</th>
<th>Reference in SOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>F – Forced Outage (Trip)</td>
<td>Faults that cause loss of supply.</td>
<td>Fault Outage.</td>
</tr>
<tr>
<td>E – Forced Outage (Emergency)</td>
<td>Faults that do not cause loss of supply but require an emergency outage to repair.</td>
<td>Forced Outage.</td>
</tr>
<tr>
<td>M – Corrective Planned Outage</td>
<td>Defects that do not cause loss of supply. Plant is OK to stay in service until an outage is arranged.</td>
<td>Planned Outage, but before its next Preventive Maintenance.</td>
</tr>
</tbody>
</table>

2. The second character will identify the component type:

<table>
<thead>
<tr>
<th>Second Character</th>
<th>Type of Components Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Conductor Assembly</td>
</tr>
<tr>
<td>I</td>
<td>Insulator String Assembly</td>
</tr>
<tr>
<td>S</td>
<td>Support Assembly (Steel tower, timber pole etc)</td>
</tr>
<tr>
<td>X</td>
<td>Cross-arm</td>
</tr>
<tr>
<td>F</td>
<td>Foundation</td>
</tr>
</tbody>
</table>
3. The third character will identify the cause type:

<table>
<thead>
<tr>
<th>Third Character</th>
<th>Type of Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Lightning</td>
</tr>
<tr>
<td>W</td>
<td>Adverse Weather (wind, ice, galloping)</td>
</tr>
<tr>
<td>N</td>
<td>Adverse Nature (tree, vegetation)</td>
</tr>
<tr>
<td>F</td>
<td>Pole Top Fire (pollution)</td>
</tr>
<tr>
<td>H</td>
<td>Human Intervention (crane, vandalism, sabotage etc)</td>
</tr>
<tr>
<td>E</td>
<td>Equipment (design, material, aging)</td>
</tr>
<tr>
<td>O</td>
<td>Other (but known)</td>
</tr>
</tbody>
</table>

A typical record would look like this, **FSF**, meaning a forced outage (trip of relays involved) of a wooden pole that had a pole top fire.

13.3.3.3. TPES

The TPES database is used to record failures of the secondary equipment according to the appropriateness of the relay operations when called or not into the operation.

There are three distinctive relay failure modes that need to be recorded by using the guidelines shown below:

- when called to action but failed to operate;
- when called to action but operate wrongly or partially;
- when not called to action but operated on its own accord.

Asset management investigates all such incidents, and the investigation report findings are also entered into TPES database against the relevant relays for future reporting of the secondary equipment performance index.
13.4. Required Reviews

There is the need to perform a number of reviews by the business functions to make use of the recorded and reported information.

The reviews and the review outcomes are used to improve the asset performance and asset management documentation so that the developed and implemented asset management model benefits the company.

13.4.1. Asset Maintenance

The relevant staff from asset management, asset maintenance service providers and the asset owner conduct regular meetings every three months to assess asset maintenance over the previous period, with two main purposes, to:

- determine the adequacy of asset maintenance instructions and requirements;

- optimise and prioritise the maintenance work further to the initial exercise done during the formulation of the asset maintenance plan (refer to Sections 6.4.8 and 7.3.8.6).

The first part involves an assessment of maintenance of assets by reviewing statistical reports on asset preventive and corrective maintenance work and to recommend changes to the remaining maintenance work or the current asset maintenance and management documentation.
The main issues discussed and evaluated are:

- maintenance costs and relevant budgets;
- recurrence of the required work;
- warranty repairs;
- availability of spare parts;
- competency of employees;
- availability and costs of repair and refurbishment services;
- emergency responses;
- backlog of work and its priority allocation;
- maintenance policy and services appropriateness;
- relevance of the standard maintenance jobs;
- relevance of the maintenance instructions.

A summary of findings is produced as a result of the above discussion.

The second part involves an assessment of the changes in the asset renewal and network development plans, and of the above summary of performed corrective and emergency works.

It results in recommendation for any changes necessary to the remaining maintenance work or the other two asset plans.

13.4.2. Asset Performance

The relevant staff from asset management, system planning, system operations, the asset owner and maintenance services conduct regular meetings every three months to assess the performance of the assets over the previous period.
They assess asset performance indicators by reviewing statistical reports on asset performance, ie asset failures, emergencies and forced outages.

The main issues to be discussed and evaluated are:

- frequency and location of failures,
- recurrence of failures,
- assessment of asset condition,
- new environmental and regulatory requirements,
- safety of employees,
- safety of public,
- safety of adjacent plant,
- ability to manage the process (manage rather than be failure driven).

A summary of findings is produced as a result of the above discussion, and then cross-referenced to and coordinated with the findings and the recommendations in Section 13.4.1.

13.4.3. Asset Maintenance Plan

The relevant staff from asset management and asset maintenance service providers conduct regular monthly meetings to assess the execution and appropriateness of the current asset maintenance plan over the previous period, and to determine the adequacy of the plan for the next period.

They also discuss summary of asset maintenance and asset performance reviews from Sections 13.4.1 and 13.4.2, to assess the impact of the recommended changes to the asset maintenance plans and to the on-going and future scheduled maintenance activities.
They also review the overall company’s financial performance over the previous period and decide if any adjustments in the asset maintenance plan are required.

13.4.4. Network Development Plans

The relevant staff from asset management, system planning and system operations conduct regular meetings every three months to assess the mutual impacts of future network developments and asset renewal requirements to the current and future asset projects (see Appendix 22.12).

They also review the overall performance of the network over the previous period, using reports from the various asset reviews in Sections 13.4.1 to 13.4.3.

13.4.5. Asset Owner Requirements

The relevant staff from asset management and the asset owner conduct regular annual meetings to assess any new internal or external requirements and their impacts on the asset management process and its procedures and work plans.

They also review the overall performance of the asset management model taking into account the results of other reviews performed throughout the year and their outcomes.
13.4.6. Benchmarking and Results

Asset management is responsible for arranging and coordinating benchmarking activities on a regular basis on at least a by-annual basis.

They should use a number of suitable benchmarking studies readily available nationally and internationally, that are undertaken by variety of national and international bodies, industry associations and benchmarking specialist companies (eg ESAA, UMS, CIGRE, etc).

They should produce regular reports comparing the results from their own benchmarking studies and from others released through industry organisations (ESAA) or other bodies (CIGRE) to assess the success of the current work and to define future goals.

The benchmarking study results are used to indicate how close the management and maintenance results and practices used in the company are to the other study participants, and to indicate the need for improvements (see Appendix 22.13).

That should be followed with a detailed review of the identified improvement possibilities in procedures and documentation by organising relevant skilled working groups incorporating internal and external specialists (see Appendix 22.14), to result in the updating and improvement of the targeted asset management and maintenance policies and practices.
13.4.7. Asset Management Plan

The Plan is reviewed in full by asset management at least annually to check the mutual impacts of network development plan and asset management plan recent changes.

This is also necessary to confirm the status of the work in progress, update its contents with the results of various other reviews throughout the year and to produce its updated version.

A procedure is used to establish assets that will require some work in the future and needs to be included in the Asset Management Plan is shown in the process flow chart in Fig.13.1.

Asset management develops on an annual basis a 'first cut' list of assets considered to be a possible candidate for the update of their maintenance documentation or for some work on them (eg modification, refurbishment or replacement) from the Asset Directory.

The assets are identified on the basis of analysing plant reliability, age, failure rates, and their assessed condition, and put into a list called Assets Under Review.

The items on the initial list are then subjected to a high level analysis. The analysis covers the impact of new developments and planned upgrades, and assess how critical the asset position is in the system, its current condition, and likely cost and benefits of asset renewal options.

An investigation will be initiated to assist in determining the future preferred action if appropriate.
FIG. 13.1: ASSET MANAGEMENT PLAN PROCEDURE
Information should be gathered regularly from other electricity authorities and industry forums and used to assist in assessments to arrive at the decision to refurbish or replace.

This may lead to a refinement in decisions when the 'first cut' list is prepared.

The initial list is reviewed annually in conjunction with network planning and system operations before long-term capital budget projections are set-up in the company with the asset owner.

The refined 'first cut' list is a basis for the creation of the Asset Future Projects portfolio, indicating expected actions and time frames, and presenting estimates for the annual review of the capital budget.

Asset management prepares detailed technical and financial business cases as required, and presents them to the company’s management through the proper procedure for requesting maintenance and capital funds.

The approved proposals are then handed over to project management for the project execution according to the existing project management practice.

Asset management continues its involvement with the approved projects as a sponsor until the projects are completed, or if the above performance and planning reviews identify the need for their possible deletions or for updates in their scope of work and/or timing.
13.4.8. Asset Management Process Performance

Asset management needs to measure the success of the asset management process by assessing if it is meeting the set-up performance targets for plant and network performance by reviewing the network performance indicators. A number of indicators are used to objectively measure outcomes of the process, and the main ones are listed below:

- number and assessment rating of site inspections;
- percentage of overall plant failures;
- number of explosive failures;
- number of incidents with conductor on ground after fault;
- line failures rate per 100km of lines;
- percentage of fault outages;
- ratio of preventive to corrective maintenance work.

The results are distributed on a monthly basis to all other business functions, and presented and reviewed through an annual workshop amongst the representatives of the functions.

13.4.9. Asset Management Process

Asset management needs to ensure that the adopted model and its asset management process are proper and applicable for the current business, and therefore needs to subjected to the relevant audit and review exercises, carried out by internal and external specialists providing such audit services.
The reviews should be performed at least by-annually, and should be used to confirm the model and its associated processes are sound, up-to-date, well and properly documented and managed.

The review outcomes should also be used to identify areas and procedures with possibilities for further improvements or refinements to further the performance of the business functions and respective betterment of the network performance and the business as a whole.

For example of Sections 13.4.8 and 13.4.9 outcomes see Appendix 22.15.

13.4.10. Development Work and Results

It is the responsibility of asset management to use the outcomes of all the above reviews and reports to initiate the necessary development work.

They need to prepare conditions for the advancements that have been identified in major areas for improvements, by organising working groups and external consultants in support to implement the recommended work.

That should enable the realisation of significant benefits in the company by defining and implementing measures to use new policies, practices and technology in the asset management process of the transmission assets to achieve best returns and safe operation of the network assets.

Example of one development group proposal is given in Appendix 22.16.
There are a number of asset incident reports that need to be initially prepared from basic asset databases and analysed on a regular basis to achieve the continuous review and monitoring of performance and condition of the assets.

The results of these initial reports are then examined, catalogued, and used for updating a number of other asset performance databases.

The outcomes of those asset incident reports and other reports from the referred performance databases are then used to detect and highlight assets with deteriorating maintenance, operational or financial performances and decay in their overall condition.

The first level reviews and subsequent detailed assessments, where found necessary for the highlighted asset, will give an initial indication of any necessary action or show if further, and more comprehensive, investigations and assessments are warranted.

A business case analysis outcome will determine and recommend necessary works for the assets deemed to require a more detailed review. The business case outcome will also decide which responsible groups are required for the recommended works and in what timeframes.

The sequence of the reporting, and reviewing of the above reports, are presented in Fig.14.1.
* - repairs  
  - refurbishments  
  - modifications  

** - load growth  
  - fault level increases  
  - new customers

FIG. 14.1: REPORTING SEQUENCE AND REVIEW OF REPORTS
14.1. Asset Incident Reports

14.1.1. Corrective Maintenance Works

This report is produced monthly to monitor and review all maintenance work done on assets other than planned preventive maintenance work as defined by the asset maintenance policy and criteria document, ie outside asset preventive maintenance regimes (refer to Section 13.3.2.1).

All corrective maintenance work listed on the report is analysed to check which activities were performed during the preventive work, and which were not.

Only those activities performed as part of the preventive work are not counted as plant failures, where all other activities performed on their own, ie not during the preventive regime maintenance work, are deemed failures.

They will then be entered into the failure database following the relevant process and the coding as described in Section 13.3.

The report contains the following details to be used to analyse regular performance of assets, to calculate the number of plant failures, and to produce other performance statistics:

- facility denominator (substation, circuit, phase, line name, pole number);
- type of asset (manufacturer name and asset type description);
- description of fault;
- type of fault;
- date of incident;
- asset serial number;
• work order number;
• repair crew identification code;
• corrective action taken;
• date of repair;
• cost of repair;
• corrective action type;
• success of repair work;
• any outstanding work to be done at a later stage.

This specified review of the corrective maintenance activity involves more than just checking of the details of each of the individual defect.

It also includes all previous maintenance work done on the selected plant with a defect, for the reason of checking the following:

• has that type of repair occurred before, and how many times;
• was that repair done before or after preventive maintenance, and how far away from it;
• what type of repair procedures was applied in the past (same or different);
• was the repair performed by the same or different service provider or the crew.

That should provide enough initial information to conclude if that defect was an isolated occurrence, or if a trend is emerging for that particular unit, or the whole plant family that needs to be further investigated.
14.1.2. Protection Equipment Operations

This report is produced fortnightly from the TPES protection relay operation records to identify and review all network incidents that have caused the protection relays to operate (refer to Section 13.3.2.2).

All relay operation records listed in the report are analysed to find out the activities that were caused by the plant-related incidents.

Only the relay operations due to the plant failures are counted, and are deemed failures. All other records due to other reasons are not counted.

The records are then entered into the failure database following the relevant process and the coding as described in Section 13.3.

The report contains the following details that are used to analyse regular performance of assets, to calculate the number of plant failures, and to produce other performance statistical data explained in Section 14.2.3:

- type of asset;
- facility denominator (substation, circuit, phase, line name, pole number);
- date and time of incident;
- description of fault;
- fault type;
- cause and circumstances of the fault;
- action taken.
14.1.3. System Operation Disturbances

This report is produced fortnightly from the SOD database network incident records to identify and review all network incidents that have been caused by the network assets themselves (refer to Section 13.3.2.3).

All incident records listed in the report are analysed to find out the activities that were caused by the asset-related incidents.

Only the incidents due to the plant failures are counted, and are deemed failures. All other records due to different network reasons are not counted.

The records are used to assist with updating of the failure databases following the relevant process and the coding as described in Section 13.3.

The report contains the following details that are necessary to analyse the above asset-related incidents in the network:

- type of circuit affected;
- facility denominator (substation, circuit, phase, line name, pole number);
- date and time of incident;
- description of incident;
- incident type;
- cause and circumstances of the incident;
- action taken.
14.2. Asset Performance Reports

These reports are prepared monthly using data in the TPMS, TLMS and TPES databases, and are used to perform a detailed analysis of asset performance.

The outcomes will highlight all the assets and their equipment types that represent the main contributors to the obtained asset failure rates that will require further work to determine reasons for their poor performance.

Each of these reports covers a particular asset, ie switchgear, lines and protection relays. The lists are further expanded to identify the specific equipment types and their locations to easily highlight the ones with the most recorded number of failures.

The failures of the same or similar models are aggregated, and then sorted out by voltage levels to make it easier to highlight problematic equipment items or types from the produced list.

The review of that information is used to determine if a further analysis of asset failures for asset types represented in these failures is warranted.

This review also assists in making an initial decision if the asset should be:

- considered for some action in the future (proceed to seek benefits for its repair, refurbishment, modification or replacement);
- recommended for further investigation of its maintenance regime and servicing;
• highlighted to obtain further information about its performance or condition.

These identified assets are then registered as new candidates for the Assets Under Review in the Asset Management Plan, and will need further investigations if some action for them is not already in progress.

14.2.1. Primary Plant Failures

The report is prepared monthly to indicate the number of problems by the asset types of plant defects that required repairs during the year, and to enable the analysis and identification of the especially problematic items (see Appendix 22.17).

To be able to do that, the report highlights all plant items with more than a few defects with their asset family type and manufacturer.

The report also identifies all defects that happened on the plant under their warranty periods, which are promptly referred to the original manufacturer for analysis and repair action.

All similar items that could be affected by the same problems are subsequently checked and re-confirmed with their manufacturers for future work requirements or service restrictions.

The report findings are also cross-referenced to other asset activities in progress, as given in the Asset Management Plan.

The report indicates the items already under control as some action is due, or it is in progress, thus not only saving time by avoiding investigation
of the same problems again, but also ensuring no problem is neglected or left undetected.

14.2.2. Line and Cable Failures

The report is prepared monthly to indicate the number of problems experienced in the performance of transmission lines by the line types and areas that required repairs during the year, and to enable the analysis and identification of the especially problematic lines (see Appendix 22.17).

The report highlights all lines with more than a few defects in more detail, with a special emphasis on incidents that have caused forced or fault outages and a loss of power supply, or represented a hazard to the public, with the clear asset identification.

The report findings are also cross-referenced to other asset activities in progress, as given in the Asset Management Plan.

    The report indicates the items already under control, as some action is due, or it is in progress, thus saving time by avoiding investigation of the same problems again and also ensuring that no problem is neglected or left undetected.

14.2.3. Secondary Equipment Failures

The report is prepared monthly to indicate the number of problems experienced in the performance of the protection relays, by producing a system operation relay operation index on a 12-month moving average.
The report highlights the deterioration of relay performances, and prompts an analysis and identification of the especially problematic relay types by identifying incidents where relays did not perform their expected duty, or malfunctioned when not called into operation.

The report findings are also cross-referenced to other asset activities in progress, as given in the Asset Management Plan.

The report indicates the items already under control, as some action is due or it is in progress, thus saving time by avoiding investigation of the same problems again, and also ensuring that no problem is neglected or left undetected.

14.2.4. Asset Failures Summary

This report is produced at least annually to highlight all equipment types that fared prominently throughout their total years in service with regard to the defects and failures in their operation.

The report contains the following information:

- Specification, item and purchase order numbers, and order date;
- Voltage level, manufacturer and manufacturing type;
- Equipment type;
- Number of total failures recorded, and defects year-to-date;
- Average age;
- Number in use.
The report is used to perform a detailed analysis of the listed equipment (see Appendix 22.18) to identify items predominant in the number of defects for their further review.

14.2.5. Asset Population, Attrition and Failures Summary

This report is produced at least annually to highlight equipment types that fared prominently throughout their total years in service with regard to having terminal failures in service. Subsequently to the failure, the plant was removed and disposed (see Appendix 22.19).

The report is used to perform a detailed analysis of that equipment, and it contains the following information:

- Specification, item and purchase order numbers, and order date;
- Voltage level, manufacturer and manufacturing type;
- Equipment type;
- Number of units originally ordered;
- Number of units still service;
- Number of total failures recorded;
- Average age.

The report is used to perform a detailed analysis of the listed assets to identify items predominant in the number of terminal failures for their further review.
15. **REQUIRED OUTPUT DOCUMENTATION**

One of the main features of the developed integrated model is the need to have a range of specified output documentation.

The output documentation is used in the defined asset management process to collate outcomes of initial procedures and to present the outcome information in a format that is easy to use. It further defines procedures that will ensure action on those outcomes by the required business functions.

15.1 *Asset Management Plan*

All information generated from the asset management processes is collated and issued in a document called an Asset Management Plan.

The Plan deals only with the ongoing performance of the assets currently installed in the system. The Plan needs to be updated with relevant changes from other areas that have impact on the Plan.

The Asset Management Plan is the end result of the involvement of a number of responsible business functions that perform associated asset management procedures.

Its purpose is to identify assets that need some action in the future and to define what that action is, or the additional information needed to assess the condition of the asset to estimate its remaining useful and safe operational life before some work is required.
The plan contains details of all current and future approved or planned asset renewal activities based on the importance that the assets represent to the operations of the transmission network and with regard to the planned enhancements of the network.

Therefore, the plan represents an expected long-term strategy for the transmission network assets currently in service.

The objectives of the Asset Management Plan are to ensure that:

- assets with suspected performance, high maintenance costs and poor condition are identified, recorded, and have a critical level assigned;
- the activities are in place to investigate and review the above assets;
- business case analysis is performed on the relevant identified assets to determine best outcome and required action for improvement of the suspected assets and to mitigate the impact of their defects or failures on the performance of the network;
- long-term plans are put in place to implement the outcomes and recommended actions from the above business cases;
- input to the company’s long-term business plans to reflect the necessary maintenance and capital expenditures to additionally maintain, renew and replace assets as their life is expended;
- the safety of employees, customers and the public is protected;
- environmental impact is acceptable;
- long-term viability of the business is ensured;
- shareholder value is increased.
The Asset Management Plan covers the total population of the transmission network assets, ie all transmission primary and secondary equipment as presented in the Asset Directory.

The performance of the total population is reviewed monthly, through an application of a range of regular reports, and annually, when the assets in the Asset Directory are subjected to a number of high level reviews of their service performance through analysis of a number of annual reports.

The relevant reports used for these reviews were presented in Chapter 14.

The outcome of those reviews is contained in a list of assets with a possibly suspected performance that will warrant a closer scrutiny, and is called Assets Under Review.

15.1.1. Assets Under Review

Assets Under Review is a list of equipment that has been determined from the initial reviews of the Asset Directory to warrant more detailed analysis.

That initial review may lead to one of three basic outcomes:

1. Performance is still acceptable, or other plans render it satisfactory for the time being, so no further action is needed;

2. Further information is needed about the plant in question to reach a proper conclusion and prepare necessary recommendations on its future. The plant item is then referred for more investigation work, and is listed in the Asset Investigations part;
3. The plant is assessed that it will definitely need some action in a near or later future, and is included in the Asset Future Projects part. The listed projects are grouped into the time frames of 5 years, 10 years, 15 years, and over 15 years.

15.1.2. Asset Investigations

Before or during a more detailed assessment of performances from the items in the Assets Under Review list, additional information or data may be found to be necessary prior to making any reasonable decision about the identified suspected asset.

Records about investigations and their status are in the Asset Investigations.

This can include a number of special inspections, tests and measurements; seeking input from the manufacturer and other similar companies, and may also include various trials and joint research projects with other authorities, companies, universities and manufacturers.

Outcomes of such investigations can be split into two main groups:

1. No additional work will be required for the asset as:
   (a) the relevant units can be relocated to less important or demanding locations in the network; or
   (b) no action at all as asset failures will be sufficiently catered for by the existing generic or special contingency plans for a specified period;

2. The assets in service will require some additional action earlier or later into the future, and should be added to the list of Asset Future Projects. A
detailed business case analysis process will apply in due course to decide their final fate (eg. refurbishment, modification, etc).

15.1.3. Update of Documentation

The results of an asset investigation or a business case analysis could often point out that the best way to solve the identified problems would be through an update of its handling in the maintenance process without any significant physical work required on the asset.

That could include altering the asset maintenance approach such as maintenance policy requirements, maintenance servicing details or maintenance access instructions, which is then registered through the update of its relevant documentation.

Another method would be through altering one of the existing generic contingency plans, including varying the current policy of holding necessary spares, or an option to develop a special contingency plan.

15.1.4. Asset Future Projects

The Asset Future Projects list represents the potential work necessary to address the plant renewal options.

The following range of timeframes are considered:

- **0-5 years** - Plant that will be considered for action within the next five years, with the recommended type of action and timing presented with
as many details as possible, including type and exact estimates of the required funds;

- **6-10 years** - Plant that will need to be considered for action in five to ten years, with the estimated type of recommended action and its timing, and a reasonable estimate of funds that would be required;

- **11-15 years** - Plant to be considered for action between 10 and 15 years, with a very rough description of the recommended type of action and timing, with a broad estimate of action and funds that could be required;

- **over 15 years** - Plant to be considered for action after 15 years in service, with a basic description of the recommended type of action, its timing and possible cost estimates for the work.

The projects from this potential work program are subjected to a detailed business case analysis when they are due according to their anticipated timeframe, or earlier, if the performance of the asset in question deteriorates, to determine if and when the project should actually proceed.

When the outcome of the business case is positive for a certain type of action, the recommended action and the timing proposal will be prepared and submitted through a standard company procedure for obtaining capital or maintenance funds.

When the approval for the recommended works and required funds has been received, the relevant maintenance or capital project will be added to the list of Asset Planned Projects.
Other projects rejected for the time being are referred back to the future project list, with an estimated timing for their next review.

15.1.5. Asset Planned Projects

This is a list of the approved projects to be done in the near future arising from the detailed business case analysis of projects taken from the list of Asset Future Projects, but not yet started.

15.1.6. Asset Current Projects

This is a list of all previously approved projects that are currently in progress in the area of asset renewals (eg modification, replacement, repair and refurbishment).

15.1.7. Asset Completed Projects

This part contains a list of all projects completed since the previous Asset Management Plan was issued.

15.2. Asset Maintenance Plan

The Asset Maintenance Plan is a complete list of all planned and required maintenance works necessary for the transmission network assets currently operating in the network to ensure that the assets continue to fulfil their intended function in a cost-effective manner.
The plan also serves another important purpose, that is to achieve a proper coordination and optimisation of all maintenance and capital works through the model defined reviews, by having the full visibility of all maintenance works.

That will avoid a situation where several different maintenance and capital works are being planned or done on the same asset by various business functions in the same or similar period.

It also provides a good basis for the coordination and optimisation in regard to capital planned works that are contained in the Asset Management Plan and the Network Development Plans.

The programme of all required asset maintenance works contained in the asset maintenance plan is divided into the respective maintenance category works as per definitions in Section 7.3.7, which are summarised in the following:

- Preventive maintenance work;

- Corrective maintenance work;

- Major works (a major asset works for which maintenance operating fund approvals have been obtained).

The formulation of the plan is covered in Section 7.3.8, with the subsequent maintenance budget proposals being prepared by following Section 7.3.9.
15.2.1 Preventive Maintenance Work

This part contains all required preventive maintenance work that will be scheduled using defined maintenance policies for various plant items as programmed in the maintenance works database (MIMS).

The work is represented with maintenance standard tasks (MST), which are linked to maintenance standard jobs (MSJ) that contain the identification of a known service provider and agreed costs for the standard job.

The service provider work schedulers initiate the actual work by transforming the standard tasks into the work orders.

15.2.2 Corrective Maintenance Work

This part covers all known work for a plant that requires additional interventions for problems identified in routine inspections and patrols, or additional defects, found during the execution of the preventive maintenance or other corrective maintenance works, which could not be fixed immediately due to technical or financial reasons.

The list of the corrective works should include the following information about the required works:

- asset identifier and plant type;
- description of work;
- timeframe;
- duration;
• outage access type;
• other necessary equipment and plant;
• spare parts necessary;
• cost estimates;
• risk assessment if not done in required time;
• service provider and skills necessary.

15.2.3 Major Works

This type of work is a summary of planned and budgeted actions on plant items or lines hardware for which a business case analysis and maintenance funds approval has been previously obtained (involves technical, financial and planning analysis) for the work to proceed in the required time frame.

This work would typically cover the following three maintenance type groups; overhaul or refurbishment, modification, and remedial or repair.

15.2.4. Maintenance Codes

All works need to be linked to appropriate, previously-defined codes for the asset responsibility centre, activity type and maintenance service group as given in Section 7.3.7 for different asset types.

That will enable reporting and discussion to achieve an even and manageable spread of the maintenance work per asset families, per geographical areas, and per service providers for the whole of each year.
The responsible centre code used for the account codes in work orders is different for the primary and the secondary assets to enable a proper maintenance cost analysis.

Separate activity codes are used to form an account code in work orders for the maintenance work activities.

It is also required to use codes for the individual maintenance service providers in a work order to enable the analysis of the service providers involvement.

15.3 Business Case Studies

The regular analysis and review of asset performance leads to the initial list of assets with a suspected condition, as explained in Chapter 13.

That list is then further subjected to another high-level analysis and investigation, where required, to determine if any action is required in the future, and if the asset needs to be included in one of the Asset Management Plan lists defined in Section 15.1.

This further review leads to the asset being included in the Asset Future Projects portfolio, which indicates expected actions and required action time frames with rough cost estimates as a basis for the long-term capital and maintenance budget forecasts.

When the right time comes for action on a particular asset project from the Asset Future Projects portfolio, a detailed technical and financial business
case needs to be prepared. That is done according to the Asset Business Analysis Manual following the procedures explained in Chapters 9 and 13.

The final proposal is presented to the management through the company’s standard capital and large maintenance project approval procedure.

The possible outcomes of the asset business case analysis are presented with a recommendation to pursue a course of action selected from the options described in Section 9.5.

Briefly, the recommendations may propose that no additional work will be required on the asset itself, but with some other action, or that the asset will require some action, and a recommendation for approval of capital or maintenance funds is made.

After the approval is obtained, the recommended project is handed over to project management for its execution, who will provide regular updates on its course to asset management throughout the project works.

The relevant project will also be moved from the Asset Future Projects to the Asset Planned Projects part of the Asset Management Plan.

An example of the actually prepared, approved and completed business case for the replacement of 132kV circuit breakers is presented in Chapter 16, with a discussion about the whole procedure.
15.4. Special Contingency Plans

One of the outcomes from an asset business case for the identified suspected asset could be a recommendation to solve the identified problem by the development of a special contingency plan for that group of assets.

The plan would cover possible failures of the targeted assets over a specific period of time while some other planned developments occur and make the assets in question redundant, or significantly diminish their importance for the network reliability or financial impact of their failure.

The preparation of such special contingency plans can be assigned to internal or external resources, or most likely by a combination of both.

Typical examples of such special contingency plans are the plans that have already been developed and implemented as an outcome of business case analysis on the following subjects:

1. The metal clad indoor switchboards contingency plan deals with the emergency response in the event of failure of metal clad indoor switchboards in selected transmission zone substations while they are retired through the network augmentation project (see Appendix 22.20). It provides a mobile switchboard with quick reconnecting capabilities to limit power supply losses over a certain short period;

2. The rapid response spare transformer (transformers mounted on a mobile platform) plan deals with a number of substations that might in some rare circumstances lack the capacity for the expected loading in those exceptional circumstances.

The plan enables a quick restoration of supply with a temporary application of that mobile transformer at the affected substations while a
failed transformer is removed from the substation and a permanent spare unit is installed in its place;

3. The cable contingency plan for the metropolitan inner city area deals with the inner city substations that might be left without proper power supply in the event of the failure of some major inner city cables amongst those substations.

   The plans will enable the quick erection of an overhead line between any of the affected substations through the nominated city streets to bypass the failed cable, thus restoring the full power supply to the affected central business district.

There could also be a requirement for other special contingency plans for catastrophic events considered well beyond normal operating risks to cover such events in the specific periods of a high load growth before other contingencies are made in the generic contingency plans.

   A preparation of such plans is the responsibility of the network development function.

That could typically include events such as:

- Loss of a whole terminal substation (eg. if light plane crashes);
- Expecting unusual storms that can cause widespread damage (eg. cyclone);
- Rare system events (eg cascade tripping of 330kV lines caused by a high unusual humidity);
- Coincident events (eg multiple bushfires in a very dry summer affecting multiple major lines).
The thesis has explained and formulated the relevant documentation and procedures for the preparation and review of business case on a non-performing asset that is necessary for a full implementation and running of the model and its process.

That has been applied to a real case, and the details of the review are given in the following Sections.

16.1. Introduction

The company purchased a total of 65 units of the circuit breaker under two specifications, 12/MU, Items 1&1A (27 units, 23 in 1963 and 4 in 1967/8) and 10/K, Item 1 (38 units in 1967).

There were 30 units still in service (46 %), 12 units of Specification 12/MU (44 %) and 18 units of Specification 10/K (48 %).

Major problems occurred associated with their high-pressure hydraulic systems, some requiring up to six repairs per year, causing frequent plant outages and incurring high repair costs on top of their expensive regular preventive maintenance work.

These problems were not been resolved despite a number of initiatives and investigations, involving several manufacturers and own staff.
Due to the design of their hydraulic system that uses high gas pressure to operate the unit, most of the components are worn out.

A number of parts were dismantled and resealed with new gaskets, but the gas and oil leaks were repeatedly occurring within a short period.

Some of these units were soon to be replaced through other approved network development projects due to the fault level increase, but there were no plans for the replacement of fifteen units in any of the future network development projects.

Therefore, there was the need to assess the remaining fifteen units and prepare a business case for the possible improvement of their performance or for their replacement by using the developed business case analysis and its risk assessment matrix from Chapter 9.

16.2. Calculation of Business Case Component Risk Factors

The relevant business components had their risk factors calculated to enable determination of the risk ranking as per Section 9.2:

16.2.1. Age

The units are 31 to 35 years old. The expected operating life for that type of equipment is 40-45 years, and their risk factor is therefore rated at three.
16.2.2. Frequency of Failures

The above units have recorded a high number of failures causing outages for their repair, diverting resources from other planned preventive works.

The summation of these failures is shown below:

<table>
<thead>
<tr>
<th>Location</th>
<th>Failures over the Last Five Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Terminal (WT)</td>
<td>34 failures</td>
</tr>
<tr>
<td>East Perth (EP)</td>
<td>12 failures</td>
</tr>
<tr>
<td>Merredin (MER)</td>
<td>4 failures</td>
</tr>
<tr>
<td>Bunbury (BU)</td>
<td>No records of previous performance</td>
</tr>
</tbody>
</table>

The average failure rate is approximately \( \frac{50}{15}/5 = 0.66 \), and the risk factor is therefore rated at five.

16.2.3. Condition

The condition of these units is not satisfactory, with frequent gas and hydraulic oil leaks through various seals and repetitive breakdowns of their hydraulic pumps and compressors.

That extensive and detailed repairs and reconditioning of the pumps and seals in-house had only a moderate success, as the units developed further leaks and faults soon after the repairs.

Many worn parts are subjected to high hydraulic gas and oil pressures during the breaker normal and fault operations (300 bars).
That is causing high corrective maintenance costs assessed at $424K for the next 12 years. The comparison to the expected cost of $700K for preventive maintenance gives the ratio in the range of 50-100%, and therefore the risk factor is rated at four.

16.2.4. Environmental & Regulatory Requirements

The possible consequence of their failures could be a release of hydraulic mediums, such as gas and oil, into the atmosphere and the surrounding soil.

That is not environmentally acceptable as there are regulatory requirements as well as certain limitations on such leaks, to which the company has agreed with various government departments and national associations to adhere to. Therefore, the risk factor is rated at three.

16.2.5. Maintenance Costs

16.2.5.1. Preventive Maintenance Costs

The above units currently in service require regular preventive maintenance, where alternating lower and higher service levels (A and B) are applied every two and four years respectively.

The costs of performing these levels of maintenance are:

Level A-Check Maintenance $ 4,770;
Level B-Full Maintenance $11,600.
The preventive maintenance work cost over the next 12 years is estimated at $48,110 per circuit breaker, or $725,000 for all units.

16.2.5.2. Corrective Maintenance Costs

The above units have a high repair rate, with the cost of corrective maintenance between 1993 and 1998 totalling $177,000 in addition to their preventive maintenance costs.

It is estimated that similar expenditure will continue to occur over the next 12 years, and will cost an additional $424,000.

16.2.5.3. Summary of Maintenance Costs

The total maintenance costs for the 15 units over 12 years will be $1.2M with a figure of $6,600 per unit per year.

The comparison to the expected replacement cost of $82K for a new unit gives the ratio of 8%, and therefore the risk factor is rated at five.

16.2.6. Replacement Costs

The proposal is to replace the defective units with new gas insulated units requiring little maintenance (checks every 12 years) and a cost of approximately $82,000 per unit to purchase, install and commission.

The difference between the replacement and continuous operation is greater than 50%, and therefore the risk factor is rated at five.
The new units will also have a higher fault current rating, and will satisfy long-term planning requirements for the respective substation sites.

16.2.7. Spare Parts Availability

The units in question are of an old design, and no original spare parts are available due to the fact that the original manufacturer ceased to exist.

Some parts are being made temporarily available by refurbishment of the surplus units replaced from other sites as part of other development projects. Unfortunately these parts are worn out, and even the refurbished ones are not in a good enough condition to guarantee the long-term secure operation of the units using the refurbished parts.

The main part spares are not available from the original manufacturer, and due to high costs to re-manufacture them on an individual basis, the risk factor is rated at five.

16.2.8. Competency of Employees

The skills to repair these units or to refurbish their parts exist within some of the company’s substation maintenance service crews, and the risk factor is rated at two.

Unfortunately, their use is limited due to lack of parts and worn components as explained in Section 16.2.7.

16.2.9. Availability and Cost of Refurbishment Services

This area is considered to be of limited use, due to factors described below, and therefore the risk factor is rated at five:
• There is no possibility for obtaining spare parts as the original manufacturer does not exist;
• No local manufacturer to provide assistance;
• High costs of re-manufacturing the main parts by others;
• Long delivery times for individually manufactured parts;
• Low success on undertaken refurbishment and modification works;
• High cost of the rework undertaken up-to date.

16.2.10. Safety of Employees

The units in question are dependent on the integrity of their hydraulic system for proper operation under normal or fault conditions.

The failure of any part due to loss of pressure in one of the phases could cause an unsynchronised operation of breaker phases, which in turn could cause an internal fault and possible damage to the unit.

As these circuit breakers include high-pressure gas and oil components, there may be a failure of its pressure vessels. An explosive outcome, however remote, could not be ruled out, and these units present a risk to the personnel performing maintenance work on the adjacent equipment.

They are considered a moderate risk for safety of employees, and the risk factor is therefore rated at three.

16.2.11. Safety of Public

The equipment does not present a direct risk to the public, as their location is well within the boundaries of the relevant substations.
However, there is an indirect risk through their impact on power supply that could endanger public safety if the power supply is lost to a large area due to an internal fault, should the unit attempt to operate under fault conditions with low hydraulic pressure and fail.

Therefore, the risk factor is rated at four.

16.2.12. Safety of Adjacent Equipment

There is a risk associated if these units have to operate under a fault condition with low hydraulic pressure causing an internal failure and a rupture. The flying debris could then damage adjacent equipment, which can be further exacerbated if, as a consequence of the failure, released oil and gas contaminate the surrounding area and the atmosphere.

The risk factor is therefore rated at three.

16.2.13. Obsolete Design Standards

The units are considered to be an obsolete and outdated design using a high internal pressure hydraulic system, and the high operating pressure has caused hydraulic oil and gas losses and accelerated wearing of pumps, valves and hoses.

The risk factor is therefore rated at four.


The persistent hydraulic medium leaks and subsequent failures of the circuit breakers to operate also cause significant concern operationally.

As their failures require significant resources for often-extensive repairs, and obtaining various parts is only possible throughoutsourcing of
their manufacture to local companies, they are causing inevitable delays in returning these units back to service thus jeopardising system security as they are installed in the following critical circuits:

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Location</th>
<th>Circuit</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT821</td>
<td>T1</td>
<td>EP831</td>
<td>EP-CBK-81</td>
</tr>
<tr>
<td>WT823</td>
<td>A to B Busbar</td>
<td>EP833</td>
<td>A to B Busbar</td>
</tr>
<tr>
<td>WT825</td>
<td>WT-SF-81</td>
<td>EP835</td>
<td>EP-NT-81</td>
</tr>
<tr>
<td>WT841</td>
<td>T2</td>
<td>EP841</td>
<td>T3</td>
</tr>
<tr>
<td>WT843</td>
<td>A to B Busbar</td>
<td>EP843</td>
<td>A to B Busbar</td>
</tr>
<tr>
<td>MER805</td>
<td>T2-805</td>
<td>MER807</td>
<td>T1-807</td>
</tr>
<tr>
<td>BU810</td>
<td>BU-MU-81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The WT circuit breakers are critical for the supply to major hospitals. The circuit breakers at EP are critical for the supply of CBK substation feeding the Westrail electrical train system.

The two MER circuit breakers are critical, as there is only a limited capability to supply the Merredin area from the 66kV system.

The unit at BU is critical for ensuring a secure supply to the South-West area customers and mines.

Any loss of the above circuits with the installed circuit breakers in question would be serious and could have a long-term consequence on the quality of supply as described above.

Their failure means an immediate loss of supply with a possible high impact and a slow power supply restoration as it could take up to a week to repair or replace the failed unit. Therefore, the risk factor is rated at four.
16.2.15. Impact on Customer

A loss of supply to sensitive load areas as described above (hospitals, rail system) from a failure of these units is disruptive and possibly dangerous, as any unit could be out of service for repairs for a significant time period.

There is also an increased risk of wider protracted supply losses, if another one of these units failed in some or the other affected circuit or substation.

Therefore, the risk factor is rated at four.

16.2.16. Impact on the Company

Any loss of supply resulting from the failure of these units in their circuits could have a significant effect on the company's business as listed below:

- Loss of supply over a wider area means a significant loss of revenue;
- Replacement and repair of equipment under emergency regime could be costly, especially if other adjacent plant has been damaged;
- Use of maintenance group resources to attend urgent and large repairs of the failed unit means other planned preventive or corrective works need to be postponed or cancelled for that year. This has an impact on the annual maintenance plan, which could in turn jeopardise integrity and security of operation of other equipment for which scheduled maintenance work had to be abandoned;
- Company's relationship with customers could suffer, which is important in the open access and increased competition environments;
- Community repercussions might be severe, particularly as some of the circuits in question supply hospitals and rail systems;
• Political ramifications should not be dismissed in the regulatory area, and could impact on various other new projects in progress.

Therefore, the risk factor is rated at four.

16.2.17. Ability to Manage the Replacement Process

It is important in this case to realise the importance of the ability to properly manage replacement work for these assets, rather than be failure driven with ad hoc requests for large unplanned repair expenditures due to their en masse replacements.

The suitable replacement plant is generally available in nine months or more and with the cost of up to $500K per year.

Therefore, the risk factor is rated at four.

16.3 Assessment of Risk Matrix

<table>
<thead>
<tr>
<th>Category</th>
<th>Weighting</th>
<th>Risk</th>
<th>Weighted Risk</th>
<th>Special Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>2</td>
<td>3</td>
<td>06</td>
<td></td>
</tr>
<tr>
<td>Frequency of Failures</td>
<td>4</td>
<td>5</td>
<td>20</td>
<td>*</td>
</tr>
<tr>
<td>Condition</td>
<td>3</td>
<td>4</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Environment/Reg.</td>
<td>3</td>
<td>3</td>
<td>09</td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td>Weight</td>
<td>Importance</td>
<td>Total Risk Factor</td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------</td>
<td>------------</td>
<td>------------------</td>
<td></td>
</tr>
<tr>
<td>Maintenance Costs</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Replacement Costs</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Spare Parts Avail.</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Competency of Empl.</td>
<td>3</td>
<td>2</td>
<td>06</td>
<td></td>
</tr>
<tr>
<td>Avail. of Repairs</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Safety of Empl.</td>
<td>5</td>
<td>3</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Safety of Public</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Safety of Equipment</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Obsolete Design</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Impact on Supply</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Impact on Customers</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Impact on Company</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Ability to Manage</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL RISK FACTOR</strong></td>
<td></td>
<td></td>
<td><strong>254</strong></td>
<td></td>
</tr>
</tbody>
</table>
16.4. **Risk Ranking for the Business Case**

The risk matrix assessment concludes that the total risk factor is 254 and the number of identified special constraints is 4.

Using the table for their range as defined in Section 9.4, the risk ranking of 'High Risk' is derived from the evaluated business case analysis of the selected and reviewed assets.

The 'High Risk' ranking means that a plan of action is required, and the desired outcome for that action with its timeframe now needs to be selected using the guidelines in Section 9.5, which is given in Section 16.5.

16.5. **Summary of the Business Case Outcome**

The outcome of this business case analysis was that the assets in question required some work and was added to the list of Asset Future Projects from the Asset Management Plan.

An additional analysis of the individual reviewed components has been performed according to the guidelines in Section 9.5, which demonstrated that the repair, refurbishment and modification options were not feasible for these units, and that the replacement of all reviewed items would be the only viable alternative.

Therefore, the recommendation of this business case outcome was to prepare a submission for a capital project approval to replace the remaining fifteen units over the next few years.
16.6. Discussion

The above presented business case is an example of an application of the developed business case analysis and review of its components on a particular non-performing asset in the transmission network.

It attempts to bring some objectivity and consistency in the way equipment performance and its short- and long-term failure operational and financial consequences are assessed.

By this, it is now possible to clearly and properly assess the impacts and viability of various outcomes for the equipment identified with a poor performance in order to determine the best way to deal with current and future problems and their repercussions.

In the above case, a portfolio of all equipment identified as being under a risk has been established, proper equipment age and condition analysis done, their operational service performance and impacts on a range of areas evaluated, and risk assessment of the relevant components completed.

An appropriate selection process has been followed, which reviewed the required actions and their practicality and costs, and cross-referenced the assets in question with future network development plans to exclude the units already planned for replacement in other projects.

The benefits of the work organised through a planned long-term replacement programme have been determined, and a proper and reasonable best outcome for the network and the company recommended.
In this instance, fifteen circuit breakers were recommended for the replacement over for the next four years (six at WT, six at EP, two at MER and one at BU), to be replaced as per the indicated proposed circuit breaker replacement schedule:

<table>
<thead>
<tr>
<th>Location</th>
<th>Position</th>
<th>Circuit Identifier</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Terminal</td>
<td>- 821, 823, 825, 841, 843 and 845</td>
<td>1998/1999</td>
<td></td>
</tr>
<tr>
<td>Merredin</td>
<td>- 805 and 807</td>
<td>2000/2001</td>
<td></td>
</tr>
<tr>
<td>Bunbury</td>
<td>- 810</td>
<td>2001/2002</td>
<td></td>
</tr>
</tbody>
</table>

Project management, engineering design and maintenance service groups were involved during the evaluation procedure, and were requested to obtain and provide the necessary detailed engineering design on the replacement plant and the relevant costing estimates, as well as to confirm that the recommended replacement time frames were feasible.

Asset management subsequently prepared a capital project approval proposal to the management for the circuit breaker replacement. It also confirmed the requirements for the company’s planned capital budgets for 1998/1999, 1999/2000, 2000/2001 and 2001/2002, seeking the asset owner functions to approve and ensure the budgets contain the necessary funds to complete this work if and when the final approval is granted.

The replacement project and the required capital funds were approved, and the project was completed as recommended.
17. **OVERALL CONCLUSIONS**

This thesis has developed in detail the successive stages leading to the establishment and implementation of an integrated and dynamic asset management model for a proper and complete management of assets installed and in service in high-voltage electricity transmission networks.

The model has been implemented, and is currently in operation in a transmission network business. It is being fully utilised to ensure that the described improvements are achieved, and that the benefits referred to are brought to fruition for the business.

Most aspects of the research have now been reported in a series of papers published in open literature and presented through lectures and presentations, conferences, workshops, schools and business forums covering the related subject.

The developed and presented model has been discussed and is well accepted, after several successful internal and external audit reviews.

The research originated from an existing inability to achieve a substantial advance in the field of asset management of the transmission network assets in service, as they grow older.

The assets have begun to require more attention and decision making on their current and future operation, maintenance and renewal activities.

It is also about the impact of those decisions on the performance and reliability of the transmission network and the whole system, companies' financial performance, and ensuring the long-term viability of the business.

It has been felt that the methodologies and systems currently available and employed throughout the relevant industry are general in their approach to asset management, and do not take a particular view and
account for the specific circumstance of the transmission business and its environment.

The original development of the new asset management model has been in terms of an effort to rectify this situation by achieving such a complete model covering all aspects of the transmission asset management required to accomplish all necessary asset management tasks.

The steps of the development from the initial situation to a new model of asset management have been presented in the thesis throughout Chapters 1 to 15. They contain defined work and business functions, their roles and links, required information transfer on a defined time basis, and supporting documentation.

The thesis starts with a detailed snapshot and analysis of the current situation, and the summary of its findings, providing a guideline for a new model, and resulting in recommendations to be incorporated in the new model.

Central to those recommendations for the new model is a detailed identification of the mechanism of transmission asset management process and all the main work and business functions in that process, with the improvements and additions to their current status.

The recommendations further identify improvements of their current links and outline relationship types for a proper operation of that process.

Following this initial work in identification of the current situation and improvements and additions necessary for a complete process, a general structure of a new and original integrated and dynamic model and its process is developed.
That includes a definition of the main policy documents covering the companies' high-level strategy intent and its application through a policy statement on the management of transmission assets.

Those documents provide a basis for understanding the role and responsibility for the asset management function in the company, as well as the expectations and goals to be achieved through its existence and operation.

Extensive work has been done to translate the main policy documents into a workable framework through a detailed development of an asset management process with the definition and roles of all aspects of the developed new model as presented in Section 6.4.

The thesis has further formulated a complete framework for the successful implementation of the developed process by presenting comprehensive information on business functions, necessary instructions and procedures, and supporting documentation.

In particular, that framework consists of the initial documentation required to start the process, procedures to be followed throughout the whole process and the procedure upkeepers, the necessary databases and data acquisition, the reporting from the databases to support the defined regular exchange of information amongst the business functions, and the necessary reviews of the exchanged information.

There is also necessary documentation for the required model supporting roles for the defined documentation being outcomes from the required reviews, with clear rules and instructions about required actions and accountabilities for the recommended outcomes based on the review of output results.
Extensive work has also been done to formulate the identified asset management tasks and set of defined links, activities, and feedback in time and content, amongst the defined business functions.

That has been completed in a dynamic and integrated way to ensure a complete and timely exchange of prescribed information, to achieve a significant improvement in the area of managing transmission assets.

This has been the original and envisaged aim of this research work.

Finally, the thesis has sought to explain, formulate and document the developed model and process, and all of its procedures and documentation, in sufficient details necessary to enable the full implementation and operation of the developed dynamic and integrated model.

The work presented in this thesis on the development of an integrated model for transmission asset management has gone a long way to improve the existing situation with asset management specifically in the electricity transmission business.

However, the presented methods, solutions and outcomes of the model are sufficiently wide and generally applicable in their scope and approach that they can be useful to other organisations that operate assets and want to adopt an approach for the total management of their assets.

Despite the improvements this thesis presents, there are still many opportunities for further in-depth research and improvements in this area and the related subject of asset management.

They include the better optimisation of decision making on asset actions in the business case analysis and maintenance work priority, and automation of interlinking amongst business functions and their databases through the increased use of computer facilities for interface links.
18. REFERENCES


19. ACKNOWLEDGMENTS

I would like to thank a number of people who have helped, supported, and guided me throughout my work towards the thesis as presented today:

Professor Tam T Nguyen, my supervisor, for his absolute belief in me, and for his strong and continuous support throughout this PhD research project;

Roy Hayes, William Wallace and Brett Hinkley for their assistance and encouragement in the early stages of this work;

My wife, Patricia; for her love, patience, support, and understanding during every stage of my life and my work.

I wish to sincerely thank Western Power Corporation and Doug Aberle, General Manager Networks, for enabling me to work in the relevant areas and on this research for mutual benefits. I also want to thank the many staff for their support and assistance all along the way; especially to Darryl Tweeddale, Don Hogg, Peter Chomiak, and Steve Tokic.

I also wish to thank support staff at the University of Western Australia for their assistance whenever needed for my work.

Finally, I want to express my deep gratitude to my lecturer at the University of Zagreb, and later manager and mentor during my first years at work, Professor Tomislav Kelemen. He provided me with continuous and unconditional support, assistance and encouragement towards continuous improvements in myself and in my work.
Nenad Kolibas (1955) graduated in Croatia from the University of Zagreb, Faculty of Electrical Engineering, with Honours in Electrical Engineering in 1978. He completed postgraduate study courses in the area of electrical engineering in 1987 at the same University.

He started his work as a cadet with KONCAR Industries Company in December 1977 in the transformer development department, responsible for the development of design, manufacture and testing of transformers.

He joined Western Power Corporation (then SECWA) in May 1988, and worked in the Plant Section. He joined the Transmission Maintenance Branch in 1994, which in 1998 folded into the Transmission Assets Branch, and then in 2001 into the Asset Strategy Branch. He has had an active role in a number of activities for the development, implementation and running of the asset maintenance and management functions for transmission network assets of the Western Power Corporation.

He is a current Chairman of the Australian Standards Committee EL/13 (Measuring and Protection Transformers) and an Australian delegate in the International Electro-technical Commission Technical Committee TC38.

He is a member of several CIGRE groups, Australian Sub-Panel 12.01, International Working Group 12.16 and a special Working Group set-up to review asset management in transmission utilities.

He has published a number of articles and papers in national and international journals and for conferences, and has given number of presentations at industry forums and technical sessions.
21. **LIST OF PUBLISHED PAPERS, PUBLICATIONS AND PRESENTATIONS RELEVANT TO THE THESIS SUBJECT**

A list of publications relevant to the thesis as referred to in the Introduction is listed below. Some of the publications have been marked with an asterisk indicating the more prominent publications that have been attached in full to this thesis in the Appendix 22.1.


22. **APPENDICES**

22.1. *More Prominent Published and Presented Papers*

**3* TRANSMISSION ASSET MANAGEMENT**

1.0 INTRODUCTION

Transmission system (lines and substations) consists of many different assets, some of them very expensive, but all with a definitive life expectancy. As their condition deteriorates with age and operation, it is reasonable to expect their failure in service at a certain point in time. When they actually fail, the impact of such a failure could be quite serious, ranging from a major loss of supply and prolonged restoration period, endangering of public and employees safety, serious environmental aspects, to significant unplanned operating and capital budget blow-outs.

Assessment of the asset condition is not a simple task, and requires a lot of information to be collected in an organised way, often over a considerable period of time. The actual decision to replace an old or suspect asset is made even more difficult by a number of additional factors that have to be taken into account, eg. planning criteria, operational circumstances, load and fault level growth, liability risks, increased maintenance repercussions, etc.

This paper discusses the experience of Western Power Corporation with the development and implementation of asset management activities, some results obtained so far through the relevant programmes, and recommends actions to be followed in the future.
2.0 ASSET MANAGEMENT MODEL

The asset management model adopted by Western Power defines asset management as a set of grouped activities that cover maintenance, repair, condition and criticality assessment, and refurbishment and timely replacement of the assets. These activities are supported by a number of databases, that will be addressed in more detail elsewhere in the paper.

2.1 Maintenance

Maintenance is an organised process to make sure all installed equipment is properly inspected, checked, tested and adjusted as per agreed maintenance provisions, and is generally divided in two main areas, maintenance policy and maintenance work specifications.

The maintenance policy defines different levels of maintenance including plant inspection prior to warranty expiration, the frequency and sequence or condition trigger, and general work instructions for each level with broad pass/fail criteria for required tests. Their contents are a combination of manufacturers' given recommendations, utility's internal experience, industry accepted practice and special updates on equipment performance obtained through contacts and involvement with national and international bodies (eg. CIGRE, IEC, etc.). The procedure for their review and update is described further in this paper. The formal document is called Transmission Maintenance Policy Manual.

The maintenance work specifications are detailed, hands-on, step-by-step servicing instructions. They originate from manufacturers' detailed maintenance manuals, and are supplemented by own extensive experience in maintaining the equipment. They are usually pertinent to the particular type/model of equipment, and they prescribe skill levels for maintenance staff, the necessary tools and plant to use, and the required standard set of
spare parts. The formal document is called Transmission Maintenance Services Manual.

2.2 Repairs

An important aspect of asset management is handling of irregularities, defects, failures and the correction of these problems, which, when done in a competent and organised way, can greatly contribute to provision of a safer and more reliable power supply.

A number of procedures have been developed and implemented which define these activities, indicating their importance. The key procedures are: guidelines for substation and line maintenance, attention to emergency breakdowns, procedure for handling of faults and initiation of work requests and procedure for obtaining replacement for failed plant. An attempt is made in the following text to briefly capture the essence of these procedures.

Irregularities and Defects

All irregularities and defects found during inspections/patrols and other maintenance work are recorded on standard report sheets, and entered into maintenance database against the relevant plant. Minor problems are corrected immediately by the maintenance groups, and defects with high expected repair costs (long outage times, new plant, extensive resources) are referred to maintenance engineers for further assessment, approval and repair arrangements.

The defects found on plant still under manufacturers' warranty are reported to the project engineer who handled the relevant project/purchase contract. They liaise with the service or plant provider to ensure plant repair is effected under the project or contract warranty provisions.

All defects assessed to pose imminent threat to personnel/public or continuity of supply are referred directly to the system operations
controllers to arrange emergency access for their temporary or permanent resolution.

Emergency Breakdowns

In the event of emergency breakdown the first priority of the operating group is to make the situation (site and plant) safe and to restore the supply. The attendance to the plant repair or replacement is then transferred to the maintenance group.

If during any of the above incidents environmental damage or pollution occurs, or there is the potential to cause one, maintenance engineers are immediately contacted to arrange immediate clean-up, and to assess environmental impacts and further remediation needs.

The maintenance engineers are required to refer any defect or problem perceived to be a possible generic fault to the asset maintenance group for further investigation, i.e. analysis of reason for the failure and extrapolation to predict future events.

2.3 Condition and Criticality Assessment

A higher level of asset management, often called asset management itself, involves a number of departments and associated processes aiming to assess plant condition and estimate its remaining safe operational life, and to rank/prioritise plant based on the importance it presents to the operation and planning of the system.

The processes, their dependencies and frequencies, and departmental links and responsibilities are defined, and presented in the Manual of Asset Procedures. All information generated from these processes is collated and issued in a document called Transmission Asset Management Plan.

The plan will be updated annually, or more often if required by a significant change in any of the relevant areas.
The main contributors to this process and their duties are described below in more detail.

**Asset Management Group**
Monitors performance and ageing of plant, analyses faults and population statistics, initiates programmes to check and assess condition of plant based on type generic faults and the results of the plant statistics, and to determine the plant remaining service life. It is also to analyse feedback from the plant regular preventive maintenance programmes (eg. incurred cost movements, spare parts consumption, amount of additional work performed, comments on check sheets, etc.), and to modify the maintenance policies as necessary. The group maintains close contacts with similar groups in other utilities, and is encouraged to participate in relevant industry organisations, activities and forums. This group is also given overall coordination for all asset management related activities other groups perform to support this process.

**Finance Group**
Assists with financial matters in determination of assets fate to ensure the financial viability of a business. The long-term business plans need to reflect the necessary capital expenditure to replace assets as their life cycle is expended.

**Planning Group**
Assesses plant criticality and the impact of its non availability on other plant in light of transmission development plans, ie.addition of new lines and substations and their significant alterations (eg. addition of new circuits, fault uprates, thermal uprates, etc.). Outage times required for this project work is also of importance, as during the work nonavailability of the plant has a significant impact on other plant.

**Operating Group**
Assesses importance of lines and circuits with related plant from an operational point of view, having knowledge of long-term outage
requirements requested by various internal and external users (expected to increase with open access to the transmission grid). Impacts of seasonal load and climate influences and generation inputs from other private sources through the grid are also reviewed.

Projects Group
The plant specialists for lines and substations are to provide expert advice in technical matters required at various stages of plant condition assessment. They provide an important link to plant manufacturers for their valuable input where needed.

Details of all current activities (eg. investigations needed, in progress, solution devised, being implemented, fully implemented, completed) are kept in a **Part 1- Asset Investigations** of a document called **Asset Management Portfolio**. An important component of all these activities is economical analysis to decide the final outcome, which can fall in two main groups:

1a) No additional work required on plant, but units will be removed to less important or demanding locations,

1b) No additional work required on plant, but there is a need to increase maintenance frequency and number of spare parts. An adjustment is made in the maintenance policy and maintenance work specifications to reflect this decision (see 2.1 above).

2a) Plant to remain in service, but subject to refurbishment on site or in workshop.

2b) Plant to be replaced over a period of time; possible use as a source of spare parts to enable a partial implementation of 1b).

The activities from second group are described below in more detail.
2.4 Refurbishments and Replacements

After completion of activities indicated above in the Part 1- Asset Investigations, the final outcome of the processes may be a definitive need to do something about the plant. The decision, which involved economic evaluation, may be continuation of further service after some type of rejuvenating action had been performed, or planned, staged removal from service over a period of time.

Details of all current activities (ie. ongoing refurbishments, uprates, modifications and replacement) are kept in a Part 2- Asset Current Projects of the Asset Management Portfolio.

Details of the recommended and approved future activities (ie. schedule for the activities listed above) are kept in a Part 3- Asset Planned Projects of the Asset Management Portfolio.

The long term (10-20 year horizon) asset replacement predictions will be identified and listed in a Part 4-Future Asset Projects of the Asset Management Portfolio.

We should bear in mind that even the final approvals are sometimes only tentative, as in the time between regular updates decisions made by all these groups can significantly alter basis on which the above recommendations have been made. It is also very important for all relevant groups to always assess the impact of their decisions on the Transmission Asset Management Plan, and to initiate the Plan review earlier than scheduled if warranted by these changes.

3.0 ASSET MANAGEMENT DATABASES

For all management activities to succeed it is paramount to have in place adequate databases for data recording and proper data acquisition procedures. The acquisition procedures ensure all relevant information is
collected in a timely and correct manner, and then properly entered in the databases. The databases can be divided in two main categories: plant data registers (Transmission Plant Management System- TPMS, Transmission Lines System - TLS and Transmission Ratings Information System- TRIS), and plant activities register (Facilities Maintenance Management System). The purpose and main features of these databases are briefly described below:

**TPMS** holds the following switchgear information - Specification and Order Details, Technical Details, Type and Unit Details, Maintenance Level Requirements, Current and Historical Locations, Defect Reports and Test Results.

**TLS** holds the following lines information - Specification, Order and Construction Details, Length and Number of Structures, Structure Details, Electrical Assembly Details (conductors and insulators), Maintenance Level Requirements and Test Results.

**TRIS** holds the following rating information about switchgear, substations, and lines-Thermal and Fault Currents, Overloading and Time Characteristics, Details of the Ancillary Components used to join Plant and Conductors (lines and cables) and Climatic Loading Curves.

**FMMS** holds the following information about substations, switchgear and lines maintenance - Location Details, Standard Type Nomination, Standard Maintenance Levels, Maintenance Activity Type, Frequency (trigger dates) and Cost (standard fees), Maintenance History, Outstanding Work Records, Cost of Maintenance Work and Work Schedules.

A set of procedures has been developed and implemented to ensure communication and reporting channels for data acquisition and recording between all relevant groups. They include: operational areas, construction and maintenance services, secondary systems service groups (protection,
communication, controls), test personnel, repair workshops, stores, regional staff and field inspectors.

4.0 RESULTS OF SOME PROGRAMMES

The results of two programmes are presented: one studied the performance of instrument transformers, and the other the performance of gap-type surge arresters. The rated voltage of all equipment is 66kV and above.

a) Instrument Transformers

Consider Fig. 1 showing fault performance of the instrument transformers for three consecutive periods (1985-1988, 1989-1992 and 1993-1996). After a high number of major failures in 1985-1988 period, an investigation was initiated to find the cause and remedy the situation. A few instrument types only were found to contribute to the high failure rate. After they had been identified, a programme was developed and implemented to test all units from these types on site. As the number of units in service was high, and gaining access is not always easy, this has taken some time to complete. All units found in unsatisfactory condition during the programme have been replaced, although sometimes it was difficult and time consuming to procure spare compatible units.

The rate of failure continued to deteriorate for the time the programmes have begun to show effects (see result for 1989-92 period). In the end, a total of over 70 units have been removed from service, and a significant drop in number of major failure has been achieved for the current period (1993-96). At the same time, population/age statistics have identified a large proportion (56%) of our instrument transformers with age over 20 years (Fig. 2), and a programme has been created to assess their condition
over the next three years. The aim is to assess their remaining service life and to prepare a long-term plan for their replacement.

b) Gap-Type Surge Arresters

Consider Fig. 3, showing fault performance of the gap-type surge arresters for three consecutive periods (1985-1988, 1989-1992 and 1993-1996). After a high number of major failures in the 1985-88 period, an investigation was initiated to find the cause and remedy the situation. Only two arrester types were found to contribute to the high failure rate. A test programme was developed and implemented to check all remaining units in service, which found a number of suspicious units. After consultation with the relevant manufacturers, all affected units have been progressively replaced, and a period of relative calm followed.

An increase in the number of failures in 1993 prompted further investigation, and resulted in findings that some units were the problem. But it also clearly identified the condition of aged gap-type units as a real problem that can be expected only to aggravate as time passes. The identified units have all been replaced, and detailed population/age statistics have been prepared. They indicate that a large proportion (72%) of our gap-type surge arresters are now over 20 years old (Fig. 4). A programme has been created to test their condition over the next three years. The aim is to assess their remaining service life and to prepare a long-term plan for their replacement.

5.0 CONCLUSIONS

In this paper we have outlined our experience in developing and implementing a comprehensive asset management model. Some elements of the model have been fully implemented, others are in the planning or
development stage. The main purpose and characteristics of involved
elements have been described, as well as the methods to ensure their proper
update and maintenance.

We have demonstrated the importance of having an asset life cycle plan, i.e.
inclusion of economical parameters, to ensure the financial viability of a
business. Fully operational, this model should put Western Power in a
strong position to properly manage its assets and achieve prevention of
problems derived from ageing, supply interruption, unexpected high
expenditure and premature asset replacement, resulting in substantial
economic benefits and increased system security and reliability.
4* MAINTENANCE STRATEGY & WHAT TO CONSIDER IN ACHIEVING THE BEST PRACTICE IN WESTERN POWER

INTRODUCTION

Western Power Corporation (WPC) is the principal electricity supplier to residential, commercial and industrial customers in Western Australia, serving more than 730,000 users across an area bigger than New South Wales, Victoria, South Australia and Tasmania combined. WPC is the trading name of the Electricity Corporation established under the Electricity Act 1994. The legislation that created the new electricity business is intended to reduce energy prices and encourage the development of competitive energy markets through a greater commercial emphasis in the operation of the utilities. WPC has responded to the challenge of the deregulated energy market by committing to an objective of achieving a 25% real reduction in average electricity prices by the year 2000.

The backbone of WPC's network, its transmission system, comprises 115 terminals and zone substations interconnected via 200 high voltage transmission lines with a total length over 6,500 km. The transmission system operates at rated voltages from 66 kV to 330 kV, with the peak (summer) load of 2,100 MW.

The main part of the above legislative change is the decision to open access to the transmission system for all users from 1 January 1997, enabling true conditions for the free electricity market. This decision will re-inforce the responsibilities of the Transmission Division, as it must embrace the spirit of micro-economic reforms and will be required to operate the transmission system as efficiently as possible. The manner in which it conducts its business will come under internal and external scrutiny, and will be judged by comparisons with industry benchmarks established on a national and an
international base. The transmission system maintenance costs represent a significant portion of Transmission Division's overall expenditure, and the proper planning and execution of its maintenance activities have a profound effect on reliability and security of the system as a whole.

This paper presents a brief outline of the maintenance strategy adopted for the transmission system and relevant activities and processes that have been initiated and implemented in order to achieve goals set in that strategy.

BACKGROUND

For a very long time, going back to the 1940's, the WPC's predecessors, the State Electricity Commission (SEC) and the State Energy Commission of Western Australia (SECWA), were primarily involved with project and construction activities in a desperate bid to satisfy ever growing electricity needs of the rapidly expanding WA economy.

The main characteristic of that period was attention to repairs and replacements after faults and failures, as the majority of the installed equipment was reasonably new.

With passage of time, it became necessary to pay more attention to some of the important equipment (transformers, circuit breakers), initially using manufacturers' instructions (which were quite rudimentary in those days). The need to seek a new approach was recognised, resulting in the creation of line and switchgear maintenance dedicated teams. In the 1980's, structural changes resulted different parts of the grid system being combined (subtransmission area, old transmission area and country areas) into a common transmission system. The maintenance responsibility was still left divided among individual regions and a central operations group, and they organised the maintenance work according their own requirements, schedules and knowledge.
In the early 1990's, the Transmission Branch was given overall responsibility for the maintenance of SECWA assets within the boundaries of its operations, described as: "The part of the SECWA system bounded by the HV terminals of the step up transformers at Power Stations and the supply side LV terminals of the step down transformer circuit breakers at zone substations, but included all step up transformers at the gas turbine sites."

The formation of the Transmission Division and the review of the transmission assets maintenance function in 1993 resulted in the recommendations for the Division to assume direct control, maintenance direction and auditing of all of its assets. That was also to include budgeting, work scheduling and organising, and monitoring and analysing of all the maintenance work. The review of the proposed maintenance objectives and corporate policies, assisted by internal, external and overseas consultants, recommended formation of a designated maintenance branch. This Transmission Maintenance Branch would undertake all the above activities, and ensure that the defined Corporate and Divisional objectives and targets were met.

MAINTENANCE STRATEGY

The maintenance work has been a requirement on individuals and organisations since physical assets have been built. Therefore, accepting that the transmission assets exist, the Divisional policy and Branch objectives with regard to the maintenance of the assets should be defined.

The Transmission Division Policy with regard to maintenance has been defined as follows:
1. Maintain facilities in such a condition to ensure the safety of employees, the public and the equipment.

2. Customer satisfaction will be of a major consideration in the preparation of the Transmission Maintenance Branch maintenance plans, i.e. reliable supply is to be a major goal.

3. Active involvement of all employees in the development of workplace maintenance plans and targets to ensure maximum input of corporate maintenance rank and file knowledge.

4. Maintain facilities in such a manner that the optimum economic life of all equipment will be achieved.

5. Strive for industry best practices.

6. Establish the true cost of maintenance for each business section, and actively and aggressively seek to improve each of its segments.

This strategy refers to the maintenance activities associated with the primary part of the transmission system, i.e. transmission lines and substation. It does not cover the secondary systems, e.g. protection, communication and supervisory control systems.

These secondary systems have similar maintenance strategies but their consideration is outside scope of this paper. Generally maintenance work is divided in two main categories:

1. **Preventive Maintenance**

This work is planned in detail and scheduled well in advance. It is subdivided into three groups:

- **Routine**- This is short duration work, involving visual inspections and minor replacements.

- **Service**- This is also short duration work, but involves more detailed
attention to equipment. A dismantling of some minor components can occur.

- **Overhaul**- This is generally long duration work, requiring significant in situ dismantling of equipment, and possible replacement of number of components.

2. **Corrective Maintenance**

   This type of work is generally unplanned, and requires immediate or reasonably quick response. It is subdivided into three groups:

   - **Emergency**- This work occurs with little or no warning and at a random incidence, requiring urgent attention because of system or safety implications. It is mainly in situ, but can develop to off site work.

   - **Deferred**- Same as above as it occurs, but does not require immediate action. It can be deferred until maintenance resources or system conditions allow for the repair work to proceed.

   - **Removal**- This is similar to deferred, but the equipment is removed from site as repair work is carried out off site.

The Transmission Maintenance Branch has specified that it's strategy will be to concentrate on the implementation of preventive maintenance in a bid to minimise corrective maintenance, and in this way best meet the company and division maintenance objectives. Performance measures have been established to monitor progress in this regard.

In order to be in a position to execute the above strategy, it is important to ensure that all equipment has preventive maintenance criteria developed and specified, and that the necessary procedures, instructions and work arrangements are well defined and documented. The common term and the best description for all these areas is maintenance standards. They are presented in more details in the following.
MAINTENANCE STANDARDS

A range of procedures and instructions have to be defined and documented in order to ensure that all installed equipment is properly maintained as per agreed maintenance provisions. They are generally known as maintenance standards. They are divided into in three generic areas:

1. **Maintenance Policy** - defines different levels of maintenance for generic equipment types (e.g. circuit breakers, batteries, lines, reactors, etc.), general work instructions for each level (area or parts to be targeted) and tests required prior/during/after work with broad pass/fail criteria for each required test.

   The levels usually include an inspection prior to expiry of warranty and two to three maintenance levels. They start from site inspection with basic checks, and finish with detailed site works, sometimes consisting of disassembly and survey of all major components. Each level has its own frequency, but they are supplemented as much as possible with condition triggers (e.g. a number of regular or fault operations, condition of oil and insulation, thermographic survey results, etc.). Their sequence is also specified, as generally the higher level always encompasses the lower one's work content.

   This policy is contained in a formal document called **Transmission Maintenance Policy Manual**.

2. **Maintenance Work Specifications** - are detailed, step-by-step servicing work instructions for every particular brand (type and model) of equipment. They also define skills required by maintenance staff, standard set of spare parts, necessary plant and tools, and reporting (e.g. check sheets) for each separate maintenance level.
They are formally issued as individual documents, but all linked to their summary called Transmission Maintenance Services Manual.

3. **Maintenance Procedures** - are formal ways of performing maintenance. This principally involves defining the roles of various groups involved in the maintenance activities (and there are many of them in big organisations such as WPC), regulating flow of information between them, ensuring mobilisation and repair in the event of an emergency, etc. These instructions are contained in a document called Transmission Maintenance Instructions Manual.

The contents of all the above Manuals and their policies are a combination of materials that originate from a number of sources, typically:

1. The manufacturers' detailed maintenance manuals and their recommendations.
2. Industry accepted practice and results, obtained through a long use and exchange of information on industry forums and bodies (e.g. ESAA).
3. Internal knowledge by our own extensive experience in maintaining the equipment.
4. Equipment performance updates made available through contacts and involvement with national and international organisations and their committees (e.g. CIGRE, IEC, SAA).

It is important to understand that the information contained in the above Manuals is not, once set, fixed and valid forever. There are mechanisms put in place which enable a constant flow of feedback information from all the users, and a regular review process on how to improve the maintenance process and adapt to a constantly changing workplace and external environment.
It must be emphasized that it is essential that all the above instructions and procedures are strictly adhered to while they are current, in order to achieve maximum benefits of the maintenance functions in the organisation.

ASSET MANAGEMENT

The asset management model that WPC's Transmission Division has decided to use is a much wider one than is general practice. We have defined asset management as a group of activities that cover regular (preventive) maintenance, repairs (corrective maintenance), condition monitoring and assessment, and refurbishment or timely replacement of assets, i.e. their whole life-cycle process.

An important issue here is proper distinction between capital and operating costs, as their incorrect use can greatly influence the total picture of maintenance costs.

The lines and substations consist of various components, each with different expected life duration. It is necessary to adjust accounting procedures to reflect that fact, and put in place proper depreciation procedures, which in turn will ensure correct operating vs capital outlay budgeting.

There are many contributors to this process, and their dependencies and responsibilities are described in a document called Manual of Asset Procedures. All activities in the process are supported by a number of databases that are outlined, with the main contributors, in more details further in the paper.

All information generated from these activities is collated and form a document called Transmission Asset Management Plan. The plan is updated annually, or more often if there is a significant change in any of the relevant areas.
THE MAIN CONTRIBUTORS

1. Asset Management Group monitors performance and ageing of equipment, analyses faults and population statistics, and initiates repair-replacement programmes. It also has overall co-ordination of asset management related activities in the organisation.

2. Finance Group assists in financial matters, particularly with regard to financial viability of the business by ensuring that the long term business plans reflect the necessary capital and operational outlays as the life of the equipment is expended.

3. Planning Group reviews assessed remaining life of the equipment against the transmission development plans, i.e. to check if they are to be replaced or upgraded as a part of system alterations due to increase in fault levels, load levels or new customer connections.

4. Operations Group assesses importance and criticality of the relevant equipment, and gives it a priority status.

5. Projects Group provides expert advice in technical matters, and also estimates costs for each particular asset project.

THE ASSET DATABASES

For all asset management activities to succeed it is essential that proper databases and acquisition procedures for collection of all relevant information are established. The databases are divided in two categories, equipment data registers and equipment activities registers:

1. The equipment data registers are Transmission Plant Management System (TPMS), Transmission Lines Management System (TLMS) and Transmission Ratings Information System (TRIS). They hold a range of equipment technical and contract information such as type and unit details,
specification and order details, maintenance level requirements, current and historical locations, defect reports, climatic loading curves, thermal and fault ratings, overload capabilities, structure details, electrical assembly details and test results.

2. The equipment activities registers are Facilities Maintenance Management System (FMMS) and Transmission Protection Equipment System (TPES). They hold equipment location details, maintenance activity type details, frequency and cost, maintenance work history, outstanding work and work schedules.

BENCHMARKING

Benchmarking is an important tool, which is used as part of the process to improve the efficiency and effectiveness of the maintenance operations. The benchmarking programme can assess the relative functional performance (productivity vs service level) of each utility based on actual demonstrated results and identify the practices and strategies, which have made successful utilities "best performers".

WPC have participated in a number of consultant facilitated studies which benchmark core functions with a number of similar utilities in Australia and overseas countries, typically New Zealand, Europe and America. Maintenance activities for transmission substations and power lines have been benchmarked. In some areas best practice was achieved, in others WPC was able to gain valuable information on how performance of some core functions can be improved.

Considerable effort is made to ensure the "level playing field" throughout the study when comparing performance. Great care is taken to minimise the impact of currency exchange rates, variation in the application of corporate
overheads, operating environment, etc, and to achieve a consistent approach to the assessment of service levels.

An example of subfunctional areas benchmarked in a 1995 study on substation maintenance is listed below:

- Distribution Breaker Maintenance
- Substation Field Operations
- Transmission Breaker Maintenance
- Switch Maintenance
- Transformer Maintenance
- Battery Maintenance
- OLTC/Regulator Maintenance
- Reactive Equipment Maintenance
- Distribution Relay Maintenance
- Non-Electric Plant Maintenance
- Transmission Relay Maintenance
- Other Substation Maintenance
- SCADA/RTU Maintenance
- Protection/Control System Uprate
- Substation Relay Maintenance

Some of the results of the benchmarking study are presented in detail then summarised in an interesting presentation, an example shown below for some subfunctions. A summary of best performance practices was found to be:

- **Maintenance Strategy**: Integrated system approach versus traditional task based maintenance which evaluates total cost of ownership and risk exposure of policy decisions.
• **Asset Strategy:** Life-cycle cost impacts of refurbishment, replacement and maintenance costs of alternative equipment configurations are formally analysed, supporting technical evaluations in design making.

• **Planning and Scheduling:** Integrated system maintainers leverage maintenance opportunities by co-ordinating multi-discipline teams to complete required activities with minimum site/outage time.

• **Resource Strategy:** Multi-skill work teams developed to support the integrated system approach offer productivity enhancement and cost containment opportunities.

**CONCLUSIONS**

In this paper we have presented the scope, standards and characteristics of maintenance activities developed and implemented for the primary plant of Western Power Corporation's transmission system. They should ensure that, in the arena of open access to the system, its assets are properly maintained and their condition monitored, thus achieving prevention of major problems and control in planned asset replacements. This in turn should lead to containment of ageing problems, minimising supply interruptions and avoiding uneconomic asset usage, resulting in substantial economic benefits and increased system security and reliability, commensurate with achieving world best maintenance practices.
WPC is the trading name of the Electricity Corporation established under the Electricity Act 1994. The legislation that created the new electricity business is intended to reduce energy prices and encourage the development of competitive energy markets through a greater commercial emphasis in the operation of the utilities.

WPC has responded to the challenge of the deregulated energy market by committing to an objective of achieving a 25% real reduction in average electricity prices by the year 2000. The backbone of WPC’s network, its transmission system, comprises 115 terminals and zone substations interconnected via 200 high voltage transmission lines with a total length over 6,500 km. The transmission system operates at rated voltages from 66 kV to 330 kV, with the peak (summer) load of 2,100MW.

The main part of the above legislative change is the decision to open access to the transmission system for all users from 1 January 1997, enabling true conditions for the free electricity market and requiring the transmission system to operate as efficiently as possible.

The transmission system maintenance costs represent a significant portion of overall expenditure, and the proper planning and execution of maintenance activities have a profound effect on reliability and security of the system as a whole.

This presentation will give a brief outline of the maintenance strategy adopted for the transmission system and relevant activities and processes that have been initiated and implemented in order to achieve goals set in that strategy.
MAINTENANCE STRATEGY

1. Maintain facilities in such a condition to ensure the safety of employees, the public and the equipment;
2. Customer satisfaction will be of a major consideration in the preparation of the maintenance plans, ie reliable supply is to be a major goal;
3. Active involvement of all employees in the development of maintenance plans and targets to ensure maximum input of corporate maintenance rank and file knowledge;
4. Maintain facilities in such manner that the optimum economic life of all equipment will be achieved;
5. Strive for industry best practices;
6. Establish the true cost of maintenance for each business section, and actively and aggressively seek to improve each of its segments.

In order to be in a position to execute the above strategy it is important to ensure that all equipment has preventive maintenance criteria developed and specified, and that the necessary procedures, instructions and work arrangements are well defined and documented, and to have in place adequate, easy to use databases and proper data acquisition procedures. The acquisition procedures ensure that all relevant information is collected in a timely and correct manner, and then correctly entered in the databases. A set of procedures has been developed and implemented to ensure communication and reporting channels for data acquisition and recording between all relevant branches. They include operational areas, construction and maintenance services, secondary systems service groups, test personnel, repair workshops, stores, regional staff and field inspectors.
Databases currently in use in Transmission division can be split into two types:

- Plant registers (TPMS, TLS, TRIS)
- Plant activities register (FMMS)

**MAINTENANCE STANDARDS**

A range of procedures and instructions have to be defined and documented in order to ensure that all installed equipment is properly maintained as per agreed maintenance provisions.

They are generally known as maintenance standards. They are divided into in three generic areas:

- **Maintenance Policy**
- **Maintenance Work Specifications**
- **Maintenance Procedures**

The contents of all the above Manuals and their policies are a combination of materials that originate from a number of sources, typically:

1. The manufacturers’ detailed maintenance manuals and their recommendations;
2. Industry accepted practice and results, obtained through a long use and exchange of information on industry forums and bodies (eg ESAA);
3. Internal knowledge by our own extensive experience in maintaining the equipment;
4. Equipment performance updates made available through contacts and involvement with national and international organisations and their committees (eg CIGRE, IEC, SAA).
Asset management is a group of activities that cover regular (preventive) maintenance, repairs (corrective maintenance), condition monitoring and assessment, and refurbishment or timely replacement of assets, i.e., their whole life-cycle process.

A  Asset Management Procedures Manual

   A1  Asset Management Responsibilities
   A2  Asset Management Databases
   A3  Asset Management Decision Process

B  Asset Management Portfolio

   Part 1 - Assets Under Review- Plant Directory - This represents a complete list of all our primary assets showing our transmission network consisting of primary equipment and transmission lines.

   - Plant Under Review - This consists of a review of plant in the above directory. All available information that is relevant to the plant in question has resulted in a list of plant to be considered for inclusion in asset management plan and for further investigation. The items chosen to be reviewed first have been initially assessed as the ones representing items of maximum age, items with a large number of units removed from service, items with the highest number of faults or overall maintenance incidents or costs.

   - Sundries - It contains minutes of meetings of various groups involved in this work, the relevant correspondence, and other working items.
Part 2 - Asset Future Projects - 0-5 years - Plant to be considered for action within the next five years, with the recommended type of action and timing.

- 6-10 years - Plant to be considered for action in 6-10 years, with the recommended type of action and timing.

- over 10 years - Plant to be considered for action after 10 years, with the recommended type of action and timing.

Part 3 - Asset Investigations - Before or during assessment of certain items of plant under review it is necessary to obtain additional information about the plant. This also includes number of tests and measurements, and various trials and joint research projects with other authorities, companies, universities and manufacturers.

An important component of all these activities is an economic analysis to decide the final outcome, which can fall in two main groups:

1a) No additional work required on plant, but units are to be reallocated to less important or demanding locations.

1b) No additional work required on plant, but it will be necessary to vary maintenance frequency or maintenance service instructions to reflect these requirements (eg. different servicing frequencies, changed scope of work during service, etc.).

2a) Plant is to remain in service, but it will be subject to refurbishment or modification on site or in a workshop.

2b) Plant is to be replaced over a period of time; possible use as a source of spare parts to help with activities in 1b).

Part 4 - Update of Manuals - Policy Manual or Services Manual

- As a result of plant investigations and reviews it is possible that some outcomes would not point to the need to perform a refurbishment, modification or replacement of the plant. The identified problems could
sometimes be better addressed by altering the plant maintenance policy or service instructions (see 1b) above).

Part 5 - Asset Planned Projects - Where details of the recommended and approved future activities arising from business case analysis, raised from the list of recommended activities listed in Part 2 - Asset Future Projects above are retained.

Part 6 - Asset Current Projects - Where details of all current ongoing activities in the areas of Repairs, Refurbishments and Replacements are retained.

Part 7 - Asset Completed Projects - Where details of completed activities are retained.

C Asset Management Other Information

This area contains various information gathered from other authorities and National and International organisations and publications on asset management strategies and policies.
A power utility system (lines, substations, feeders) consists of many different assets, some of them very expensive (eg major terminal transformer units are worth around $4.5 M). For example, Western Power Corporation (WPC) Transmission System consists of 115 terminals and zone substations, comprising approximately 13,000 individual items of plant, interconnected with high voltage transmission lines in excess of 200 in number and with a total length of 6,500 km. The transmission system operates at rated voltages from 66 to 330 kV, with the peak (summer) load of 2,350 MW. All the above items have a finite life expectancy. Their condition normally deteriorates with age, use and operation, and it is reasonable to expect they will fail in service at a certain point in time.

There are number of issues associated with the actual failure incident(s). The impacts of such failure could be quite serious, ranging from major loss of supply and prolonged restoration period, loss of revenue, customer losses, endangering of public and employees safety, serious environmental aspects and possible litigation consequences, to significant unplanned operating and capital expenditures.

Additionally, the now deregulated energy market and the spirit of micro-economic reform place increased pressure on WPC to operate the electricity system as efficiently and economically as possible. The manner in which it conducts its business in the open access environment will come under industry and government scrutiny, and will be judged by comparisons with industry benchmarks established on the performance of national and international utilities.
Asset management represents a comprehensive approach to dealing with all the above issues. This process is a dynamic one, ie it must be repeated regularly to ensure all changes in other development plans are promptly accounted for. The long-term view (10-20-year horizon) and dynamism of the process are the main characteristics of properly implemented and run asset management process.

This paper discusses the reasons for the development and experience obtained with implementation of an in-house asset management system and the impacts on future activities.

II. ASSET MANAGEMENT MODEL

The asset management model adopted by Western Power defines asset management as a set of grouped activities that cover maintenance and repair, condition and criticality assessment, refurbishment and timely replacement of the assets.

A. Maintenance

Maintenance is an organised process to make sure all installed equipment is properly inspected, checked, tested and adjusted as per the agreed maintenance provisions. It is formed of three main areas, namely maintenance policy, maintenance work specifications and maintenance procedures.

1) Maintenance Policy: This defines different levels of maintenance including plant inspection prior to warranty expiration, the frequency and sequence or condition trigger, and general work instructions for each level with broad pass/fail criteria for any required tests. It is derived from a combination of manufacturers' given recommendations, the utility's internal experience, industry-accepted practice and special updates on
equipment performance obtained through contacts and involvement with national and international bodies (eg CIGRE, IEC). This policy is specified within the **Maintenance Policy Manual**.

2) **Maintenance Work Specifications**: These are detailed, hands-on, step-by-step servicing instructions. They originate from manufacturers’ detailed maintenance manuals, supplemented by extensive in-house experience in maintaining the equipment. They are usually pertinent to the particular type/model of equipment, and they prescribe skill levels for maintenance staff, the necessary tools and plant to use, and the required standard set of spare parts. The work specifications are defined within the **Maintenance Services Manual**.

3) **Maintenance Procedures**: These are written instructions that define how to handle a diversity of maintenance work (eg substation and line maintenance, emergency breakdowns, handling of faults and initiation of work requests, obtaining replacements for failed plant, etc). The procedures are defined within the **Maintenance Instructions Manual**.

**B. Asset Management Plan**

An Asset Management Plan is the end result of the involvement of number of branches in the asset management processes. It aims to assess plant condition and estimate its remaining useful and safe operational life in order to define any actions required on plant, based on the importance it presents to the operation and planned enhancement of the system.

The outcome of these activities can fall in two main groups:

a) No additional work is required on plant, and it will be removed to a less important or demanding location, or its maintenance frequency or scope of work will be changed.

b) Plant requires some action, where plant will remain in service, but undergo work on site or in the workshop, or it is to be replaced over a
period of time. Some units may be used as a source of spare parts to back
up units in service during implementation of the replacement project.
The Plan is updated annually, or more often if there are significant changes
in any of the relevant areas.
The above processes, with links, dependencies and responsibilities of the
branches involved are defined in the Manual of Asset Management
Procedures. A brief description of the branches involved is given below.

1) Maintenance Branch: This group monitors performance and ageing of
plant, analyses faults and population statistics, initiates programmes to
check and assess condition of plant based on generic type faults and the
results of the plant statistics, with the objective to determine plant
remaining service life. This group is also responsible to analyse feedback
from regular preventive maintenance programmes (eg incurred cost trends,
usage of rotational spares, amount of additional work performed, comments
on check sheets). The group maintains close contacts with similar groups in
other utilities, and is encouraged to participate in relevant industry
organisations, activities and forums.
This group is also given overall coordination for all asset management
related activities other groups perform to support this process.

2) Finance Branch: It assists with financial matters in determination of the
assets fate to ensure the financial viability of a business. The long-term
business plans need to reflect capital and operating expenditures to repair or
replace assets as their life cycle is expended.

3) Planning Branch: It co-ordinates transmission development plans and
obtains capital project approvals.

4) System Operations Branch: It determines the importance of critical lines
and circuits from an operational point of view that enables proper planning
of plant work based on system reliability and open access obligations.
They also assess system long-term outage requirements, based on requests by internal and external users (expected to increase under open access regime), to determine optimum timing for plant replacement.

5) Projects Branch: It provides specialist technical advice and project cost estimates required at various stages of plant condition assessment. They are the link to plant manufacturers for their input where needed. They also run the replacement/refurbishment projects after approval is granted.

III. REFURBISHMENTS AND REPLACEMENTS

After completion of activities indicated above there may be a specific need to do something about the plant. The decision, which involves operational, safety, environmental and economic evaluation of the plant, may be to continue its further service after some type of rejuvenating action has been performed, or to plan staged removal of plant from service over a period of time. Details of proposed activities and their background must be presented in an open way, so that the work and consequences are transparent to all users of the system under open access rules.

- Current activities are listed as Asset Current Projects. (ie ongoing refurbishment, uprate, modification and replacement works).
- Details of the approved future activities are kept as Asset Planned Projects (ie scope of work, timing, risk assessment).
- The long-term (10-20 year horizon) requirements for asset works are identified and listed as Future Asset Projects (ie asset condition, critical impact analysis, end of economical life prediction, proposed action and its timing). It should be borne in mind that even the final approvals to proceed with the work are only tentative. As time passes and work progresses, various decisions are made by the above groups and other users of the system (current and potential) that can alter the basis on which the above
recommendations had been made, prompting changes to the asset management plan.

It is therefore important that all relevant groups are aware of the asset management plan details, and that they assess the impact of their decisions on the plan. They need to initiate review of the plan earlier than any scheduled annual update cycle if warranted by these decisions.

IV. RISK MANAGEMENT AND INSURANCE CONSEQUENCES

The above structured approach to the monitoring of plant performance, continuous assessment of its condition, and preparation of dynamic action plan to address any found problems, presents an excellent basis for appropriate Risk Management of the company’s business.

Risk Management is recognised as an integral part of good management practice. It enables WPC to minimise losses and maximise opportunities for improvements. Where risks cannot be minimised or eliminated, at least not in the short term, they will be covered by appropriate insurance policies to safeguard the Corporation’s financial viability.

The benefits of having a comprehensive Asset Management Plan in terms of risk management are a reduction of incidents, high standards of accountability, reduction of insurance premiums and a reduction of the potential risks of liabilities for WPC.

V. ASSET INFORMATION ACQUISITION

In order that all the above asset management activities and processes succeed, it is paramount to define required datasets and to implement adequate procedures for their acquisition. The acquisition procedures
ensure all defined relevant information is collected in a timely and correct manner, and then properly entered in the databases.

A number of procedures have been developed and implemented to ensure that communication and reporting channels for data acquisition and recording between all relevant groups takes place. They include: operational areas, construction/maintenance services, systems service groups, test personnel, repair workshops, stores, regional staff and field inspectors.

VI. RESULTS OF SOME PROGRAMMES

A. Change of Maintenance Policy
A 66 kV bulk oil type circuit breaker maintenance procedure was found to be very expensive and of long duration, and an investigation was initiated. It was found that the actual work could be changed to three different levels, instead of the only one currently used, as not all the work was needed every time. After detailed analysis of various work and cost options, it was recommended to change its maintenance policy by initially performing only the lowest level of maintenance every four years or after a prescribed number of fault operations. This includes contact resistance measurements and oil quality tests. The test results are then used to determine if the new level two (on-site oil filtering) or level three (on-site oil change and contacts servicing) is required. The necessary changes were also made in its maintenance service manual.

B. Change of Maintenance Service Level
A number of 132 kV circuit breaker units were reported with badly corroded pull rods and coupling pieces during their regular maintenance. A couple of units were fully dismantled and a careful examination of all parts
was arranged. Based on the result of inspections and information obtained from the manufacturer it appeared that corrosion was completely random and not related to any particular batch. The parts in question were supposed to be designed for outdoor use without experiencing corrosion.

After reviewing all available data a decision was made that the most economical and practical solution was to change maintenance service level. All affected units are now subject to changed working instructions during their servicing. They include a mandatory dismantling of rods and coupling pieces, and inspection of their condition during every level 'B' type maintenance work. The parts are brushed, cleaned with a solvent and greased with a special resin based corrosion preventive compound for outdoor use. In the event any pull rod is corroded too badly, the rods on all three phases must be replaced as design of the pull rods has been slightly modified compared to the old design. The manufacturer has agreed to supply necessary number of new parts to replace all rods and coupling pieces corroded beyond repair free of charge.

C. Refurbishment Project

After several explosive failures of this a 22 kV circuit breaker type, an investigation was initiated that revealed a generic design problem (main gaskets insulation deterioration). This in turn lead to leaking of the internal insulating compound and ingress of moisture, causing internal flashover and failure. The problem of finding a solution to prevent this problem was exacerbated by a presence of PCBs in the insulating compound dating back to its original filling time. An innovative removal and repair procedure has been developed and implemented, with the manufacturer’s input. It was assessed that was a better option than to replace the affected units.

It was recommended to replace all poles on the affected circuit breakers with refurbished poles during normal maintenance work, and to send them
back for further refurbishment to be used on the next site. A special working area was set up in the workshop. A few spare pole sets were found in the store, and refurbished to enable this work to be completed on circuit breakers in service.

D. Replacement Proposal

A number of gas insulated circuit breakers of particular type have been identified with constantly leaking gas, causing repeated loss of gas alarms and requiring frequent re-gas of the units on site. It posed a threat to electricity supplies and to system security. Also, the release of a free SF6 gas in the atmosphere is not environmentally acceptable, as it has a very high Greenhouse Warming Potential. Additional maintenance costs for SF6 gas and maintenance crews attending the faults have been assessed.

The manufacturer has abandoned this circuit breaker model, therefore spare parts would be very difficult to obtain. This would result in long waiting periods and very high costs to manufacture them on an individual basis. Adjacent equipment is at risk as the units may operate under fault conditions with insufficient gas pressure within the unit to guarantee its 100% safe operation.

Any loss of these circuits would mean complete loss of supply to sensitive load areas, and in most instances for a protracted period, depending on the ability of the system to temporarily feed customers from alternate sources. There would be a significant production time lost in mine site operations, and disruption of supply to any townships affected. Loss of associated circuits would also have had a significant effect on the Western Power business, as it would mean significant loss of revenue. The replacement and repair of equipment under emergency conditions would be very costly, particularly if other adjacent plant had been damaged. Western Power’s
relationship with its customers would suffer, which is very important in the open access and increased competition environment.

A serious attempt was made to resolve these problems through repair or redesign through a number of initiatives and investigations, involving the manufacturer and WPC staff. Five leaking units were completely dismantled and resealed with new gaskets, but the leaks repeatedly re-occurred on three units within a short period of time. This method was therefore abandoned due to high costs, difficult access to units and low rate of success. It was considered that the costs and risk of further failure were too high to continue this programme and they needed speedy replacement.

A detailed economic evaluation of their replacement costs vs repair/maintenance costs (life cycle cost analyses) shows favourable returns for WPC. It was therefore recommended that the circuit breakers in question should be replaced.

VII. CONCLUSIONS

This paper has outlined our experience in developing and implementing a comprehensive asset management model to support our business in the deregulated electricity market. The main purpose and characteristics of asset management model components have been described, as well as the processes to ensure proper update and maintenance of the Asset Management Plan.

A few examples were presented to indicate how problematic plant is identified, assessed, appropriate action taken based on available data, and major problems avoided by dealing with the problem in a proper and timely manner.

This model should enable Western Power to properly manage its assets and achieve the prevention of problems derived from ageing, supply
interruptions, unexpected high operating and capital expenditures and premature asset replacements. It will also have a significant impact on the corporate risk reduction.

The importance of having a life cycle plan for electricity system assets has been shown. It will ensure the security and reliability of the system and the long-term financial viability of the company. It will also benefit all internal and external users in the open access environment, resulting in realistic and transparent open access charges, bringing long-term economic benefits to all parties.
1.0 INTRODUCTION

A transmission system is made up of a very large number of individual and very different assets. With their condition deteriorating with age and operational use, it is reasonable to expect their failure in service at a certain point in time. The impacts of such a failure could be quite serious, depending on their type, location, size and cost. A supply authority is faced with a range of outcomes, which may be major loss of supply and prolonged restoration period and endangered public and employees’ safety. Serious environmental aspects and liability issues, and significant unplanned operating and capital budget costs could also occur. Therefore it is considered important to implement a formal system to continually assess asset condition, and present and review an action plan to deal with those assets under review, based on their total life-cycle cost. This is not a simple task, and requires detailed information before any decision can be made. Such information includes asset condition and residual life, planning criteria, operational circumstances, expected load and fault level growth, potential liability risks, increased maintenance, etc. This paper discusses how Western Power Corporation is dealing with the above issues using in-house developed and implemented asset management procedures.

2.0 ASSET MANAGEMENT MODEL

The asset management model adopted by Western Power defines asset management as a set of grouped activities that cover maintenance and
repair, condition and criticality assessment, refurbishment and timely replacement of the assets. A flow chart of the Asset Management Model is presented in Fig.1.

2.1 Maintenance

Maintenance is an organised process to make sure all installed equipment is properly inspected, checked, tested and adjusted as per agreed maintenance criteria. It is formed of three main parts that are; maintenance policy, maintenance work specifications and maintenance work procedures.

The maintenance policy defines the different levels of maintenance criteria and general scope of work with broad pass/fail criteria for any required tests. The maintenance work specifications are detailed plant servicing instructions for the particular type and model of equipment. The maintenance work procedures define how to perform a variety of maintenance functions.

Working groups are made up of a cross-section of maintenance, design and asset management staff who develop and update the above documents.

2.2 Condition and Criticality Assessment

Asset management staff monitor the performance and ageing of plant by analysing population fault and maintenance statistics. The results are then used to initiate testing programmes to check and assess the condition of suspect plant and to determine the remaining service life.

This data gathering and analysis also uses feedback information from regular preventive maintenance actions (eg incurred cost trends, spare parts consumption, additional work performed, comments on check sheets, etc) together with information from other groups, eg Finance, Planning, Operating and Project areas.

The whole process is presented in the flow chart shown in Fig 1, with details of the processes and the dependencies of departmental links and responsibilities defined in the Manual of Asset Procedures.
After reviewing the information obtained throughout the above processes, the final outcome of the assessment study can fall into one of two groups:

2.2.1 No additional work is required on plant, but there is a need to adjust information in one of the three maintenance manuals (on maintenance policy, maintenance work specifications and maintenance work procedures) to reflect this decision,

2.2.2 Plant will require certain actions, ie continue service after being subjected to repair or refurbishment to remedy the cause of the problem, or to be replaced over a period of time.

2.3 Asset Management Plan

All information generated from the asset management process is collated and issued in a document called the Asset Management Plan. The Plan contains details of all current activities (ie policy document updates and ongoing refurbishments, uprates, modifications and replacements) and of the approved future activities.

It also shows an expected long-term (10-20 years) strategy for any actions needed (ie predicted replacement and repairs). The Plan is updated annually, or more often if required as indicated by any significant changes in the relevant areas. Therefore it is very important for all relevant groups to assess the impact of their plans and decisions on the Transmission Asset Management Plan, and to initiate its review and change earlier than scheduled if warranted.

The Asset Management Plan also presents an excellent base for appropriate risk management studies. Risk Management is recognised as an integral part of the Company’s business management.
3.0 ASSET MANAGEMENT DATABASES

All asset management activities need to be adequately recorded on suitable databases to enable correct analysis of plant performance. Data acquisition procedures are set to ensure that all relevant information is collected in a timely manner, and then correctly entered into the relevant databases. The databases are divided in two categories; plant data registers and plant activity registers.

A number of procedures have been developed and implemented to ensure that adequate communication, reporting and recording of data is achieved among all relevant groups. These groups include operational areas, construction and maintenance services, secondary systems services, test personnel, repair workshops, stores, regional staff and field inspectors.

4.0 ASSET MANAGEMENT ASSESSMENT STUDY

There are number of issues that need to be considered before a proposal is presented for any action required of a particular item of plant. They are listed below with relevant comments on their priority, associated weighting factors, risk evaluation, and cost implication (life cycle cost assessment):

4.1 Age
The age of the units is taken in account, and is given a low-weighting factor. The risk factor is calculated from the current age against the total expected life of plant.

4.2 Frequency of Failures
The frequency of failures is given a high-weighting factor as it influences network performance, increases maintenance costs, causes loss
of supply and revenue, and reflects badly on customer satisfaction. The risk factor is based on the number of failures per unit per year.

4.3 Condition
The condition of units can be a significant factor, which leads to failures and uncertainty of future performance, and is given a medium-weighting factor. The risk factor is based on the amount of additional maintenance work required in excess of regular preventive maintenance for a particular plant model.

4.4 Environmental/Regulatory Requirements
Normally plant is sufficiently well designed to avoid any significant impact on the environment, so the weighting factor is rated as medium. The risk factor is based on the effects of any possible release of gas in the atmosphere or oil in the ground.

There is a special constraint to be considered where the risk factor of 5 is assigned, i.e., an immediate action plan is required. The reason might be associated with new obligatory legislation, or plant that is situated on environmentally sensitive areas (e.g., underground water catchment), etc.

4.5 Maintenance Costs
The maintenance costs are a significant portion of the company's operating expenditure. These costs are then compared against the costs to repair, refurbish or replace the plant under consideration. Appropriate life cycle cost evaluation is then undertaken to find the most economical solution. They are given a medium-weighting factor. The risk factor is based on the total maintenance costs over the cost for new equipment of the same characteristics.

4.6 Replacement Costs
A proposal may be to replace the defective units with a new model that requires very little attention. It this then weighted against the repair or refurbishment options through an economic analysis of the remaining in
service life, and is given a medium-weighting factor. The risk factor assigned is based on the ratio of new against existing costs.

4.7 Spare Parts Availability
This issue is very important, as a number of manufacturers have ceased to exist or have abandoned making the particular model or spare components. In the case of a major fault occurring, spare parts could be very difficult to obtain, which would result in long waiting periods or very high costs to manufacture the parts on an individual basis. Therefore a high-weighting factor is assigned. The risk factor is determined from the number of main parts currently available, their costs and delivery periods.

There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required. The reasons may be that no spare parts could be obtained from any source, or their delivery periods and costs are considered extreme.

4.8 Competency of Employees
The skills to repair or completely refurbish the affected unit within Western Power are assessed, and this could significantly influence any final decision. A medium-weighting factor is assigned. The risk factor is determined from available skills analysis.

There is a special constraint to be considered where the risk of 5 factor is assigned, coincident with the risk factor assigned in 4.9, ie an immediate action plan is required. The reasons may be that no skills exist to attend the affected plant, or a location where extreme repair periods and costs would be incurred.

4.9 Availability/Cost of Refurbishment Services
The skills to repair or completely refurbish the affected unit external to Western Power are also assessed, and influence any final decision. This is given a medium-weighting factor. The risk factor is determined using a combination of factors described previously.
There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required. The reasons may be that no skills exist to attend the affected plant, or a location where extreme repair periods and costs would be incurred. The decision on risks for both areas 4.8 and 4.9 may be a combination of factors listed below:

a) Difficulty in obtaining spare parts,
b) Remote locations of the units in question,
c) Difficulty in arranging longer access to these units (eg feeders supplying mining sites),
d) Low success rate on previously trialed refurbishments and modifications,
e) High cost of the rework required.

4.10 Safety of Employees

The units in question may also pose a risk for the crew that performs work on adjacent circuits, as the unit may operate under fault conditions with insufficient security to guarantee its safe operation. Therefore this is given a high-weighting factor. The risk assessment is based on the probability that maloperation or failure could lead to incidents.

There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required.

4.11 Safety of Public

Equipment maloperation may present a direct risk to the public. That is a direct risk in the form of flying debris or exposed live conductors. It may not always be possible on occasions to mobilise a crew to site in sufficient time to quickly restore customer supply, leading to hazards occurring in the general public domain. Therefore this is given a high-weighting factor. The risk is assigned on the probability of an incident occurring, its possible duration, and the size and type of location that could be affected by the plant failure.
There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required.

4.12 Safety of Adjacent Equipment
There is a real risk associated with suspected units having to operate under fault conditions, as any adjacent equipment could be damaged by flying debris, further exacerbating the consequences of failure, and could cause a further release of any contaminated particles into the atmosphere. This is given a medium-weighting factor. The risk is assigned on the probability of an incident occurring, its possible duration, and the size and type of location that could be affected by the plant failure.

There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required.

4.13 Obsolete Design Standards
Sometimes units are considered to be of obsolete design, with inherent design imperfections, poor tolerances, etc, causing failures (eg jamming of operating mechanisms), but generally perform their duties as required. This instance is given a low-weighting factor. The risk is assigned on the probability of an incident occurring, its possible duration, and the size and type of location that could be affected by the plant failure.

4.14 Impact on Quality of Supply
Any loss of supply from affected circuits has consequences on quality of supply. It could cause complete loss of supply for a protracted period, depending on the ability of the system to temporarily feed customers from alternate sources. This is given a high-weighting factor. The risk is assigned on the probability of an incident occurring, its possible duration, and the size and type of location that could be affected by the plant failure.

There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required.
4.15 Impact on Customer

Any loss of supply could lead to a long and very disruptive loss of supply, sometimes to sensitive load areas. There could be significant production time lost in mine site operations, disruption of supply to general public, etc. This is given a high-weighting factor. The risk is assigned on the probability of an incident occurring, its possible duration, and type and size of customer(s) that could be affected by the plant failure. There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required.

4.16 Impact on Western Power

Any loss of supply could have a significant effect on the Western Power business as listed below:

a) Loss of supply over a significant period of time would mean significant loss of revenue,
b) Replacement and repair of equipment under emergency situations would be very costly, particularly if other adjacent plant has been damaged,
c) Western Power relationship with customers would suffer, which is a very important consideration in the environment of open access and increased competition,

This is given a high-weighting factor. The risk is assigned on probability of an incident occurring, its possible duration, cost to restore to the original condition, and the amount of revenue that could be lost by the plant failure. There is a special constraint to be considered where the risk factor of 5 is assigned, ie an immediate action plan is required.

4.17 Ability to Manage the Replacement Process

The Company’s ability to manage the replacement process by adequate equipment condition assessment and the long term planning to replace
equipment that is under risk, rather than be failure driven with all the associated consequences is important.

This is undertaken by suitable equipment condition and risk assessment processes, the selection of an adequate course of action to deal with the risks, implementing operational arrangements to ensure secure supply and the safety of operational staff, and the timely ordering of replacement equipment.

It is also prudent business sense that action is taken to limit the potential risks, and realise any possible savings in long term operating costs by arranging suitable plant replacement programmes.

5.0 REFURBISHMENT PROJECT

An example of the application of the process discussed above follows, using a combination of weight and risk factor analysis.

After several explosive failures of a 22 kV circuit breaker type, an investigation was initiated that revealed a generic design problem (main gasket insulation deterioration). This in turn lead to leaking of the internal insulating compound and ingress of moisture, causing internal flashover and failure. The problem was to find a solution to prevent this problem.

A full assessment study has been undertaken using this process where all aspects of the case were reviewed, as per the above clauses 4.1 to 4.17.

An innovative removal and repair procedure has been developed and implemented with the manufacturer’s input, enabling the company to use local skills and parts in an economical way.

It was then recommended to change all poles on the affected circuit breakers during normal maintenance work with poles previously refurbished in the workshop. This solution was particularly cost effective,
compared to the replacement of all units with new equipment, as there were spare poles for refurbishment in abundance from other failed units.

This has also represented a permanent fix for the duration of the remaining life of the units in question, as they have already passed more than a half of their expected service life.

6.0 CONCLUSIONS

In this paper we have outlined our experiences in developing an in-house asset management model, to enable proper and cost effective long-term management of our transmission equipment.

The purpose and characteristics of the main elements of one part of the model have been described (asset management strategies), as well as the need and methods employed to ensure proper information acquisition is undertaken to support the process.

The importance of including life-cycle costs to determine the long-term asset management plan has been emphasized. This will achieve the continuous security and reliability of the system and the financial viability of the business, while addressing defective plant in an orderly fashion.

Such a structured approach to the monitoring of plant performance and planning of any remedial actions presents a sound basis for appropriate Risk Management of the Company’s business.

This model now enables Western Power to properly manage its transmission assets in the long term by preventing problems derived from ageing plant. This will avoid major supply interruptions, unexpected high expenditures, risk of premature asset replacements, and will result in substantial benefits to all users in an open access environment.
1.0 INTRODUCTION

The previous paper "Asset Management" has briefly outlined an asset management model and its structure, relevant procedures and supporting documentation that are used to manage the transmission infrastructure.

In this paper we will now cover those activities in more detail to show which asset performance reports are prepared and analysed, and how they are used to assess and review asset performance.

These reports highlight equipment in poor condition or not performing, which should then be further reviewed to determine the need for further action for asset over certain period of time.

The reports also identify processes that are not satisfactory and need review. The outcomes of these activities and relevant recommended actions are presented in a document called the 'Asset Management Plan'.

The paper also presents more details about the 'Asset Business Case Analysis' process, ie how to prepare an asset business case for management approval to ensure recommended action is effected in a required time frame.

2.0 MAIN ASSET PERFORMANCE MANAGEMENT REPORTS

2.1 Plant Corrective Maintenance Report

This report is produced fortnightly to monitor and review all maintenance work other than preventive maintenance work as defined by the criteria document, ie outside preventive maintenance regimes.
The report contains the following details, which are used to analyse regular performance of assets, to calculate number of plant failures and to produce a number of other performance statistic data (explained later in this document):

- facility denominator (switchyard or line name, circuit and phase details),
- description of fault,
- work request details (when fault reported, cost estimate, work priority assessment),
- corrective action taken,
- time of repair,
- cost of repair,
- type of asset (manufacturer name and asset type description),
- asset serial number,
- work order number,
- repair crew identification code,
- corrective action type,
- success of repair work (completed, partially done and what is the outstanding work required, not done as other work required, cancelled).

When the report is produced, all listed corrective maintenance work is analysed to check which activities were performed during the preventive work, and which not. Those performed as part of preventive work are deemed plant faults, but are not included in plant failures statistic.

Those activities performed on their own, and not during preventive work, are then assessed to prepare them for data entry in the plant failure data base. This process and relevant coding is described below in 2.2.

Checking of each corrective maintenance activity involves more then
just the details of the particular activity. It also includes review of all maintenance work done on that plant beforehand.

They are several reasons for it:
- has this type of repair occurred before, and how many times,
- was it before or after preventive maintenance, and how far away,
- what type of repair procedures was applied in the past (same or different),
- was the repair performed by the same or different crews.

Based on the above information it is now necessary to make decision if it is necessary to proceed with further investigation of performance and condition of the particular plant, and to consider benefits of repair, refurbishment, and modification and replacement process.

2.2 Plant Failure Report

Only the maintenance activities done separately from the regular preventive maintenance work (ie requiring special access to plant between regular maintenance intervals) are counted as a plant failure.

Such corrective activities of plant should be reviewed and assigned a proper failure code according to the list below:

F Faults, which cause loss of supply (forced outages)
- FV Violent, explosive, type of failure.
- FM Unit is repaired on site after failure.
- FR Unit is removed from site and discarded.
- FRR Unit is removed from site, repaired and returned to site or to store.

M Faults, which do not cause loss of supply (and allow units in service until an outage can be arranged)
- MM Repairs are completed on site.
- MR Unit is removed from site and discarded.
-MRR Unit is removed from site, repaired and returned to site or to store.

This report should be produced at least every month to perform a detailed analysis of fault and equipment type represented in these failures.

The plant is analysed by type, ie a separate report is prepared for specific plant (eg circuit breakers, power transformers). The results for same or similar models/voltages are aggregated to highlight problematic items.

2.3 Asset Performance Reviews

To measure success of the asset management process there is a need to assess how it is meeting its stated company set performance indicators for plant performance by reviewing performance of the transmission network.

Some of the indicators that should be used in such process are listed below:

- A number and assessment rating of site inspections,
- A percentage of overall plant failures,
- A percentage of faults during plant maintenance,
- Number of explosive failures,
- Number of conductor and polers on ground after faults,
- Line failures per 100 km,
- Number of emergency outages with and without loss of supply.

2.4 Plant Performance Statistics Review

The relevant staff from Asset Management and Asset Services Branches will assess performance of the network assets over the previous three months to establish plant performance trending indicators by reviewing all available statistics (failures, maintenance, emergencies and forced outages) during their regular quarterly review meetings.
The main focus of the review is to analyse the above performance reports and to exchange relevant information for future actions or on success of current remedial actions already in progress.

The main issues to be discussed and evaluated are:
- frequency of faults and failures per plant types,
- new environmental and regulatory requirements,
- maintenance costs of repairs and preventive work,
- re-occurrence of faults,
- spare parts availability,
- competency of employees,
- availability and costs of external repair and refurbishment services,
- safety of maintenance practices.

2.5 Plant Planning Reviews

The relevant staff from Asset Management, Planning and Operations should meet on regular basis to assess future network developments, asset plan requirements, and mutual impact of these plans on current and future asset projects and system operations.

They should also review performance and trend indicators of the network assets over the previous period by analysing plant statistics available from the reports presented above.

3.0 ASSET MANAGEMENT PLAN

All information generated from the asset management processes is collated and issued in a document called the ‘Asset Management Plan’. The ‘Asset Management Plan’ is the end result of the involvement of various departments and associated asset management processes described in the previous paper. It aims to assess plant condition and estimate its remaining
useful and safe operational life in order to define any actions required on plant, based on the importance it presents to the operation and planned enhancement of the system.

The ‘Plan’ is updated at least annually and addresses asset replacements, refurbishments and modifications, and relevant maintenance documentation (policies, servicing, instructions and contingency plans). It also shows asset long-term strategy for asset actions.

The objectives of the ‘Asset Management Plan’ are to ensure that:

- Plant performance will meet current customer requirements;
- Plant capacity and condition will enable customer requirements to be met in the future;
- Faults can be repaired without jeopardising system security;
- Supply is restored quickly;
- World class industry practice levels are achieved for 'whole of life' costs, including long-term uprate and refurbishment programmes;
- The long-term business plan reflects necessary capital expenditures to replace assets as their life is expended;
- The safety of employees, customers and the public is protected; and
- Environmental impact is acceptable.

3.1 Asset Management Plan Development

The principal steps in preparation of an ‘Asset Management Plan’ are:

a) The Assets Branch develops, on an annual basis, a 'first cut' list of plant that is considered a possible candidate for update of its maintenance documentation, or could be in need of modification, refurbishment and replacement. The plant is identified by analysing statistics on plant age,
reliability, failure rates, and known or assessed condition. The outcomes of these proceedings are contained in the part ‘Assets Under Review’. The relevant reports with their frequency of producing and way of use are given in more details later.

b) Information is regularly gathered from other electricity utilities, industry bodies and forums, and used to assist with constant improvement of criteria used to arrive at the refurbish/repair/replace decisions.

c) The initial list is reviewed annually before capital budget is set in conjunction with Planning, System Operations and Projects. It is necessary to determine impact of new developments, planned upgrades, plant position and criticality, plant current condition, and likely cost and benefits of refurbishment/replacement programme.

d) The Assets Branch then finalises the list and includes it in the ‘Asset Management Plan’, indicating expected actions and time frames. The ‘Plan’ also specifies what additional work is necessary in the future where plant condition, reliability and cost are not currently well defined or known.

e) Assets Branch prepares a detailed technical and financial business case and a capital project approval submission where required in a standard format for each individual plant item. The replacement projects are dealt with in time for required action time frame.

f) Regular development and planning reports issued by the Planning Branch are analysed and used to identify possible deletions or updates (in scope of work and timing) for items listed in the ‘Asset Management Plan’.

g) Plant maintenance and fault reports statistics from the relevant plant databases should be produced and analysed on a regular basis to identify possible additions to the ‘Asset Management Plan’.

h) There should be an annual review of the ‘Asset Management Plan’ against network development plans and of the status of work in progress to assist in updating of the ‘Plan’.
3.2 Asset Management Plan Structure

The 'Asset Management Plan' consists of the following main parts:

**Part 1 - Assets Under Review**
- **Plant Directory** - This is a complete list of the primary assets, consisting of primary equipment and transmission lines. It represents the total population and is reviewed annually. This is a high level review of plant performance, the outcome of which is a list of plant below with possibly suspect performance that warrants closer scrutiny.
- **Plant Under Review** - This is a list of plant determined from the initial review and then subjected to more detailed analysis. This analysis may lead to one of three outcomes:
  1. Performance is acceptable and no further action is needed.
  2. Further information is needed about the plant in question to reach a conclusion and recommendation. This work is called 'Asset Investigations'.
  3. The plant is assessed to need future action and is included in the plan of 'Asset Future Projects'. The projects are grouped into time frames of 5 years, 10 years, and over 10 years.

**Part 2 - Asset Investigations**
Before or during the assessment of items on the 'Plant Under Review' list it may be necessary to obtain additional information about the plant. This can include a number of inspections, tests and measurements, and may include various trials and joint research projects with other authorities, companies, universities and manufacturers.
ASSET MANAGEMENT PLAN
PROCESS CHART

Plant Directory

Review Performance

Plant under review

No action needed

Analyse Plant

Asset Investigations

Investigate Plant

No action needed

Asset Future Projects

Business Case Analysis

Defer Project

Asset Planned Projects

Approve Projects

Asset Current Projects

Undertake Projects

Asset Completed Projects
The final outcome of these investigations can fall in two main groups:

1. No additional work required on the plant, but:
   (a) units are to be reallocated for use at less important or demanding locations in the network;
   (b) it will be necessary to vary maintenance policy, maintenance servicing or maintenance instructions (eg different servicing frequencies, changed scope of work during service, etc);
   (c) plant failures will be catered for by generic or specially developed contingency plans for a specific period of time,

2. The plant is to remain in service and is added to the list of ‘Asset Future Projects’ for:
   (a) refurbishment or modification on site or in a workshop;
   (b) replacement over a period of time, possibly used for spare parts.

**Part 3 - Update of Documentation**- As a result of ‘Asset Investigations’ or ‘Asset Business Case Analysis’ it is possible that an outcome would not point to the need to perform a refurbishment, modification or replacement of the plant. The identified problems could sometimes be better and more efficiently addressed by altering the plant manuals for maintenance policy, maintenance servicing or maintenance instructions, using an already existing generic contingency plan, or by initiating a specially developed contingency plan.

**Part 4 - Asset Future Projects**- The ‘Asset Future Projects’ represents the potential work necessary to address plant refurbishment or replacement issues. This may include projects for the installation of new technology condition monitoring equipment onto existing plant.

- **0-5 years** - Plant to be considered for action within the next five years, with the recommended type of action and timing;
- **6-10 years** - Plant to be considered for action within the following five years, with the recommended type of action and timing;
• over 10 years - Plant to be considered for action after 10 years, with the recommended type of action and timing.

Projects from this potential work program are subjected to a detailed business case analysis as they mature to determine if the project should proceed. If the outcome of the business case is positive the project will be added to the list of 'Asset Planned Projects', and approval for capital or operating expenditure for the recommended action and timing will be then sought.

Part 5 - Asset Planned Projects- This is a list of the details of the recommended projects arising from the detailed business case analysis of projects taken from the list of ‘Asset Future Projects’.

Part 6 - Asset Current Projects- This is a list of details of all current projects, either approved or ongoing, in the areas of refurbishment and replacement.

Part 7 - Asset Completed Projects- Lists of details of all projects completed since the last ‘Asset Management Plan’ was issued.

3.3 Establishing Asset Review File

The initial work procedure to be undertaken for setting up each item is:

• Create a new file and obtain a transmission asset management (TAM) file number,

• Run the latest plant current locations report from an appropriate database,

• Prepare a population/age/dissipation report,

• Run the latest failure report from an appropriate database,

• Run the latest corrective maintenance (fault history) report,

• Obtain preventive maintenance criteria details and maintenance costs for current assets,
Propose and assess possible modification and replacement options, and obtain information for their basic costing,

Seek necessary input from Plant Section and Asset Services about the above preliminary options,

Indicate if further investigation will be required before the work on a business case could proceed. This might include consulting other plant specialists, manufacturers, authorities and industry bodies as required, or conduct a series of site or indoor laboratory tests,

Send the list of plant locations to the Planning Section and obtain their comments from future development plans and impact on plant,

When assessments involve instrument transformers request comments from Protection Section with reference to future protection upgrade projects that would affect instrument transformer projects,

Send the list of locations for affected plant to the System Operations to obtain their assessment of locations criticality, and possible impacts on system security and reliability of supply,

Make preliminary findings if this plant type is a candidate for eventual replacement, refurbishment and modification, or update of maintenance manuals and contingency plans, and include in list of ‘Future Projects’,

If further action is recommended, obtain detailed cost estimates from the Projects Group,

A detailed business case and capital or operating project approval will be prepared for each individual plant item of the replacement project, according to its required timing.

4.0 ASSET BUSINESS CASE ANALYSIS

There are number of issues that need to be considered before a proposal is presented for any action required of a particular item of plant. The individual
components are grouped by similarity of the area they address, and the assessed ratings of a group are then used for an overall asset condition assessment in the business case presentation.

Details of each group and its components are including their priority, associated weighting factors, risk evaluation, and cost implication (life cycle cost assessment) are given below.

**Group 1 Age**
The age of the units is given a low-weighting factor. The risk factor is calculated from plant current age versus the total expected life of plant.

**Group 2 Condition**
The condition of plant is a significant factor in determining plant performance, as it leads to failures and makes its future performance uncertain. It is given a high-weighting factor, and is calculated from frequency of failures and faults.

The frequency of failure risk factor is based on the number of failures per unit per year, and the frequency of fault risk factor is based on the amount of additional maintenance repair work required in excess of preventive maintenance during regular maintenance intervals.

**Group 3 Environmental/Regulatory Requirements**
Plant is normally well designed to avoid any significant impact on the environment, so the weighting factor is rated as low.

There might be special circumstances where a plan for an immediate action could be considered, eg new legislation, certain areas proclaimed as sensitive areas (eg underground water catchment), etc.

**Group 4 Spare Parts and Services Availability**
In assessing this group the following issues should be addressed:

a) Spare parts availability,

b) Competency of employees to perform work,
c) Availability and cost of external servicing.

A number of manufacturers have ceased to exist or have abandoned making the particular model or spare components. In the case of a major fault occurring, spare parts could be very difficult to obtain, which would result in long waiting periods or very high costs to manufacture the parts on an individual basis.

The skills to repair or completely refurbish the affected units within or outside the company should be investigated and assessed. A combination of factors listed below will be useful in the above assessment:

f) Difficulty in obtaining spare parts,
g) Remote locations of the units in question,
h) Difficulty in arranging access (eg feeders supplying mining sites),
i) Low success rate on a previously trialed refurbishment or modification,
j) High cost of the rework required.

There might be special circumstances where a plan for an immediate action should be considered where the risk factor 5 is assigned, ie all the above factors are assessed as poor.

**Group 5 Safety**

In assessing this group the following issues should be addressed:

a) Safety of employees,
b) Safety of public,
c) Safety of adjacent equipment.
The units may pose a risk for the crews that perform work on adjacent circuits, as the unit may operate under fault conditions with insufficient security to guarantee its safe operation. Equipment maloperation may present a direct risk to the public. That is a direct risk in the form of flying debris or exposed live conductors. It may not always be possible on occasions to mobilise a crew to site in sufficient time to quickly restore customer supply, leading to hazards occurring in the general public domain. There is also a real risk associated with suspected units having to operate under fault conditions, as any adjacent equipment could be damaged by flying debris, further exacerbating the consequences of failure, and could cause a further release of any contaminated particles into the atmosphere. There might be special circumstances where a plan for an immediate action should be considered where the risk factor 5 is assigned, ie all the above factors are assessed as poor.

**Group 6 Obsolete Design Standards**

Sometimes units are considered to be of obsolete design, with inherent design imperfections, poor tolerances, etc, causing failures (eg jamming of operating mechanisms), but generally perform their duties as required. This may sometimes have influence on other groups, spare parts availability, expensive maintenance, special skills required, safety problems and operational restrictions, and must be then properly addressed.

**Group 7 Impact on Customers and Company**

In assessing this group the following issues should be addressed:

a) Impact on quality of supply,

b) Impact on customer,

c) Impact on company.

Any loss of supply from affected circuits has consequences on quality of supply. It could cause complete loss of supply for a protracted period,
depending on the ability of the system to temporarily feed customers from alternate sources. In a case of sensitive load areas there could be a significant production time lost in mine site operations, disruption of supply to general public, etc.

Such a loss of supply could also have a significant effect on the company’s business in a form of:

- Loss of supply over a significant period of time would mean significant loss of revenue,
- Replacement and repair of equipment under emergency situations would be very costly, particularly if other adjacent plant has been damaged,
- Relationships with customers would suffer, an important consideration in the environment of open access and increased competition.

There might be special circumstances where a plan for an immediate action should be considered where the risk factor 5 is assigned, ie all the above factors are assessed as poor.

**Group 8 Costs**

The maintenance costs can contribute significantly to the company’s operating expenditure, and they have to be assessed for the life of equipment.

These costs should then be compared against the costs to repair, refurbish, modify or replace the plant under consideration, using net present value matrix (life cycle cost evaluation) to find the most economical solution. In assessing this group the following issues should be addressed:

a) Maintenance costs,
b) Repair costs,
c) Modification costs,
d) Refurbishment costs,
e) Replacement costs.

**Group 9 Ability to Manage the Replacement Process**

It is important to realise the importance for the company to properly manage its plant in the long run by initiating necessary action for equipment that is assessed under risk even in the long term rather than to wait for failures.

That might sometimes require plant replacements before they reach the end of their individual life. This is undertaken by:

- A suitable equipment long term condition and risk assessment,
- The selection and review of all possible courses of action to deal with the risks, and assessment of how each type of action can limit the identified risks,
- Identification of possible savings in long term operating costs (tangible and intangible) by arranging suitable plant replacements, and how will it lead to improvement of company’s strategic result area indicators,
- Implementing suitable interim arrangements to ensure secure supply and the safety of staff,
- A business long term financial approach to plan timely implementation of repair, refurbishment, modification or replacement programmes.

**5.0 CONCLUSIONS**

The papers 'Asset Management' and 'Infrastructure Replacement' have outlined the development and implementation of a comprehensive asset management model to support an electricity utility business in the deregulated electricity market. The main purpose and characteristics of main components of an asset management model have been described. We
have presented details of the process to establish and maintain an Asset Management Plan, and how to prepare a business case for asset replacements in an electricity system using a life cycle costing.

This model should enable the utilities to properly manage their assets, and prevent problems derived from ageing asset population, eg supply interruptions, unexpected high operating and capital expenditures and premature asset replacements. It should also contribute to the corporate risk reduction.

It will ensure the security and reliability of the system and the long-term financial viability of the company. It will also benefit all internal and external users in the open access environment, resulting in realistic and transparent open access charges, bringing long-term economic benefits to all parties.
14* ASSET MANAGEMENT PROCESS FOR TRANSMISSION ASSETS

1. INTRODUCTION

This paper gives a description of an asset management process developed and implemented by WPC to upkeep its transmission assets and to manage the relevant documentation.

There are number of different maintenance, planning and management systems that other businesses have in use, but this the first one to connect all activities and groups involved in management of transmission assets in single interconnected and mutually affected system. Assets management process for transmission assets is defined through a number of internal documents. Some of them give a high level overview of the asset management process while others give more details for the relevant particular areas.

The paper also provides some indication on how to collect and prepare data, necessary reports to run, how to analyse their results, and how to act on the relevant outcomes and their recommendations.

2. ASSET MANAGEMENT MODEL

2.1 Model Overview

An asset management model ensures that:

a) all assets receive adequate on-going care,

b) performance and condition of assets in service are continuously monitored and reviewed,

c) plans are prepared for asset short and long term strategies.
The model specifies documentation that defines all necessary activities, responsible groups to perform those activities, databases and reports they use to perform their task successfully, and format and content of the expected outcomes of their activities.

The model is based on the two main activity streams necessary to cover all requirements for assets in service:

a) definition and execution of maintenance and repairs of assets, with a broad term of asset maintenance management;
b) monitoring of asset performance, assessment of condition and location criticality of assets, and planning of necessary actions to respond to the identified asset problems (e.g., modification, refurbishment, replacement), with a broad term of asset renewal management.

The model structure and its process, functions and procedures, required base documentation, and results and output documentation is presented on Fig 1.

2.2 Development of the Model
The model begins with an asset management strategy for the transmission assets, presented in the document Asset Management Strategy. It follows with a definition of aims and goals for the asset management process in the transmission business, which is presented in the document Asset Management Policy Manual.

The model is then further defined in two other base documents: Asset Management Process and Asset Management Procedures. The first one covers the process and main functions of asset management process. The second one deals with documentation that is required to support the above
process, procedures to follow, databases to be used, reports to be prepared, and format and contents of the required outcomes.

The Fig. 1 also shows a link to development plans for the transmission system. They contain required future works in the transmission network to cater for fault level increase, new connections and increase in load transfer. It is essential to correlate all asset works between management works and development plans.

2.3 Asset Maintenance Management

Asset maintenance management is an organised process that makes sure all installed equipment has adequate and up to date maintenance policies and that necessary instructions how to do maintenance are in place for assets inspection, checks, testing and adjustment. Dedicated and qualified maintenance service providers apply work per these instructions and policies on a regular basis.

It also defines procedures for effecting asset repairs, emergency response and follow-up actions in the event of asset failures, contingency provisions to assist in event of asset failures, and for proper handling of replaced assets when failed or under performing assets require replacement.

The maintenance work is handed to internal and external service providers through Service Level Agreements. They are monitored and assessed by using various maintenance analysis techniques for effectiveness and efficiency of their work.

Some documents prepared and issued to cover the above areas are considered base documents:

- Maintenance Policy Manual,
- Maintenance Servicing Manual,
- Maintenance Instructions Manual,
- Service Level Agreements,
- Generic Contingency Plans,

Others contain an outcome of the requirements in above base documents, eg Maintenance Plan.

2.4 Asset Renewal Management

The asset renewal process with required inputs & outputs and the information flow is shown on Fig. 2. Asset renewal management covers:

a) asset strategies
b) asset information management
c) asset performance

Some documents prepared and issued to cover the procedures, responsible groups, required databases and necessary reports are considered base documents:

- Management Strategy,
- Management Policy,
- Management Process,
- Management Procedures,
- Business Case Analysis Manual,

Others contain results, being an outcome of the requirements in above base documents, eg:

- Asset Management Plan,
- Business Case Studies,
- Special Contingency Plans.
3. REQUIRED DOCUMENTATION FOR MODEL IMPLEMENTATION

3.1 Maintenance Policy Manual
The Maintenance Policy Manual defines frequency (periods) and different levels of maintenance for transmission lines, cables and plant.

3.2 Maintenance Services Manual
The Maintenance Services Manual defines maintenance servicing work specifications, which are detailed, hands-on, step-by-step servicing instructions used by crews performing maintenance.
These instructions originate from the manufacturers' maintenance servicing manuals and instructions, and are supplemented by extensive in-house experience in maintenance and exchange of information with other utilities and service providers through the industry bodies and forums (eg CIGRE, users workshops, etc).
They prescribe required skill levels for maintenance staff for various maintenance levels, and parts, tools and equipment necessary to successfully execute relevant maintenance tasks.
They also specify tests and measurements to be performed prior and after maintenance work with acceptable test results.

3.3 Maintenance Instructions Manual
The Maintenance Instructions Manual contains instructions that define how to handle the diversity of maintenance activities performed by a variety of internal and external service providers.
3.4 Service Level Agreements

Service level agreements define relationships to service providers and cover the following areas:

a) Service Level Agreement Purpose and Policy,
b) Scope of the Agreement that defines Assets, Services to be Provided, Rework for Services Provided, and Qualification of Personnel,
c) Performance Management that establishes Performance Measures, Budget and Cost Accounting, Acknowledgment for Services Delivered Well, and Need for Improvement,
d) Continuous Improvement System that provides for Periodic Reviews, SLA Revisions, and Work Performance Improvements.

3.5 Generic Contingency Plans

The generic contingency plan document provides planned responses to possible asset failures, resulting from consequent or independent coincident events, where such failures take the transmission system outside the boundaries of planned operational risks.

The events can be caused by a variety of causes:

➤ Environmental sources such as lightning, fires, earthquakes, cyclones, birds, trees;
➤ Human sources such as vandalism, accidents;
➤ Malfunctioning of other equipment, explosions of adjacent plant and failure of protection systems.

These plans ensure that every transmission asset in the network can be suitably replaced and power supply restored in the proper time.
The asset identified in need of further consideration beyond the scope of the generic contingency plans will require a special contingency plan.

3.6 Business Case Analysis Manual

The main items used to assess asset performance and condition assessment in a business case are:

(1) The age of plant,
(2) The frequency of failures,
(3) The plant condition,
(4) Reviewing impact of changes in environmental and regulatory requirements,
(5) The current and future maintenance costs,
(6) The replacement costs for new solutions,
(7) The spare parts availability,
(8) The skills available internally or externally to repair or completely refurbish the affected units,
(9) Safety of employees, customers and public is part of a constant review to ensure that equipment operates under fault conditions with paramount security,
(10) Integrity of equipment adjacent to faulted one and risk of releasing contaminated substances and particles into the ground or atmosphere,
(11) Obsolete design standards are reviewed for older units in service,
(12) Impact on quality of supply,
(13) Impact on customer,
(14) Impact on utility,
(15) Business ability for a proper and timely management of its asset replacement programme.
4. ASSET MANAGEMENT FUNCTIONS

4.1 Asset Management
Asset management is responsible for management of asset management process and documentation relevant to that process, and for overall coordination of all other activities related to asset management that are performed in other areas.

4.2 Network Planning
Network planning is responsible for setting network planning criteria and plant performance standards to meet the system needs, and for preparing network development plans to cater for future load growth and new connections.

4.3 Maintenance Services
Maintenance services have the responsibility for construction, commissioning and maintenance of transmission assets, including short-term planning and scheduling services for the required work and local maintenance work analysis and correction.

4.4 System Operations
System operations are responsible for the day to day operation of the transmission system and use of power system assets to deliver the product to the customer. That includes responsibility for operational reliability, security and quality, and for the SCADA operations to support this activity.

4.5 Engineering
Engineering is responsible for providing engineering solutions and services in the area of design, drafting and cost estimating for failed asset replacements and new installations based on planned renewal projects.
4.6 Project Management
Project management is responsible for establishing and management of planned asset replacement projects arising from approved capital project recommendations to replace assets according to asset renewal programmes.

4.7 Finance
Finance is responsible to analyse requirements for operating and capital expenditures and to determine responsible costs to ensure the ongoing financial viability of the business.

5. ASSET MANAGEMENT DATABASES

Databases are required for recording of assets and asset management activities in transmission business, and they can be divided into two areas:

5.1 Asset Information Registers
- Transmission Plant Management System
- Transmission Lines Management System
- Transmission Protection Equipment System
- Transmission Ratings Information System
- Transmission Geographical Information System.

5.2 Asset Activities Register
An integrated information management system is used throughout the company to record all asset activities.

It contains details of location and plant fitted to that location, asset standard type nominations, standard maintenance levels, required maintenance and testing activities, frequencies (trigger dates), standard job templates and their cost, maintenance history and repair activities, outstanding maintenance work with its cost and planned future schedules.
6. ASSET MANAGEMENT PROCEDURES

There are number of procedures that are required to enable the asset management work to succeed, and the main ones are briefly given below:

6.1 Recording of Assets Data
All assets need to be recorded to enable setting and planning of their maintenance and monitoring of their performance and condition in service.

6.2 Recording of Maintenance Work
All maintenance activities need to be recorded against the relevant assets to enable analysis of their system and maintenance performance.

6.3 Recording of Asset Failures
All corrective maintenance work done separately from asset preventive outage programme is considered an asset failure, assigned proper failure codes and recorded for future analysis.

6.4 Review of Maintenance/Failure Statistics
The above statistics are reviewed on regular basis to determine assets with poor performance or high maintenance costs.

6.5 Review of Network Development Plans
This review needs to be done on a regular basis to ensure that assets maintenance and renewal plans are timely adjusted against actions foreshadowed in the network planning future projects.

6.6 Review of Asset Management Plan
The Plan needs review to incorporate any new non-performing assets, assets dealt with from since the last review, and impacts of changes in development plans.

6.7 Review of Asset Management Process
The asset management process and its success in managing performance of assets in service need to be subject of regular reviews to confirm that the
model and its procedures are adequate. One of the tools that should be used in that assessment is benchmarking vs its industry peers. The results of such studies should then be used through development work to close the identified gaps in performance or policies.

7. ASSET MANAGEMENT REPORTS

Continuous monitoring, review and analysis of assets performance reports expose assets with deteriorating maintenance and system performance.

7.1 Asset Corrective Maintenance Work Report
Review of this report is used to decide if asset maintenance regime or servicing instruction needs to be investigated to obtain more information about its performance or condition.

7.2 Asset Failures Report
The review of report information will enable to determine if a further analysis of asset failures for asset types represented in these failures is warranted.

7.3 Asset Failures Summary Report
This report is used to highlight on a regular basis asset types that have fared prominently throughout their total years in service with regard to their failures when analysing the failures number, type and percentage to their total population.

7.4 Asset Population/Attrition/Performance Summary Report
This report is used to highlight asset types that have fared prominently throughout their total service years with regard to their terminal failures (ie plant had to be removed after the failure and discarded).
The above and other reports results and reviews are used to show if and what further action is required on assets, which are then selected for the 'Plant Under Review' part of the Asset Management Plan.

8. ASSET MANAGEMENT OUTPUT DOCUMENTATION

8.1 Maintenance Plan

Maintenance Plan is a complete list of maintenance work to be done on the assets currently operating in the system to ensure that they continue to fulfil their intended function in a cost-effective manner.

The maintenance work in the Plan has three main maintenance categories:

- Preventive maintenance work,
- Corrective maintenance work,
- Major works (after business case analysis for modification or refurbishment and operating funds approval).

8.1.1 Preventive Maintenance Work

This work is planned in detail with its scope and frequency and the work party, it is scheduled well in advance, and always catered for in the work budget:

- Routine maintenance: substation rounds, alarm checks; line aerial and ground patrols:
- Servicing maintenance: CB maintenance, injection and testing of relays, line washing.

8.1.2 Corrective Maintenance Work

This category is subdivided into three groups:

- Emergency (unplanned) maintenance. This type of work occurs with no warning and at random incidence when equipment fails or needs to be taken out of service immediately before it fails;
- Deferred (1) (planned) maintenance if corrective action is taken sometimes in same financial year;
- Deferred (2) (planned) maintenance, if corrective action can be taken in the later financial years.

8.1.3 Major Works
This type of work is always planned and budgeted for in operating budget. It is classified as major work on plant types or line hardware that needs a business case and operating funds project approval (involves technical and financial business case analysis) before the work can proceed. It is divided into three groups:
- Overhaul (refurbishment);
- Modification;
- Remedial (repair).

8.1.4 Maintenance Codes
A number of responsibility centres, activity types and maintenance service groups have been set up for maintenance activities to enable setting up annual budgets and to monitor work and expenditure per asset and per service provider throughout the year.

8.2 Asset Management Plan
The Asset Management Plan is the end result of asset management process that aims to assess condition and remaining useful and safe operational life for assets. It identifies renewal actions that installed assets might need in the future to ensure their effective, efficient and safe ongoing performance in system. Asset renewal is therefore focused on managing the performance of existing installed assets through major repairs, refurbishment, modification and replacement of assets, or update of their maintenance policies.
The Plan contains details of all current and future, approved or planned, activities for the installed assets based on the asset condition and importance of the asset to the system operations and security.

8.2.1 Assets Under Review

An outcome of the review of all asset performance forms Assets Under Review list, ie assets that warrant further analysis. That analysis may lead to one of the outcomes:

(i) Performance is acceptable, no action;
(ii) Further information is needed about the asset in question. That work is called Asset Investigations;
(iii) The asset is assessed to need future action and is included in the plan of Asset Future Projects in 5-year timeframes with a 20-year horizon.

8.2.2 Asset Investigations

Asset Investigations lists assets requiring additional information about the plant performance, condition and other details before decision can be made. The outcome results of these investigations are then used to refine initial assessment of asset condition and performance made in 8.2.1.

8.2.3 Update of Documentation

Update of Documentation is a result of Asset Investigations or Asset Business Case Analysis, where identified problems can be corrected by altering asset management documentation.

8.2.4 Asset Future Projects

Asset Future Projects lists the assets that have been assessed as requiring some work in the future, but a deeper analysis of their condition will be required to determine the best option to resolve the problems.

8.2.5 Asset Planned Projects

Asset Planned Projects is a list of the projects recommended to proceed after a detailed business case analysis of project has been undertaken from
the list of Asset Future Projects, and have received an approval but have not started yet.

8.2.6 Asset Current Projects

Asset Current Projects is a list of all current on-going approved projects in the areas of asset renewal (repair, refurbishment, modification, and replacement).

8.2.7 Asset Completed Projects

Asset Completed Projects is a list of all asset renewal projects completed since the last Asset Management Plan was issued.

8.3 Business Case Studies

A detailed analysis and review of asset performance of assets with a suspected condition, listed in Asset Future Projects with required time frames for action, to determine required action.

When the time comes, asset management prepares a detailed technical and financial business case for a particular asset project.

8.4 Special Contingency Plans

One of the outcomes of the asset business case studies for the suspect asset is a special contingency plan for that group of assets, to cater for their possible failures over specific period of time, or while some other planned developments occur.

Typical examples of such plans are Metalclad Indoor Switchboards Contingency Plan and Rapid Response Spare Transformers Plan.

There are also other special plans for response to particular catastrophic events beyond normal operating risks, such as Catastrophic Failures in Terminal Stations Plan.
9. CONCLUSION

In this paper we have presented our own, in-house developed, integrated asset management model used for looking after transmission assets. We have also presented its characteristics and procedures, and how it has been successfully implemented in the company.
Fig. 2

New Network Development Plans
New Regulations and Policies (Environment, Safety)
Results of Research and Investigations by Working Groups
Plant Failure Statistics and Technical Performance Assessment
Plant Management Systems (TPMS, TPES, TLMS)
Failures Reporting

New System Performance Specifications
Asset Performance Review
Asset Management Plan

Business Case Analyses Manual
- Refurbishment, Repair, Modification, or Replacement of plant
- Update of:
  - Maintenance Policies
  - Mte Services
  - Mte Procedures
  - Generic Contingency Plan
  - Make Special Contingency Plans

Work Management System (MIMS)

Work Performed

New Corporate Business
New System Operations
Results and Analysis of Benchmarking Studies
Changes in Technology

Plant Maintenance Statistics and Performance Assessment
Defects/Costs Reporting
Coordinates changes in Annual Outage Plan
System Outage Annual Plan
22.2. Map of Western Australia
22.3 WPC Transmission South-West Integrated System
POLICY

The purpose of maintenance is to keep plant in an acceptable condition, with adequate availability at minimum system cost over its life. This can only be done if maintenance is done in a controlled way. It is Networks policy to control maintenance by having a fully coordinated and documented maintenance system. This ensures appropriate maintenance practices are uniformly adopted across the whole of the state.

THIS MANUAL

This manual is issued by the Asset Strategy, and defines the maintenance requirements for all the primary plant, lines and cables in the transmission part of the networks.

The manual defines the responsibilities of all groups involved in the maintenance activity, from planning through to actual performance.

In addition, the manual lays down the criteria on which the plant is to be maintained. The criteria for some items of plant have not been agreed as yet but as they are, they will be issued to you for inclusion as part of this document.

It must be remembered that as the maintenance process is refined, revisions to the various portions of this document will be made. As such, each manual is issued to a specific position, and that position will receive all subsequent updates and revisions.

Thus should the manual be forwarded to another position, please do advise the Maintenance Development Engineer so that the circulation records can be amended.

This manual is part of the Asset Strategy overall documentation system and should be read especially in conjunction with Transmission Maintenance Services and Maintenance Instructions Manuals.
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22.5. Maintenance Instructions Manual Structure

NETWORK ASSETS SECTION – ASSET STRATEGY BRANCH

Transmission Maintenance Instructions Manual

No.1 Procedure for Obtaining a Replacement Plant (#381904) Rev 11

No.2 Guidelines for Transmission Line Maintenance and Minor Construction Work (#381996) Rev 6

No.3 24 Hours Maintenance Call-Out Procedure (#365180) Rev 16

No.4 Mobile Communications - Safe Practice (I) (#382078) Rev 4

No.5 Procedure for Handling of Fault Reports and Raising of Work Orders (#377730) Rev 4

No.6 Guidelines for Transmission Substation Maintenance Work (#382063) Rev 4

No.7 Live Line Work (I) (#386230) Rev 2

No.8 Procedure for Plant Warranty Inspections (#386245) Rev 3

No.9 Procedure for Recovery and Disposal of Wooden Poles (I) (#386482) Rev 5

No.10 Procedure for Outage Requirements (#373461) Rev 3

No.11 Reporting System for Near Miss/Hazard/First Aid/Fire (I) (#386511) Rev 2

No.12 Communication Protocol Between TAB and TLS (#386521) Rev 2

No.13 Financial Management Procedures (#1011999) Rev 0

No.14 Maintenance Activities Classification (#365656) Rev 8

No.15 Service Protocol Between PA and TSS (#396529) Rev 3
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<td>2500</td>
<td>17500</td>
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<td>20782240</td>
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<td>Maint Correct - O/H lines</td>
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<td>100000</td>
<td>20000</td>
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13053332
SUMMARY

1.0 INTRODUCTION
   1.1 Background
   1.2 Process

2.0 SCOPE
   2.1 Nature of the Plan
   2.2 Events
   2.3 Plant

3.0 PLANNING CRITERIA
   3.1 N-1 & N-2 Criteria
   3.2 Central Business District Criteria
   3.3 Modified N-1 Criteria
   3.4 Radial Connections

4.0 PLANT RESTORATION TIMES

5.0 MAJOR TRANSMISSION
   5.1 Contingency Events
   5.2 Emergency Spares
   5.3 Transformers
   5.4 Static VAr Compensators
   5.5 Circuit Breakers
   5.6 Instrument Transformers
   5.7 Surge Arresters
5.8 Reactive Compensation

6.0 CBD SUBSTATIONS

7.0 REGIONAL SUBSTATIONS

7.1 Contingency Events
7.2 Emergency Spares
7.3 N-1 Firm Transformers
7.4 Modified N-1 Transformers
5.5 Circuit Breakers
5.6 Instrument Transformers
5.7 Surge Arresters

APPENDIX A – Issues for Review and Investigation
### 22.8. Network Development Plans Summary

#### FIRM PROJECTS

<table>
<thead>
<tr>
<th>PROJ No.</th>
<th>SP ENG</th>
<th>PROJECT DESCRIPTION</th>
<th>CPA VALUE (SM)</th>
<th>PROJECT FINISH DATE</th>
<th>GROUP</th>
<th>PROJ ENG</th>
<th>ORIG ESTIMATE REQST DATE</th>
<th>ESTIMATE DUE DATE</th>
<th>CPA APPROVAL DATE</th>
<th>PPD ISSUE DATE</th>
<th>Last Revision Date: 28 November 2001</th>
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<tr>
<td>56477</td>
<td>CC</td>
<td>Kojonup - Albany Line Route Identification &amp; Approvals</td>
<td>0.250</td>
<td>1-Nov-02</td>
<td>SRVCS</td>
<td>R Teh</td>
<td>24-Aug-01</td>
<td>Rec 4/9/01</td>
<td>5-Dec-01</td>
<td>N/A</td>
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<td>GL</td>
<td>Murdoch Land Purchase</td>
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<td>30-Jun-02</td>
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<td>R Teh</td>
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<td>31-Dec-01</td>
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<td>56483</td>
<td>PA</td>
<td>MER-MRT Line Route Identification and Approval</td>
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<td>30-Dec-01</td>
<td>SRVCS</td>
<td>R Teh</td>
<td>29-Jun-99</td>
<td>Compl 22/6/99</td>
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<td>56537</td>
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<td>KW-MED-CC81 - Line Uprate</td>
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<td>56633</td>
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<td>Merredin - 22kV Capacitor Bank</td>
<td>0.350</td>
<td>30-Nov-03</td>
<td>SUBS</td>
<td>T Murphy</td>
<td>29-Jan-99</td>
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<td>30-Jan-02</td>
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<td>P Peach</td>
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<td>15-Mar-02</td>
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## 22.9. Corrective Maintenance Works Summary

### Q/T Report-Activity WOs

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<tr>
<th>Plant ID</th>
<th>Ph</th>
<th>Work Order #</th>
<th>Closed Date</th>
<th>Work Order Description</th>
<th>Manuf # Serial #</th>
<th>QT Report # Priority</th>
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<tbody>
<tr>
<td>A 502.0</td>
<td>CB</td>
<td>TW032331</td>
<td>3/12/01</td>
<td>QT:11143 Refurbish Poles in Workshop</td>
<td>M09000 680161</td>
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<tr>
<td>A 809.5</td>
<td>VT</td>
<td>TW032989</td>
<td>11/12/01</td>
<td>QT:54805 Low Nitrogen level in VT</td>
<td>E59850 SVT1242</td>
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<tr>
<td>ALBT1</td>
<td>TX</td>
<td>TW031964</td>
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<td>QT:43368 Oil leak from top of TX</td>
<td>E63850 A31B3387/1</td>
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<td>E63850 A31B3387/2</td>
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<tr>
<td>BCH520.0</td>
<td>CB</td>
<td>TW032237</td>
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<td>QT:52557 Regas SF6 breaker</td>
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<tr>
<td>BHK701.5</td>
<td>SA</td>
<td>TM001478</td>
<td>15/05/01</td>
<td>Flashover of B ph-Replace all 3 SAs</td>
<td>S46020 35058838</td>
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<td>BKF802.0</td>
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<td>TW033916</td>
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<td>QT:35219 Low SF6 gas in CB</td>
<td>A14691 8421116</td>
<td>35219 T4</td>
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<td>BNP520.4</td>
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<td>QT:32970 Oil leak from the gate valve.</td>
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<td>BNP808.0</td>
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<td>QT:32970 White phase leaking, low oil.</td>
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<td>BP 705.5</td>
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<td>QT:45093 Oil low and leaks on TX</td>
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<td>QT:44839 Will not close.</td>
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<td>BYF506.0</td>
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<td>QT:42068 Main Drive shaft leaking</td>
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<td>QT:42066 Oil leak on breaker</td>
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<td>CK T1</td>
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<td>TW033909</td>
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<td>QT:34962 (Callout) Bleed bucholz.</td>
<td>T96890 20205</td>
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<td>CLP503.0</td>
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<td>TW032308</td>
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<td>QT:44542 Oil leak on sight glass</td>
<td>M09000 418155</td>
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<td>CLP504.0</td>
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<td>QT:44543 CB black and burn't</td>
<td>G12740 681407</td>
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<td>CLPT1</td>
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<td>TW032269</td>
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<td>QT:49478 Lighting tripped TX protection</td>
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<td>CO 701.5</td>
<td>DIS</td>
<td>TW026863</td>
<td>13/12/01</td>
<td>QT:44513 Isolator hard to operate</td>
<td>S71781 S02292</td>
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<tr>
<td>CPN318.0</td>
<td>CBC</td>
<td>TW029318</td>
<td>18/10/01</td>
<td>Refurbish motor &amp; G/box &amp; RSD to stores</td>
<td>Y93960 YS/M/89/075</td>
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<td>CPN320.0</td>
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<td>TW030475</td>
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<td>QT:40343 Gearbox repairs</td>
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<td>EP T5</td>
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## Q/T Report-Switching WOs

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<th>Maint Type</th>
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<td>TW027279</td>
<td>Switching(CALLOUT) Broken X-arm pole 410</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>08/07/01</td>
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<td>C</td>
<td>NT NOR</td>
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<td>TW028496</td>
<td>Switching for (Callout) TX tripped out</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>22/08/01</td>
<td>AC</td>
<td>C</td>
<td>K T3</td>
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<tr>
<td>TW028523</td>
<td>Switching-accidental tripping-MW701.0 CB</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>25/07/01</td>
<td>AC</td>
<td>C</td>
<td>CT MW</td>
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<td>Switching FAULT PATROL</td>
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<td>V1</td>
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<td>23/08/01</td>
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<td>C</td>
<td>C NF</td>
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<td>TW029362</td>
<td>Switching:Tripping due to vandalism</td>
<td>T1</td>
<td>V1</td>
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<td>V1</td>
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<td>ST SF</td>
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<td>V1</td>
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<td>AC</td>
<td>C</td>
<td>SF WT</td>
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<td>TW029456</td>
<td>Switching-Line trip as pilot relay fall</td>
<td>T1</td>
<td>VZ</td>
<td>T3</td>
<td>20/08/01</td>
<td>AC</td>
<td>C</td>
<td>GTNDUR</td>
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<td>VZ</td>
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<td>23/08/01</td>
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<td>CT VP</td>
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<td>TW029458</td>
<td>Switching-HAY s/s out-ASSS fails</td>
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<td>VZ</td>
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<td>25/08/01</td>
<td>AC</td>
<td>C</td>
<td>HAY</td>
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<td>TW029972</td>
<td>Switching Fault patrol (Nothing found)</td>
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<td>V1</td>
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<td>C</td>
<td>CT PNJ</td>
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<td>V1</td>
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<td>Switching-Pole 13 Callout-Remove foreign</td>
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<td>V1</td>
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<td>C</td>
<td>CK HE</td>
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<td>TW030556</td>
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<td>V1</td>
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<td>C</td>
<td>EP F</td>
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<td>V1</td>
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<td>TW030560</td>
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<td>16/09/01</td>
<td>AC</td>
<td>C</td>
<td>WKTSR2</td>
</tr>
<tr>
<td>TW030595</td>
<td>Switching (CALLOUT) CAR v POLE 57</td>
<td>T1</td>
<td>V1</td>
<td>T7</td>
<td>08/10/01</td>
<td>AC</td>
<td>C</td>
<td>NT MJ</td>
</tr>
<tr>
<td>TW030879</td>
<td>Switching Replace blown isul MER509.0</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>12/10/01</td>
<td>AC</td>
<td>C</td>
<td>MERB505P1</td>
</tr>
<tr>
<td>TW031038</td>
<td>Switching FAULT Patrol &amp; Repairs</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>21/10/01</td>
<td>AC</td>
<td>C</td>
<td>C NF</td>
</tr>
<tr>
<td>TW031053</td>
<td>Switching for callout - buszone trip</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>21/10/01</td>
<td>AC</td>
<td>C</td>
<td>N BB7A</td>
</tr>
<tr>
<td>TW031222</td>
<td>Switching QT:37499 Line Patrol/cut trees</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>30/10/01</td>
<td>AC</td>
<td>C</td>
<td>MU NT</td>
</tr>
<tr>
<td>TW031223</td>
<td>Switching Line Patrol/cut trees</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>30/10/01</td>
<td>AC</td>
<td>C</td>
<td>MU NT</td>
</tr>
<tr>
<td>TW031378</td>
<td>Switching Hay 317.0 CBC failed.</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>02/10/01</td>
<td>AC</td>
<td>C</td>
<td>HAYT1</td>
</tr>
<tr>
<td>TW031959</td>
<td>Switching (Callout) busbar earthed live</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>25/10/01</td>
<td>AC</td>
<td>C</td>
<td>MC T2</td>
</tr>
<tr>
<td>TW032082</td>
<td>Switching Tripped due to RTU malfunction</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>05/10/01</td>
<td>AC</td>
<td>C</td>
<td>MGAGTN</td>
</tr>
<tr>
<td>TW032083</td>
<td>Switching Tripped due to GTN RTU damage</td>
<td>T1</td>
<td>V1</td>
<td>T3</td>
<td>05/10/01</td>
<td>AC</td>
<td>C</td>
<td>GTN</td>
</tr>
</tbody>
</table>
### 22.10. Protection Operations Report

#### General Fault Report Comments

**TRANSMISSION SYSTEM**

**Fault Type:** All

<table>
<thead>
<tr>
<th>Date</th>
<th>Report</th>
<th>Fault No</th>
<th>Faulted</th>
<th>Date</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-Jan-02</td>
<td>01-Jul-01 to 31-Dec-01</td>
<td>Non</td>
<td>6643 LN MW CT</td>
<td>25/7/2001 13:36:00</td>
<td>TEM workgroup accidently tripped MW 701.0 while working on MW 705.0. See IR 281.</td>
</tr>
<tr>
<td>Non</td>
<td>6648 LN GTN DUR</td>
<td>2 20/8/2001 14:41:00</td>
<td>GTN 617.0 trip initiated when protection staff attempted to reset red led flag on pilot relay. Inspection found internal damage to pilot relay contacts as well as trip counter. Cause attributed to load on trip counter ct exceeding MB/relay contact make / break rating. See IR 285 for more details. DMS 1030384.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non</td>
<td>6661 LN EP F</td>
<td>2 11/9/2001 7:57:00</td>
<td>Earthing contractor working adjacent to EP 66kV yard dug up 2 pilot cables. EP7-RV and EP7-F. EP-F72 tripped as a result at the EP end only. No pilot operation at F Sub, therefore no CB operation of F307.0. F relay operation checked during pilot re-commissioning and found to be ok. EP-F72 pilot does not have Pilot supervision. Intertrip from EP tp F only operates with EP LBU operation. Therefore this pilot operation is considered correct.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non</td>
<td>6666 GEN MU 0</td>
<td>4 24/9/2001 10:38:00</td>
<td>Human error trip, protection staff operated the wrong relay on the unit tx instead of the unit auxiliary tx. See IR 293, DMS 1011786.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non</td>
<td>6668 RTU GTN 0</td>
<td>1 5/10/2001 10:51:00</td>
<td>Servere lightning storm near GTN. District staff report direct line strike near GTN sub. Suspect this caused damage to the RTU at GTN which later resulted in spurious operation causing a TASS starting sequence. See also fault report 6667 for line fault and IR 295, DMS doc 1013156.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non</td>
<td>6678 GEN CPS 0</td>
<td>1 9/11/2001 3:07:00</td>
<td>CPS G1 tripped due to loss of water level control. UFLS stage I operation, (MGA 48.93 Hz).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non</td>
<td>6687 TX COL 0</td>
<td>1 26/11/2001</td>
<td>Human error during switching for maintainence. IR 303 from INS, DMS # 1048071.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 22.11. System Operation Disturbances Report

<table>
<thead>
<tr>
<th>SD No.</th>
<th>Date/Time</th>
<th>Circuit</th>
<th>Incident Code</th>
<th>Cause of Disturbance Code</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3333</td>
<td>01Jul01 15:23</td>
<td>OC T3</td>
<td>Forced with no Interruption</td>
<td>CB: Oil/Gas/Pressure</td>
<td></td>
</tr>
<tr>
<td>3334</td>
<td>08Jul01 02:15</td>
<td>NT-NOR 81</td>
<td>Fault with no Interruption</td>
<td>LINE: Failure</td>
<td>OC 515.0 &quot;Low Gas Trip/Close lockout &amp; LV TX/BS Trip Circuit Defective&quot; alarm operated. Feeders off loaded and OC T3 HV circuit breaker switched off. OC515.0 re-gassed and OC T3 and feeders normalised. Broken X-arm on pole 410 at Boondine Road, Clackline. (Nearest corner Auroanson Rd) The 132kV conductor fell on to the 22kV line. Only MGA end of line tripped. (TS 804.0 did not trip). Line de-energised to release seagull trapped on overhead earth wire.</td>
</tr>
<tr>
<td>3335</td>
<td>08Jul01 09:29</td>
<td>MGA-TS 82</td>
<td>Fault with no Interruption</td>
<td>Lightning/Thunderstorms</td>
<td>APLD operated due to fault on BLD615.0. (Coolgardie Feeder) Line restored after phone check with SCE control room. (Refer to SD3338) APLD operated due to fault on BLD615.0. (Coolgardie Feeder) Line restored after phone check with SCE control room. (Refer SD3337) Low oil level in SR1. SR1 de energised to allow oil level to be topped up.</td>
</tr>
<tr>
<td>3336</td>
<td>09Jul01 10:06</td>
<td>E-NF 72</td>
<td>Forced with no Interruption</td>
<td>Bird/Animal/Insect</td>
<td>Line tripped at TLN end only (TLN701.0) due to fault on LV side of transformer. Fault on 33kV feeder at BLD Substation. Tap changer runaway - tap 19 indicating 20.2 kV. Suspected blown or damaged VT fuse. Note: Transformer was switched out of service. Transformer taken out of service, low tap changer oil. Leaking around input drive shaft. Circuit breaker MRT 604.0 low gas, taken o.o.s. to re gas. Capacitor CB603.0 low gas, was re gassed. CB was not on at the time. Outage to regas MRT X15.0 circuit breaker.</td>
</tr>
<tr>
<td>3337</td>
<td>11Jul01 15:48</td>
<td>BLD-PRK 61</td>
<td>Fault with Interruption</td>
<td>APLD Protection</td>
<td>Feeder at BLD Substation tripped on fault switching. Fault on on 33kV feeder at BLD substation. Feeder at BLD Substation tripped on fault switching. TEM were working on MW 705.0 and accidently tripped MW 701.0. Mundaring Weir substation blacked out for less than one minute. Switching Programme SO10848 had transformers configured with T1 off and T2 and T3 in parallel. Controller incorrectly put T2 and T3 in auto after looking at the voltage control page which showed T2 and T3 in master. After a while T3 picked up the reactive</td>
</tr>
<tr>
<td>3338</td>
<td>11Jul01 15:48</td>
<td>BLD-WMS 81</td>
<td>Fault with Interruption</td>
<td>APLD Protection</td>
<td></td>
</tr>
<tr>
<td>3339</td>
<td>13Jul01 12:21</td>
<td>MRT SR1</td>
<td>Forced with no Interruption</td>
<td>CAP/REA/SVC: Oil/Gas/Pressure</td>
<td></td>
</tr>
<tr>
<td>3340</td>
<td>16Jul01 05:17</td>
<td>RV-TLN-VP 71</td>
<td>Fault with Interruption</td>
<td>Customers Equipment</td>
<td></td>
</tr>
<tr>
<td>3342</td>
<td>24Jul01 03:47</td>
<td>BLD-WMS 81</td>
<td>Fault with no Interruption</td>
<td>APLD Protection</td>
<td></td>
</tr>
<tr>
<td>3343</td>
<td>24Jul01 15:26</td>
<td>D T3</td>
<td>Forced with no Interruption</td>
<td>FUSE: Failure</td>
<td></td>
</tr>
<tr>
<td>3344</td>
<td>24Jul01 12:30</td>
<td>WE T1</td>
<td>Forced with no Interruption</td>
<td>TX: Failure</td>
<td></td>
</tr>
<tr>
<td>3347</td>
<td>24Jul01 14:31</td>
<td>MRT SR1</td>
<td>Forced with no Interruption</td>
<td>CB: Failure</td>
<td></td>
</tr>
<tr>
<td>3346</td>
<td>24Jul01 14:31</td>
<td>MRT CAP61A</td>
<td>Forced with no Interruption</td>
<td>CB: Failure</td>
<td></td>
</tr>
<tr>
<td>3345</td>
<td>24Jul01 14:11</td>
<td>MRT Equip not in a Cct</td>
<td>Forced with no Interruption</td>
<td>CB: Failure</td>
<td></td>
</tr>
<tr>
<td>3343</td>
<td>24Jul01 07:15</td>
<td>BLD-PRK 61</td>
<td>Fault with no Interruption</td>
<td>APLD Protection</td>
<td></td>
</tr>
<tr>
<td>3341</td>
<td>24Jul01 03:47</td>
<td>BLD-PRK 61</td>
<td>Fault with no Interruption</td>
<td>APLD Protection</td>
<td></td>
</tr>
<tr>
<td>3344</td>
<td>24Jul01 07:15</td>
<td>BLD-WMS 81</td>
<td>Fault with no Interruption</td>
<td>APLD Protection</td>
<td></td>
</tr>
<tr>
<td>3350</td>
<td>25Jul01 13:36</td>
<td>CT-MW 71</td>
<td>Fault with no Interruption</td>
<td>Maintenance Error</td>
<td></td>
</tr>
<tr>
<td>3354</td>
<td>27Jul01 10:39</td>
<td>CO T3</td>
<td>Fault with no Interruption</td>
<td>Switching Operation</td>
<td></td>
</tr>
</tbody>
</table>
To: Engineer Network Planning       From: Primary Assets Engineer

Thank you for the opportunity to comment on your long-term development plans in the South Fremantle and Cannington Terminal load area 66kV substations in the light of ageing equipment still in service in those substations.

Please find a general overview for the requested sites for the time being, bearing in mind that a more detailed and conclusive review would take more time.

That work will be organised over the next few months, and another feedback will be supplied later in the year.

**South Fremantle Load Area Substations:**

North Fremantle: Most equipment (CBs, CAPs, DES and some VTs) will require replacement in 8-12 years, with the indoor switchboard probably requiring replacement of the indoor oil filled circuit breakers over the next 5 years.

Edmund Street: Some CBs, CTs, DES, SAs and VTs will require replacement in 7-10 years.

O’Connor: Most equipment (CAP, CBs, CTs, DIS, DES and VTs) will require replacement in 8-10 years.

APM: Some equipment (CBs, CTs, DIS, SAs and VTs) will require replacement in 5-8 years.

Myaree: Some equipment (CBs, CTs, DIS, SAs and VTs) will require replacement in 5-10 years.

**Cannington Terminal Load Area Substations:**

Victoria Park: Most equipment (CA, CBs, CTs, DIS and VTs) will require replacement in 5-10 years.
Rivervale: Some equipment (CBs, CTs and VTs) will require replacement in 8-12 years.

Collier: Most equipment (CBs, CTs, DIS, SAs and VTs) will require replacement in 5-10 years, with the indoor switchboard probably requiring replacement of the indoor oil filled circuit breakers over the next 5 years.

Clarence Street: Some equipment (CBs, and VTs) will require replacement in 8-10 years. The indoor switchboard is planned for retirement in 2007, with a chance to have a failure before that date as it has low testing results of the main busbar insulation.

Tate Street: Some equipment (CBs, CTs, DIS and VTs) will require replacement in 10-12 years.

Mundaring Weir: Some equipment (CBs, CTs and DIS) will require replacement in 10-12 years.

We hope the above answers your initial query and additional information will be supplied as it comes to hand.
To: GM Networks        From: Primary Assets Engineer

BACKGROUND

Western Power (WPC) has participated in the ITOMS 99 benchmarking survey. The survey has used 1998 data.

INTRODUCTION

UMS has presented WPC with a summary of end results from the above survey. The results have highlighted the need to analyse the outcome for some items where the results indicate poor/bad performance by WPC in comparison to world and ANZ averages.

There are eight such areas, four line areas and four substation areas, and a summary of the analysis outcome is given below.

SUMMARY

Overhead Lines

132kV Line Maintenance

Maintenance Costs-15 % of costs reported incorrectly (cost of new replacement poles $300K),
- an abnormal year with 22 % of reported costs being for pole testing ($500K),
- an abnormal year with 12 % of reported costs being for line maintenance work to catch up with old problems ($250K),
- a reduction of 9 % of 1998 reported costs has now been achieved (from $400K to 200K) due to installation of leakage current (pollution) monitors on lines, and using their readings to reduce line washing costs.

Cost Conclusion: The total reported 1998 cost would be reduced by 58 %, or approx. 2.5 times, bringing it above ITOMS and ANZ averages.

Further savings are expected with implementation of improved assessment procedures for new work with our current service providers.

Service Levels-5 % of reported fault outages reported incorrectly (actually forced outages),
- 44% of reported fault outages are successful re-close operations, but performed manually. As their duration is therefore more than 1 minute they are deemed fault outages and not transient faults. They almost all originate due to lightning strikes during the summer season,

- 6% of reported fault outages are caused by others (eg customer trips, car vs pole, vandalism etc),

- 16% of all reported fault outages line returned to service with no cause found,

- 5% of all reported fault outages caused by external bushfires,

- 24% only of all reported fault outages caused by actual line equipment faults.

**Service Levels Conclusion:** The service level could be reduced by 52%, or approx. 2 times, bringing it to EURO and ANZ averages.

That would be achieved by installation of auto re-close equipment or construction of overhead wires to prevent impact of lightning strikes on all lines seasonally affected by lightning during summer season (ie remove the affect of the fault quickly or avoid the fault altogether).

It is doubtful we would justify the expense against the performance benefit gained. Some improvements could be made by reviewing the practice of not re-closing on some lines, as no permanent faults have been discovered.

**220-330kV Line Maintenance**

**Maintenance Costs**-an abnormal year with 45% of reported costs being for one cyclone event ($182K),

- a reduction of 25% of 1998 reported costs has now been achieved (from $125K to $25K) due to installation of leakage current (pollution) monitors on lines, and using their readings to reduce line washing costs.

**Cost Conclusion:** The total reported 1998 cost would be reduced by 70%, or approx. 3 times, bringing it to the ITOMS best performance.

**Service Levels**-50% of reported fault outages (3) are successful re-close operations, but performed manually. As their duration is therefore more than 1 minute they are deemed fault outages and not transient faults. They almost all originate due to lightning strikes during the summer season.

- 17% of reported fault outages (1) are caused by external bushfires,

- 33% only of all reported fault outages (2) caused by actual line equipment failure, and these 2 outages were actually the same incident (HIW micro burst).
Service Levels Conclusion: Firstly, the extremely small sample size (6) makes the statistical analysis meaningless and the numbers volatile. Secondly, the service level could be reduced by 50%, or approx. 2 times, bringing it to ITOMS and ANZ averages.

That would be achieved by installation of auto re-close equipment or construction of overhead wires to prevent impact of lightning strikes on all lines seasonally affected by lightning during summer season.

The abnormal event (microburst) is not expected to re-occur which will further improve reported service level to ITOMS best performance.

132kV and 220-330kV Line Patrol/Inspection

Maintenance Costs - Best performer.

Cost Conclusion: No comment, as the cost is very low.

Service Levels-Calculated from the above line service levels (number of line fault outages).

Service Levels Conclusion: Comments from maintenance items above are applicable here as well. With the changes implemented as indicated, line patrols and inspection service levels would be at or above the ANZ and ITOMS averages.

Overall Conclusions: We can expect significant improvement in the results from the next ITOMS, especially in cost. We may have to accept the limited lightning performance of our lines.

No major differences or deficiencies have been identified in our maintenance and asset practices in comparison to the best practice themes listed by UMS.

SUBSTATIONS

132kV Transformer Maintenance

Maintenance Costs - Best performer.

Cost Conclusion: No comment, as the cost is very low. Some increase in cost possible with the introduction of the dielectric testing during routine maintenance, but detecting problems early should reduce repair costs.

Service Levels-24% of reported fault outages are switching errors,
- 18% of reported fault outages are distribution feeder re-close operations on very close in faults that the LV breaker cannot handle,
- 18% of reported fault outages are caused by other plant failures,
- 40% of reported fault outages are caused by non-operational reasons (vandalism, birds, lightning, and cars/pole).

**Service Levels Conclusion:** The service level could be reduced by 42%, or approx. 2 times, bringing it to the ANZ average by eliminating switching errors and by installing fault distance sensitive o/c relays on feeder circuit breakers to avoid re-close on very close faults.

Further improvements could be made by reviewing the non-operational fault outages to determine if better access restrictions, phase clearances/insulation and lightning protection practices should be introduced.

**220-330kV Circuit Breakers Maintenance**

**Maintenance Costs:** 90% of costs are caused by three units of one type of breaker, 330kV Brown Boveri.

**Cost Conclusion:** The cost area remains uncertain even though we are replacing the three problem units through a capital project. Seven units of the same type remain in service.

They can have similar type failures at any time and, depending on the estimated costs, a decision will have to be made on a case by case basis to repair them or to replace them.

**Service Levels:** 50% of reported fault outages (2) are 330kV Brown Boveri type,
- 25% of reported forced outages (1) is caused by a gas loss of GEC FE2 type,
- 25% of reported forced outages (1) is caused by a gas loss of ASEA HPL type.

**Service Levels Conclusion:** Firstly, the extremely small sample size (4) makes statistical analysis meaningless and the numbers erratic.

Secondly, the service level could only be significantly reduced from the 4 faults experienced by removing all outstanding Brown Boveri units and a full refurbishment of all FE2 and HPL units. This would obviously incur a very high capital cost to remove a very small number of events.

Our present policy is to monitor the performance of the breakers and repair the faults as they occur. We will make a decision to replace the breakers as/if we find their actual costs too high compared to expected life...
cycle costs. Operations have not put a high risk priority on the outages, as they are happy with available redundancy in the switchyards.

Therefore we do not expect improvement in the service levels for the next ITOMS.

132-220-330kV Disconnector & Earth Switch Maintenance

Maintenance Costs - Best performer.

Cost Conclusion: No comments, as cost are very low.

Service Levels-20 % of reported fault outages (1) reported incorrectly (multiple operation),
- 40 % of reported fault outages (2) are on one faulty unit,
- 40 % of outages (2) were reported as forced because a repair crew happened to be on site and an outage arrange immediately. Otherwise these would have been done as planned work and not counted in the ITOMS service levels.

Service Levels Conclusion: Firstly, the extremely small sample size (4) makes statistical analysis meaningless and the numbers erratic.

The service level would be very difficult to predict in view of a very few outages. Further inquires will be made with some of the best performers to confirm that they reported only one or zero outages and their practices to achieve this.

132-220-330kV Instrument Transformers & Other Equipment Maintenance

Maintenance Costs - Best performer.

Cost Conclusion: No comment, as the cost is very low. Some increase in cost possible with the introduction of the dielectric testing during routine maintenance, but detecting problems early should reduce repair costs.

Service Levels-40 % of reported fault outages (3) reported incorrectly,
- 15 % of reported fault outages (1) due to lightning strike,
- 15 % of reported forced outages (1) due to detected low oil to prevent explosion,
- 15 % of reported fault outages (1) due to vandalism,
- 15 % of reported fault outages (1) due to plant failure before testing.
Service Levels Conclusion: Firstly, the extremely small sample size (4) makes statistical analysis meaningless and the numbers erratic.

The service level could be reduced by 40 %, or approx. 2 times, bringing it to above the ANZ and ITOMS averages by eliminating data input error.

The future service levels would be very difficult to predict in view of a very few outages. Further inquires will be made with some of the best performers to confirm that they reported only one or zero outages and their practices to achieve this.

OVERALL CONCLUSIONS:

- We can still expect some improvement in the results from the next ITOMS;

- No major differences or deficiencies have been identified in our maintenance and asset practices in comparison to the best practice themes listed by UMS.
To: Manager Maintenance  From: Primary Assets Engineer

BACKGROUND

Western Power (WPC) participated in the ITOMS 1999 benchmarking survey. The survey used 1998 data.

INTRODUCTION

UMS has presented WPC with a summary of end results from the above survey.

The results have been analysed, and the areas highlighted where there was a need to further analyse poor/bad performance by WPC in comparison to world and ANZ averages.

The analysis is presented in the memo to General Manager dated 16 March 2000 (#383416).

One of the items is line maintenance cost, and it has been accepted that the maintenance policy & instruction defined process for the line maintenance has not been fully implemented.

SUMMARY

It is now the right time to discuss the best way of to implement, an also improve if possible, the procedure for line maintenance work with our main service provider, Line & Cable Maintenance Section, Westpower Services Branch, by the end of this financial year.

This review should involve Line&Cable Maintenance Section, Maintenance Management Section, and Primary Assets Section.

CONCLUSION

The Primary Assets Engineer will call an initial meeting to set up scope of work and working arrangements in early May 2000.
22.15 Asset Management Model and Process Audit

REVIEW OF WPC ASSET MANAGEMENT PROCESS-PB POWER

Asset management in WPC is described in the following series of documents:

- Asset Management Policy for Transmission Assets
- Asset Management Process for Transmission Division
- Asset Management Procedures for Transmission Division
- Business Case Analysis for Transmission Division

The Policy identifies that the long-term asset management plans will be prepared annually based on the following data:

- Age
- Condition service requirement
- Future role
- Consequence and probability of failure
- Environment
- Decay predictions
- Life cycle costs
- Potential for obsolescence
- Business needs

All proposals for major expenditure on assets are prepared in accordance with an approved process. Critical assets are ranked according to a standard risk matrix process and expenditure prioritised accordingly.

The asset management process has been in place for a limited time and therefore the success of the process in terms of the achievement of set reliability targets and optimisation of maintenance and capital expenditure cannot be assessed at this time.

The process also does not as yet incorporate the creation of new assets or the augmentation of existing assets required meeting future load requirements.

This integration of the asset maintenance/replacement process and the planning process is to be undertaken in the near future.
The asset management process combines condition based maintenance and reliability centred maintenance in order to achieve optimum performance of the assets at least cost. In accordance with modern practice, time based maintenance activities are programmed as a result of the consideration of the condition of the assets and the risk of failure.

Replacement of assets is based on a business case evaluation of the least cost option including the risk of failure over the life of the asset.

The asset management process also incorporates a review of maintenance procedures where this is identified as necessary as a result of the detailed investigation of the condition of a particular asset class or type.

Maintenance periods are lengthened or shortened depending on the specific requirement or recommendation.

The asset management process described in the WPC documents is comprehensive and should ensure that expenditure is focussed in the areas identified as requiring attention.

Provided that the process is followed and adequately monitored and that the information systems are put in place and resources are made available to provide the data and reviews that are required, PB Power believe that the resulting expenditure forecasts will be reasonable.

The asset management model used by WPC in this asset management process allows objective data on the condition of each group of assets, in the form of the expected remaining life of that group of assets, to be used to generate the replacement requirements.

This process is very similar to the process followed by the asset replacement and capital forecast model of the PB Power
INTRODUCTION

Ever since the Transmission Maintenance Branch has been created, and a decision to give it full responsibility for the Transmission Division's maintenance function, it has been our clear understanding that management of maintenance practices and costs must be our number one priority.

There are a number of reasons for it, but the two main ones will certainly have to be:

- Our desire to achieve optimum maintenance practice with minimum costs in order to maximise our contribution to the transmission business.

- With the introduction of an open access regime to the transmission system, our maintenance practices and costs will come under the close scrutiny of all future users.

They will have to be convinced that the procedures and associated costs are achieving the world's best practice results, or that procedures are in place how to get to the required targets in a reasonable time period.

All this must be subject to the overriding priority of always maintaining the safety of public and employees.

In order to answer the above challenges, the Maintenance and Power Services Branches have initiated a review of some areas by a dedicated working group (WG) of our Maintenance Policy and Maintenance Services Manuals, as documented below.

Additionally, the WG is to take into consideration obtained results of the recent UMS ITOMS 1997 benchmarking survey of international companies involved in the electricity supply industry and the switchgear maintenance.

This report provides the findings and produced recommendations of the WG on how to further improve the procedures and practices as defined in the above two Maintenance Manuals.

The review took place over a nine-month period. The items, chosen to be reviewed first, had been initially assessed as the ones representing maximum possible savings as far as resources and overall costs were concerned.
EXECUTIVE SUMMARY

The Working Group finds that:

1. The electrical inspection rounds of metro terminal stations can easily be incorporated in their regular instrument rounds, already performed by the PSB Controls Section. Details provided later in the document;

2. There is a possibility to significantly reduce regular intrusive time based disconnector and earthing switch maintenance activities. Ditto;

3. There is a possibility to reduce the frequency of regular time based instrument and electrical rounds of zone substations following a comprehensive testing programme undertaken and completed during the last three years. Ditto;

4. There is probably no need to continue with manual washing and cleaning of switchyard insulators when the live switchyard washing is introduced. Ditto;

5. There is a need to introduce live washing of substations on a regular basis with the choice of substations and their washing frequency based on the critical position of the site and pollution type and severity. The need for washing of other sites can be determined annually, using pollution assessments during regular site inspection rounds, and installed pollution monitor readings;

6. Thermographic survey of all our substations needs to be introduced on an annual basis timed to line up with the particular site maximum loading period for the high voltage side. For feeders, switching programmes to ensure maximum feeder current is available during the survey;

7. The Galileo Circuit Breaker Types ORE20, ORE30, and ORE36 could have their frequency of maintenance increased from every one to every two years. The maintenance interval triggered by the numbers of faults be increased from two to five breaker fault operations;

8. The Metro Vickers Circuit Breakers Bulk Oil Type existing maintenance procedure could be changed by introducing three different levels of maintenance instead of the existing one level only. From now on only the lowest level of maintenance will be done regularly every four years or after a prescribed number of fault operations. The results of that level of activity will then be used to determine if level two or level three are required, instead of the current practice to do just level three every time;
9. GEC Circuit Breakers Bulk Oil Type OD existing maintenance procedure could be changed by introducing three different levels of maintenance instead of the existing one level only. From now on only the lowest level of maintenance will be done regularly every four years or after a prescribed number of fault operations. The results of that level of activity will then be used to determine if levels two or level three are required, instead of the current practice to do just level three every time;

10. The WG will continue its activities to analyse the contents of both Manuals, and will initiate further reviews and/or actions where it finds appropriate.
**22.17 Plant and Line Failures Report**

**Introduction**

The attached tables present you with the fault statistics for our transmission primary plant & lines, with a summary of the main issues outlined below.

**Primary Plant**

There were 151 faults in the period July - December 2001. For main contributing plant items see page 5:

- Circuit Breakers had 72 faults.
- Current & Voltage Transformers had 15 faults.
- Power Transformers had 31 faults.
- Disconnectors & Earthswitches combined had 7 faults.
- Circuit Breakers with CTs had 21 faults.
- Others had 5 faults (capacitors, surge arresters, reactors and busbars).

There were five fault outages during this period, as described below:

1. Kalamunda Substation-T3 Cct-internal fault in the transformer;
2. Hay Street Substation-T1 Cct-internal flashover in 317.0 circuit breaker;
3. Cannington Terminal-66kV capacitor (Cap72)-loose connection;
4. Cunderdin Substation-T2 Cct-Tap changer failure in the transformer;
5. Margaret River Substation-T1 Cct-W phase fuse failure.

The percentage of failures for the above period is 2.5%, down from 2.93% in July 2001, and is based on the current primary plant population of 12072. (The target for percentage of plant failures for 2001/2002 is 2.1%. This target decreases annually by 0.2%.)

There have been three failures of plant still under warranty during this period:

1. Merredin Substation-22kV CB (516.0)-Gas leak;
2. Picton Substation-22kV CB (503.0B)-Y ph insulator broken at base;
3. Hay Street Substation-11kV CB (317.0)-Flash over.
Lines

There were 10 line faults during that period with major outages shown below:

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<th>Major Outages</th>
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The conductors were found on ground on one occasion in MGA TS 82 line due to a pole top fire.

The ratio of line failures for the above period is 0.3 and is based on transmission line length of 6750 km. (The target for line failures for 2001/2002 is 0.75.)

Graphs relating to the failure rate of substation plant and lines are presented on page 429.
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Description of Fault Codes

F – Faults which cause loss of supply (forced outages)
FV  Violent, explosive type of failure.
FM  The unit is repaired on site after failure.
FR  The unit is removed from site and discarded.
FRR The unit is removed from site, repaired and returned to site or to store.

M – Faults which do not cause loss of supply, and allow units in service until an outage can be arranged.
MM  The repairs are completed on site.
MR  The unit is removed from site and discarded.
MRR The unit is removed from site, repaired and returned to site or to store.

Note: The defect on MRT SR1 reactor is not shown on the above table.
## DETAILS OF MAJOR DEFECT CONTRIBUTORS
(2 or more failures)

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FUTURE WORK ASSOCIATED WITH MAJOR DEFECT CONTRIBUTORS

1. **Galileo 22kV Circuit Breakers – Type ORE.20**
   26 of these units will be replaced under the project 57211 before the end of 2003 and the remaining 28 units will be replaced before the end of 2004 under the project T0034382.

2. **Alstom 22kV Circuit Breakers – Type GL107**
   A gas leaking problem and an unsuitable part in the mechanism have been identified at the early stages. The unsuitable parts are being replaced at the moment at manufacturer’s cost.

3. **REYROLLE 66kV Circuit Breakers – Type 66. OSM. 10X1**
   Three complete spare breaker poles have been retained for replacements in major incidents. Individual planned CB replacements will continue if the cost for repairing leaking poles is too high.

4. **GEC 132kV Circuit Breakers – Type FG1B**
   The worst performing breaker will be replaced and refurbished to use as the replacement for the next worst performing breaker. This process will be repeated as necessary.

5. **Yorkshire 22kV Circuit Breakers – Type YSF6**
   16 units are recommended for refurbishment.

6. **GEC 33kV Circuit Breakers – Type FK1 – SF6**
   Three of these units will be replaced under project T0028388 in 2001 and another four units under project T0056700 in 2002. The performance of the remaining units is to be continuously monitored.

7. **Endurance Electric Voltage Transformers – Type DK. SVT.132**
   30 of these units are being replaced under the project T0032684. The remaining 21 units will be replaced under the project T0045902 in July/August 2002.
## 22.18 Asset Failures Report

### TRANSMISSION ASSETS BRANCH

#### UNITS DEFECT REPORT

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## 22.19 Asset Performance/Population/Attrition Report

### TRANSMISSION ASSETS BRANCH

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MANAGEMENT OF THE FAILURE OF LOW VOLTAGE INDOOR SWITCHBOARDS

INTRODUCTION

There are a number of older substations that have indoor bulk oil/compound filled switchboards. Over a period of years deterioration of the insulation can lead to failure of these switchboards. In addition the onerous switching duty required of some switchgear (in particular those on capacitor circuits) can lead to mechanical failure of the switchgear. Failure of these switchboards can result in major fire and smoke damage to equipment in the building in which the switchboard is housed. In the event that a catastrophic failure of a switchboard occurs there needs to be a plan to restore supply to customers within an agreed period of time.

Switchboard failures have already occurred at three substations and the switchgear at a fourth was consider to be in such a poor condition that it was taken out of service. It is noted that in two of the cases mechanical failure of the switchgear is strongly suspected. Tests on the switchgear have shown some to have insulation in a very poor condition. This effectively means that any of the indoor switchboards can be regarded as being at risk of failure.

This report describes the aims and scope of the project, and provides recommendations for short and longer-term contingency plans. Detailed contingency plans will be provided in separate documents.

TERMS OF REFERENCE

The terms of reference for the project team were generally as follows:

- Identify the “high risk” indoor switchboards/substations;
- Identify substations at risk of rotation for extended periods;
- Agree with Network Services Division the extent of Distribution Transfer Capacity (DTC) available;
- Develop an outline of a contingency plan for these substations;
- Establish the level of service required by Network Services Division for supply restoration;
- Review/enhance stocks of strategic spares, including reclosers;
• Develop an operational contingency plan to quickly achieve maximum DTC and restore supply to critical feeders, including use the possible use of mobile generators;
• Review the benefits of purchasing a mobile substation.

It should be noted that this report does not consider the requirements for managing the failure of the substation high voltage switchgear nor the failure of the substation transformers. These are the subjects of separate contingency/response plans.

In most cases the substation high voltage switchgear and transformers are outside the switchgear building and the risk of the catastrophic failure of the low voltage switchboard also involving them is extremely low.

In the case of a substation transformer, if a failure does occur it is expected that the appropriate Rapid Response Spare Transformers would be mobilised as part of the response plan.

**SUBSTATIONS WITH INDOOR SWITCHGEAR**

A list of the substations that have indoor switchgear is given in Appendix.

A program of testing for the switchboards listed in Appendix is currently being carried out using the initial assigned priority order specified.

The purpose of this program is to provide an ongoing assessment of the condition of the switchboards. Based on the results of the tests the switchboard is assigned a condition category that indicates the level of risk of failure.

The current category assignment based on the tests is indicated in the table. Where no category has been assigned the switchboard has not been tested.

The tests are based on similar tests carried out by power utilities in Australia and Europe and are considered to represent world best practice.

The tests are ongoing and the interval to the next test is based on the assessed condition of the switchboard.

The substations in the first three initial assigned priority groups have been identified as being at greatest risk of fire and smoke damage due to their bulk oil and/or compound content in their plant.
The substations listed in the fourth group have more modern switchboards (some using SF6 gas), and are considered to have a very low risk of fire and smoke damage.

The Transmission Assets should continue to monitor the state of the indoor switchboards and update the assignment of the risk category based on the results of the ongoing tests.

Note that it is not intended to make provision for switchboard failure at Central Business District substations, as these are designed with design criteria that allow for the complete loss of supply to the substation.

LEVEL OF SERVICE

The required time for full restoration of supply is critical to the extent of the contingency plan and to the level of resources needed.

The requirements for restoration of supply will have a major bearing on the manner in which restoration is carried out and the resources needed.

A Service Level Agreement has been signed between the Marketing and Sales Division and Transmission Division.

Amongst other items this agreement requires that, in the event of a catastrophic failure of a switchboard, full supply must be restored to the substation within two weeks.

However, this report focuses on strategies designed to meet two-week, one-week and one-day restoration times.

SHORT TERM ACTION

6.1 Catastrophic Failure

Action must be taken immediately the catastrophic failure of a switchboard occurs to restore supply. The most immediate action that can be taken is to utilise the Distribution Transfer Capacity (DTC) between the substation concerned and adjacent substations.

The Network Operations Controllers must take this action as soon as the System Operations Controllers confirm the switchboard failure. It is expected that the utilisation of DTC will take up to 2 hours to implement.

The available DTC between substations may be limited by the loading of the transformers and feeders at the adjacent substations. Where this is the case it may be possible to provide additional DTC by offloading adjacent substations using the DTC between them and other substations adjacent to
them. It is expected that the Network Operations will be able to provide any additional DTC within one day.

Where the available DTC cannot match the expected load demand, it is expected that the Network Operations will manage the situation by implementing planned rotation of load together with other means of reducing load.

Due to the way substations are now being operated it is expected that the levels of DTC available will reduce. The new Normal Cyclic Rating (NCR) criteria allows the transformers at substations to be loaded up to about 90% of the Long Term Emergency Rating (LTER).

The consequence of this is that as more substations reach this limit both the amount of DTC available and the ability to offload to adjacent substations will be limited by the loading of the transformers and not by the distribution network.

A number of the substations listed in Appendix have DTC limited due to the fact that the distribution voltage level is not the same as that used in adjacent substations. In some cases there is no DTC available.

6.2 High Risk Switchboards

If switchboard testing reveals that a substation switchboard is at risk of failure it will be necessary to have a contingency plan to deal with any failure in the short term.

When a switchboard has been identified as being at high risk of failure, System Operations will liaise with the Network Operations and other Transmission areas and a decision will be made on what action is to be taken to reduce the impact of a failure.

It is expected that in these cases temporary arrangements will be put in place to enable the switchboard to be removed from service and in due course replaced by a new switchboard.

This is expected to be a planned process not requiring immediate action.
RECOMMENDATIONS

It is recommended that:

- A contingency plan for the catastrophic failure of LV indoor switchboards is prepared based on the use of an emergency switchboard consisting of a pre-built, trailer mounted, metal frame complete with reclosers, auxiliary transformers and protection, control and communications facilities.
  
  Action: Manager Engineering

- The Transmission Engineering proceed with the design of an emergency switchboard consisting of a pre-built, trailer mounted, metal frame complete with reclosers, auxiliary transformers and protection, control and communications facilities.
  
  Action: Manager Engineering

- The Transmission Assets should continue to monitor the state of the indoor switchboards and update the assignment of the risk category based on the results of the ongoing tests.
  
  Action: Manager Transmission Assets

- The Substation Design should review the layout of each of the critical substations included in Appendix to confirm that there is sufficient space for the emergency switchboard.
  
  Action: Manager Engineering

- The Protection Design should review the protection arrangements at the remote ends of all transmission lines supplying substations that have indoor switchboards and determine the most suitable arrangements for providing temporary radial protection for inclusion in the contingency plan.
  
  Action: Manager Engineering