Development of an ISO 55000 Compliant Central Management Framework for Asset Care Plans within a Multi-Technology Portfolio of Renewable Energy Power Plants in the South African Energy Sector

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering in Engineering Management in the Faculty of Engineering at Stellenbosch University

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Declaration

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Date: ....December 2016.......

Abstract

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The conventional philosophies adopted to develop Asset Care Plans (ACPs) (tactical and non-tactical maintenance plans) for Renewable Energy Power Plants (REPPs) are often not sophisticated and therefore adequate to optimise asset performance. There is a need to utilise more sophisticated methods to develop ACPs using philosophies such as Reliability Centred Maintenance (RCM) combined with economic evaluation methods such as Asset Life-Cycle Analysis (ALCA) or other considerations such as obsolescence. Specialised skills are often required to assist in developing ACPs. The Renewable Energy (RE) industry in South Africa (SA) is in its infancy and thus offers a shortage of competency within the RE sector. The competency challenges combined with limited information sharing by Original Equipment Manufaturers (OEMs) creates a potential void in the capability of SA Asset Managers to develop ACPs for RE assets. Once ACPs have been developed they need to be continuously managed in terms of development, planning, execution and optimisation. The work planning and control, continuous improvement and competency management functions play a key role within the overall management function but need a business process to underpin the function and identify support tools.

The SA RE projects often have complex management or ownership structures. A management team could consist of an Asset Owner or shareholders, an Asset Manager managing the asset overall and the OEM performing the maintenance for an extended period as part of a service agreement. Having a clear Asset Management (AM) framework can create an operating environment where all stakeholders can work towards common goals and a Line-of-Sight can be established between the Organisational Strategic Plan (OSP), AM objectives, AM strategies, asset planning and the daily AM activities. Cases exist where a single Asset Manager or management organisation is responsible for managing a portfolio of RE projects constituting different technologies such as wind and solar Photovoltaic (PV). This provides an opportunity to centralise AM and other organisational functions. Exploiting central management platforms and resources are furthermore becoming increasingly important for AM service providers and project developers to remain competitive in the RE market where costs and tariffs are continuously declining.

The problem is that there is no framework aligned to an AM framework such as ISO 55000, that can guide Asset Managers to develop and manage ACPs for a multi-technology portfolio of REPPs. The study addresses the problem by developing a framework and business processes which can be used to establish the core strategic and planning requirements of the ISO 55000 series of standards; to use sophisticated maintenance philosophies to develop, execute, manage and optimise adequate ACPs; to facilitate continuous improvement with an emphasis on competency management to address scarce skills and optimise ACPs; and to understand the possibilities regarding centralisation, while remaining aligned with the ISO 55000 series AM framework.

The study developed a Central Management Framework (CMF) which was validated using face and user validation. The CMF was found to be substantially suitable and able to address many of the existing challenges within the SA RE sector.

Uittreksel

Die Ontwikkeling van ’n ISO 55000 Belynde Sentraal Bestuurde Bate Sorg Planne vir ’n Multi-tegnologie Portefilje van Hernubare Energie Krag Staties in die Suid Afrikaanse Energie Sektor

(“Development of an ISO 55000 Compliant Central Management Framework for Asset Care Plans within a Multi-Technology Portfolio of Renewable Energy Power Plants in the South African Energy Sector”)

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Die konvensionele filosofieë rondom die ontwikkeling van batesorgplanne (BSP’s) (takties en nie-takties) vir hernubare energie kragaanlegte (HEKA’s) is gewoonlik nie gesofistikeerd nie en dus nie voldoende vir optimale bate prestasie nie. Daar is ’n behoefte om meer gesofistikeerde metodes te benut om BSP’s te ontwikkel deur gebruik te maak van filosofieë soos betroubaarheidssentreerde onderhoud (BSO) gekombineer met ekonomiese evaluasie metodes, soos bate lewenssiklus koste analise (BLKA), of ander oorwegings soos uitgediendheid. Gespesialiseerde vaardighede word gewoonlik benodig in die ontwikkeling van BSP’s. Die hernubare energie (HE) industrie in SA is nog besig om the ontwikkel en dus ontstaan ’n tekort aan bevoegdheid in die HE sektor. Die bevoegdheidsuitdagings gekoppel aan beperkte inligtingsdeling deur oorspronklike toerusting vervaardigers (OTV’s) skep ’n potensiële vakuum in die kapasiteit van SA bate bestuurders om BSP’s te ontwikkel vir HE bates. Sodra BSP’s ontwikkel is, is dit nodig dat dit deurlopend bestuur word in terme van ontwikkeling, beplanning, uitvoering en optimalisasie. Die werksbeplanning en beheer, deurlopende verbetering en bevoegdheidsbestuur funksies speel 'n sleutel rol in die oorhoofse bestuursfunksie maar benodig 'n besigheidsproses om die funksie te onderlê asook om ondersteunings hulpmiddels te identifiseer. Die SA HE projekte het gewoonlik komplekse bestuurs- en eienaarskap strukture. 'n Bestuurspan kan bestaan uit 'n batebestuurder of aandeelhouers; 'n batebestuurder om die bate oorhoofs te bestuur en die OTV om die onderhoud oor 'n verlengde tyd uit te voer volgens 'n diensooreenkoms. Deur 'n omvattende batebestuur (BB) raamwerk te hê , kan 'n bedryfsomgewing geskep word waar alle belanghebbendes kan werk na algemene doelwitte en 'n lyn van sig gevestig word tussen die organisatoriese strategiese plan, BB doelwitte, BB strategieë, batebeplanning en die daaglikse BB aktiwiteite. Gevalle bestaan waar 'n enkele bate bestuurder of bestuursorganisasie verantwoordelik is vir die bestuur van 'n portfolio van hernubare energie (HE) projekte bestaande uit verskillende tegnologieë soos wind en son energie. Dit skep 'n geleentheid om batebestuur asook ander organisatoriese funksies te sentraliseer. Dit word ook al hoe meer belangrik vir batebestuur diensverskaffers en projekontwikklelaars om voordeel te trek uit die sentralisering van stelsels en om hulpbronne te benut om sodoende mededingend te bly in 'n HE mark waar kostes en tariewe aanhou daal.

Die probleem is dat daar geen raamwerk bestaan wat belyn is met 'n BB raamwerk soos ISO 55000, wat riglyne kan bied aan batebestuurders om BSP's te ontwikkel en te bestuur vir 'n multi-tegnologiese portfolio van HEKA's nie. Die studie spreek die probleme aan deur 'n raamwerk en besigheidsprosesse te ontwikkel wat gebruik kan word om: die kern strategiese en beplannings vereistes van die ISO 55000 reeks van standaarde te vestig; gebruik te maak van gesofistikeerde onderhouds filosofieë om voldoende BSP's te ontwikkel, uit te voer en te optimaliseer; aanhoudende verbetering te fasiliteer met die klem op bevoegdheidsbestuur om skaars vaardighede asook die optimalisasie van BSP's aan te spreek; en die moontlikhede rondom sentralisasie te verstaan terwyl dit in lyn bly met die ISO 55000 reeks BB raamwerk.

Die studie het n sentrale BB raamwerk ontwikkel wat deur aansig- en gebruiker validasie bevestig is. Die sentrale BB raamwerk is bevind om geskik te wees om die probleme in the Suid Afrikaanse hernubare energie (HE) industrie aan te spreek.

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- My family, for their support.
- Our Heavenly Father, for giving me the strength and determination to complete this project.

The Author December, 2016

Dedications

This thesis is dedicated to my Father, Lincoln Peter Robert Saunders, who unexpectedly passed away on April 13, 2016. An academic and scholar at heart whose knowledge and intellect will surpass, astound and inspire family generations to come. I know you would have been proud. My our bond grow in knowledge and through contributing to the world around us. Love you always.

Contents

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Acronyms

ACP	Asset Care Plan
ACPD	Asset Care Plan Development
AIS	Asset Information Strategy
ALC	Asset Life-Cycle
ALCA	Asset Life-Cycle Analysis
ALCM	Asset Life-Cycle Management
AM	Asset Management
AMBOK	Asset Management Body of Knowledge
AMP	Asset Management Plan
AMS	Asset Management System
BSI	British Standards Institution
CAPEX	Capital Expenditure
CBM	Condition-Based Maintenance
CdM	Condition Monitoring
CM	Corrective Maintenance
CMF	Central Management Framework
CMMS	Computerised Maintenance Management System
COFA	Consequence of Failure Analysis
COFCATs	Consequence of Failure, Cause Analysis and Task Selection
DA	Direct Agreements
DMAIC	Define-Measure-Analyse-Improve-Control
DMS	Daily Maintenance Schedule
DOM	Design-out maintenance
DSS	Decision Support System
DTMM	Delay-time Maintenance Mathematical Model
EPC	Engineering Procurement and Construction

FFM	Failure-Finding Maintenance
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode and Effects and Criticality Analysis
FRACAS	Failure Recording and Corrective Action System
FTA	Fault Tree Analysis
GFMAM	Global Forum on Maintenance and Asset Management
GW	Gigawatt
GWh	Gigawatt Hours
HAZOPS	Hazard and operability studies
HR	Human Resource
HSE	Health Safety Environment
IAM	Institute of Asset Management
IPP	Independent Power Producer
ISO	International Organisation for Standardisation
ISP	Independent Service Provider
IT	Information Technology
KPI	Key Performance Indicator
KPM	Key Performance Measurement
KW	Kilowatt
KWh	Kilowatt Hours
LC	Life-Cycle
LCC	Life-Cycle Cost
LoS	Line-of-Sight
MO	Maintenance Optimisation
MOC	Management of Change
MOM	Maintenance Optimisation Models
MW	Megawatt
O&M	Operations and Maintenance
OED	Oxford English Dictionary
OEM	Original Equipment Manufaturer
OPEX	Operational Expenditure
ORHVS	Operating Regulations for High Voltage Systems

OSMT	On-Site Maintenance Team
OSP	Organisational Strategic Plan
OWAS	One Week Advance Schedule
PAM	Physical Asset Management
PAS	Publicly Available Specification
PCM	Planned Corrective Maintenance
PdM	Predictive Maintenance
PM	Preventative Maintenance
PR	Performance Ratio
PV	Photovoltaic
RBM	Risk Based Maintenance
RCA	Root-cause analysis
RCAM	Reliability Centred Asset Maintenance
RCM	Reliability Centred Maintenance
RE	Renewable Energy
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REPP	Renewable Energy Power Plant
RMC	Remote Monitoring Center
RTF	Run to failure
SA	South Africa
SAMP	Strategic Asset Management Plan
SBO	Single Buyers Office
SCADA	Supervisory Control and Data Acquisition
SJ	Standard Job
SMART	Specific, Measurable, Achievable, Realistic and Time-bound
SPV	Special Purpose Vehicle
TBM	Time-based Maintenance
TBPM	Time-Based Preventative Maintenance
TCM	Turbine Condition Monitoring
TPM	Total Productive Maintenance
UCM	Unplanned Corrective Maintenance
WHAF	Work Hours Availability Forecast
WO	Work Order
WOS	Work Order system

Glossary

Asset

An item, thing or entity that has potential or actual value to an organisation.

Asset Care

Asset care does not only speak to maintenance but all stakeholders that have an interest in the reliable and optimal performance of plant and equipment while trying to find a balance between safety, availability, performance and cost within the bounds of long term needs and short term constraints.

Asset Care Plan

Term used to describe the combination of tactical (preventative maintenance) and non-tactical (corrective maintenance) activities that has been structured as part of a maintenance strategy or Asset Care.

Asset Management

The coordinated activity of an organisation to realise value from assets (where realisation of value involves the balancing of costs, risks, opportunities and performance benefits).

Asset Manager

The organisation could have a minority or majority shareholding in RE power generation assets and in addition to the shareholding also manages the assets. Alternatively an asset manager could manage the REPP on behalf of the RE Asset Owners. The asset manager would have an interest in developing an Asset Management System (AMS) to improve the management of the assets they manage.

Asset Owner

The organisation who has minority or majority shareholding in REPPs and would have in interest in developing an AMS to improve the management of the assets they own. An asset owner can directly manage REPPs it has a stake in or can contract out the management function.

Craft

Synonymous with trade and within this context can refer to solar technician, electricians, millwright, wind turbine technicians, etc.

Line-of-Sight

Clear alignment between the overall business objectives and the daily activities. Alignment should be established in such a way that the staff on the ground are able to link their daily tasks, via a clear path of plans, objectives and strategy statements, to aspects of the OSP.

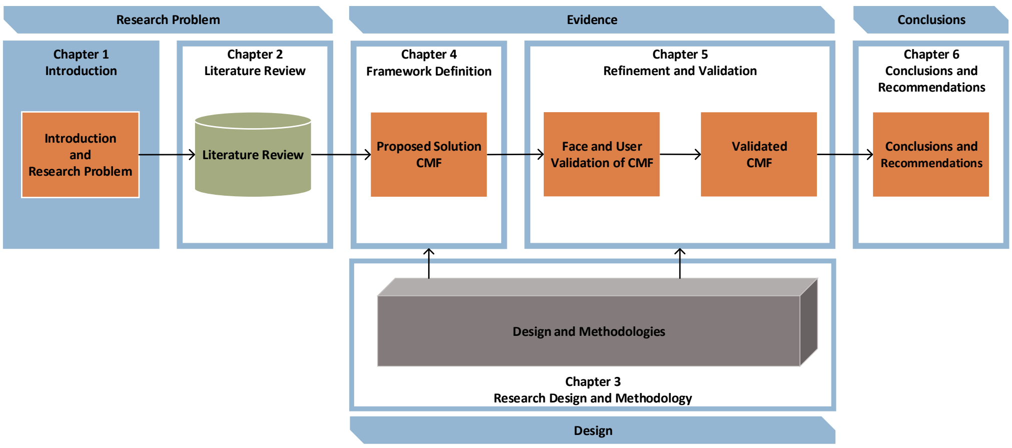
Remote Monitoring Center

A remote monitoring center is generally located centrally with the REPPs located in other parts of a country or globally. Typical functions would include monitoring of systems and subsystems or REPPs, responding to faults detected on remote Supervisory Control and Data Acquisition (SCADA) systems, follow up on plant activities such as planned and unplanned maintenance, track and log downtime and working activities on plants and the effect thereof developing operating procedures, monitoring of all systems and Key Performance Indicators (KPIs) and centrally managing planning and scheduling.

Chapter 1

Introduction

The important thing is not to stop questioning; curiosity has its own reason for existing. One cannot help but be in awe when contemplating the mysteries of eternity, of life, of the marvellous structure of reality. It is enough if one tries merely to comprehend a little of the mystery every day. The important thing is not to stop questioning; never lose a holy curiosity – Albert Einstein (1879-1955)



The present study proposes a framework supported by business processes that can be used to centrally manage Asset Care Plans (ACPs) within a multi-technology portfolio of Renewable Energy Power Plants (REPPs) while remaining aligned to the requirements of an Asset Management standard. This chapter aims to provide an introduction and context to the research undertaken. The chapter first introduces the background which leads to the research problem and research questions. The research objectives, design and methodology are then presented and the chapter is concluded with a road map which explains the logic and outline of the remainder of the thesis.

1.1 Theoretical Background

South Africa (SA) has been struggling with a power crisis over the last decade. However, over the past two decades SA has made significant progress in terms of developing its energy policies, integrated energy and resource planning. Some of these major strategic collaborations on framework development include The White Paper on the Energy Policy of the Republic of SA (DME, 1998) that revealed the need to start diversifying the energy mix and that Renewable Energy (RE) sources should be included; and the White Paper on the Renewable Energy of the Republic of SA (DME, 2003) which, as one of its objectives, strove towards producing 10 000 Gigawatt Hours (GWh) of energy from RE sources by 2013 (DME, 2003).

During 2008 the SA public power utility Eskom was forced to introduce scheduled load-shedding (black-outs) in order to prevent a shutdown of the national grid. This power crisis had a direct effect on the economy with an estimated cost of ZAR 50 billion and also resulting in investor confidence plummeting (Papapetrou, P. [Online], 2014, 5). The SA government recognised the need to speedily migrate to a more sustainable energy future. Combined with the need to build new generation capacity and international pressure to reduce carbon emissions, the SA Government set a target of 45% of new generation capacity from renewable sources by 2030 (DOE, 2013). Out of the total projected capacity of 81 350 Megawatt (MW), 17 430 MW would consist of onshore wind, solar Photovoltaic (PV) and concentrated solar power (CSP) generation (DOE, 2013, 20).

The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has successfully allocated 5243 MW via 79 RE projects (four bid rounds), investing ZAR 168 billion in economic infrastructure in SA as announced by the Minister of Energy in April 2015 (DOE [Online], 2015*a*, 2).

The REIPPPP projects have been developed, constructed and operated through a consortium of foreign and local companies. During the first three rounds of the REIPPPP 49 Engineering Procurement and Construction (EPC) contractors were involved in the planning and construction phase. A large foreign EPC presence, including Juwi Renewable Energies (Germany), Suzlon (India), Vestas (Denmark), Acciona (Spain) and Siemens (Germany), was necessary (Eberhard *et al.*, 2014, 23) due to the low availability of RE skills in SA. In many cases these projects are also managed by foreign contractors via Operations and Maintenance (O&M) agreements. Wind turbines are often purchased with long-term service and maintenance contracts that could last from five to 15 years and are inclusive of warranties, Corrective Maintenance (CM) and Time-Based Preventative Maintenance (TBPM) (Verbruggen *et al.*, 2002). Original Equipment Manufaturers (OEMs) who currently operate and maintain these RE assets under medium-term or long-term O&M agreements show resistance to the sharing of detailed maintenance information and the facilitation of technical skills transfer. Therefore, a significant gap in technical and management skills or competencies exists in terms of these RE assets being operated and maintained by SA Asset Owners and Asset Managers, leaving them dependent on foreign O&M contractors. The dominant suppliers of solar PV and wind turbine technologies are Vestas, Siemens, Nordex, ABB, Guodian, and Suzlon, SMA Solar Tech, BYD Shanghai, Hanwha Solar, 3 Sun, AEG and ABB, which are mainly foreign (Eberhard *et al.*, 2014, 23).

The RE sector is very competitive as mature technologies and industries are involved in the manufacture of components for RE technologies. The global market has also seen an over-supply of these technologies, further driving down costs and profits. Balance sheet financing by big market players has also been more prevalent during the latter rounds of the REIPPPP, further decreasing costs (GreenCape [Online] 2015, 18; Eberhard *et al.* 2014, 12,37). The market environment has favoured consolidation and larger market players such as BioTherm, Mainstream Renewable Power, Mulilo and Enel Green Power have been more dominant in the market (GreenCape [Online], 2015, 18). In a number of cases a single entity (independent power producer (IPP), Asset Manager and/or project agent) is responsible for the management of a multi-technology portfolio of RE assets. An example of this is Scatec Solar who develop, construct, own and operate utility-scale solar PV power plants through an integrated business model and on a global scale. Scatec Solar own and operate three utility-scale solar PV projects in SA and have been awarded preferred bidders status on an additional three solar PV projects in round four of the REIPPPP (ScatecSolar [Online], 2015). BioTherm, who started out as a developer and now also operates four facilities has been awarded preferred bidder status for three projects in round 4 of the REIPPPP. Globeleq, the largest Independent Power Producer (IPP) in sub-Saharan Africa, currently own and operate three REPPs in SA (Globeleq [Online], 2015).

Against this backdrop, a review of Asset Management (AM) and maintenance practices in the RE sector is discussed.

The discipline of AM has gained significant traction over the past few years. As a result, research and discussions on AM, in the industry and academia have increased. The British Standards Institution (BSI) Publicly Available Specification (PAS) 55:2008 AM framework (British Standards Institution, 2008*a*,*b*), which was replaced with the International Organisation for Standardisation

(ISO) 55000 series of AM standards (International Standards Organisation, 2014*a*, 3), states that AM institutes those systematic and coordinated practices that support an organisation, to optimally and sustainably manage their asset systems over the entire Asset Life-Cycle (ALC). AM is interdisciplinary in nature and complex; therefore PAS 55:2008 highlights the requirement to have a holistic and integrated view of AM.

An integrated Asset Management System (AMS) is critical to an organisation that relies on physical assets in order to deliver products or services and to support delivering the organisational plans that meet expectations of stakeholders (British Standards Institution, 2008*b*, x,xi). The Institute of Asset Management (IAM) *Asset Management – An Anatomy* document presents a conceptual model for AM and incorporates the Global Forum on Maintenance and Asset Management (GFMAM) 39 AM subjects that cover all of the requirements of ISO 55000 series of standards (IAM 2014*a*, 17; GFMAM 2014, 12). These 39 subjects are divided into six groups. One of these groups is *Strategy and Planning* and contains some of the core AM activities and requirements such as the AM policy, Strategic Asset Management Plan (SAMP) and Asset Management Plans (AMPs), that are required to establish an AMS in an organisation (GFMAM 2014; IAM 2014*a*, 19; British Standards Institution 2008*b*, x,xi). The departure point for the development of a AM policy, SAMP (covering the AM objectives and strategies) and AMPs is the Organisational Strategic Plan (OSP) which also drives the ALC activities across the organisation's portfolio of Assets and Asset systems (British Standards Institution, 2008*b*, xi). The importance of having alignment between the OSP and the rest of the AMS is reiterated throughout the literature. Alignment, also known as the Line-of-Sight (LoS), is important and should be established in such a way that the staff on the ground are able to link their daily tasks, via a clear path of plans, objectives and strategy statements, to aspects of the OSP (IAM, 2015*a*, 12). In order to achieve this alignment there needs to be a clear AM decision-making framework created by the AM policy (IAM, 2014*a*, 20).

The OSP and AM policy are key inputs into the SAMP. The SAMP defines the objectives an organisation needs to achieve as a result of its AM activities; outlines the time frame in which these objectives should be reached while remaining aligned with organisational objectives and AM policy; and lays out how the AMS should support this process (IAM 2014*a*, 19; GFMAM 2014, 14; International Standards Organisation 2014*a*, 8; British Standards Institution 2008*b*, x). The combination of AM strategies and objectives in SAMP provides the direction for lower-level planning within AMPs (Yates, S. [Online], 2015*a*, 1). The AMP should include information on ALC strategies detailing how each Life-Cycle (LC) phase of an asset will be approached. Other detailed information such as the maintenance program could be included covering actions such as the use of techniques such as Reliability Centred Maintenance

(RCM) to reduce maintenance costs or to improve reliability, modification of assets for improvement in performance and maintainability (Yates, S. [Online], 2015*b*, 1).

The core AM activities and the other AM subjects (39 subjects) make reference to the importance of maintenance and the use of techniques such as Failure Mode and Effects Analysis (FMEA) and RCM to build maintenance regimes and plans (IAM, 2014*a*, 28). The IAM (2014*a*, 40) states that maintenance is broadly categorised as Condition-Based Maintenance (CBM), Preventative Maintenance (PM) and CM type tasks (IAM, 2014*a*, 40) while the maintenance strategy or plan for an asset blends tasks from these groups to maintain performance.

An ACP is term which used to describe the combination of tactical (planned) and non-tactical (unplanned) maintenance activities that have been structured as part of a maintenance strategy. Tactical maintenance strategies are generally regarded as a grouping of CBM and PM activities while non-tactical strategies are a group of reactive CM activities. RCM and Total Productive Maintenance (TPM) are well known qualitative maintenance management philosophies used to schedule and specify maintenance activities, and in order to analyse historical failure data on equipment statistical maintenance interval metrics are defined and used (Dekker and Scarf, 1998).

Maintenance Optimisation Modelss (MOMs) are classified as quantitative or qualitative. Qualitative MOMs such as TPM and RCM are considered to be subjective (Arthur 2005, 252; Scarf 1997, 495). Alternatively quantitative MOMs are deterministic and stochastic such as Markov decision, Bayesian models and mixed integer linear programming (Garg and Deshmukh, 2006, 206). Criticisms of quantitative MOMs are that these techniques are theoretical and not useful in practical real-life scenarios (Scarf 1997, 494; Arthur 2005, 251). Maintenance scheduling can be challenging and warrants independent investigation as it can also consist of qualitative or quantitative mathematical models. It is imperative to implement an effective performance measurement system such as total maintenance management (TMM) or system audit approach as it increases the probability of task completion. Therefore, maintenance management information systems (MMIS) were brought into existence due to the realisation that maintenance is a critical business function and an essential component of any maintenance organisation (Garg and Deshmukh, 2006, 208).

Organisations have realised that in order to adequately manage the maintenance process it would need to be integrated into the organisational strategy as it interacts with other business functions (Pintelon and Gelders, 1992, 301). Only once this objective is achieved can it be given the required attention, be developed as critical area in a business and fulfil specific organisational goals. Therefore past research has been focused on the challenging task of developing a model that could be used to drive maintenance strategies and activities with the fundamental questions aimed at achieving effectiveness and efficiency in maintenance management (Prasad Mishra *et al.*, 2006, 141).

A diverse range of other authors have made propositions on the best practices or models in terms of maintenance management. Hassanain *et al.* (2003) present a framework model that attempts to provide a generic reference to maintenance management for constructed assets while Campos and Márquez (2011) provide a process of modelling a maintenance management framework aligned to the PAS 55:2008 AM specification that is expressed using business process modelling (BPM) languages UML 2.1 (Unified Modelling Language). Márquez *et al.* (2009) propose a generic model by integrating other models that can be used to manage the maintenance function. Their multiple phase two-part model first considers developing the maintenance strategy and thereafter focuses on the strategy implementation. Details of the model presented by Márquez *et al.* (2009) will be presented in Chapter 2, section 2.2.4.

The literature surveyed up until this point has mainly focused on overarching maintenance management approaches. However, when considering maintenance strategies for specific technologies, literature can be found that attempts to address the requirements, challenges and approaches in terms of maintenance strategies to increase the reliability, availability and revenue of wind power plants (Besnard *et al.* 2010; Nilsson 2009).

Asset Care strategies supplied by the OEM are often adopted by wind farm operators once the contract period expires. However, according to Andrawus *et al.* (2006*b*, 473) these strategies are inadequate in meeting the requirements of a performance-driven Asset Owner or operator. Studies performed specifically for wind turbines, by Andrawus (2008) and Besnard *et al.* (2010) highlight the requirement to define suitable maintenance strategies for system components according to their failure modes, probabilities and consequences. Bertling Tjernberg and Wennerhag (2012) also identify areas in the wind industry that require development: “(1) Maintenance approaches and system optimisation and cost analysis, (2) Maintenance supporting processes and data, and (3) Reliability and maintenance component models and analysis”. The importance of maintenance activity scheduling and support functions such as spares and staff management for wind turbine maintenance is also addressed (Besnard *et al.* 2009; Besnard *et al.* 2010). Wind turbine maintenance is generally a combination of time- and failure-based tasks which are costly and have other operational impact. Therefore, it is important to develop a complete maintenance strategy using modern maintenance practices (Singh *et al.*, 2014, 151). A typical modern maintenance approach which is commonly found in wind technology maintenance studies is RCM which is a formal approach to scrutinising a certain system and identifying all its functions and understanding how these functions may fail, after which a set of preventative maintenance tasks can be developed, based on safety and economic considerations. An example of an RCM implementation process can be seen in figure 1.1.

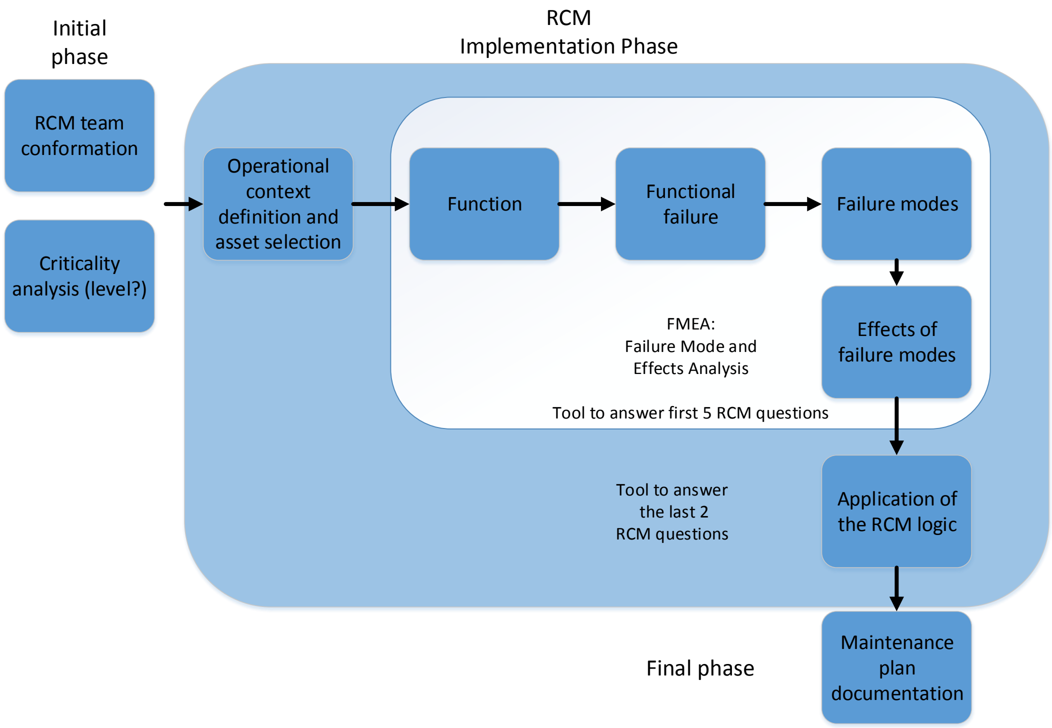


Figure 1.1: RCM implementation process (Adopted from Márquez *et al.* (2009, 174))

Research has been done regarding Maintenance Optimisation (MO) in the wind industry with Andrawus (2008) investigating qualitative and quantitative MO techniques such as RCM to improve reliability and Delay-time Maintenance Mathematical Model (DTMM) to optimise PM intervals, Eunshin *et al.* (2010) who use a partially observed Markov decision process to determine optimal maintenance strategies for wind turbines operated under stochastic weather conditions and Tian *et al.* (2011) who attempt to optimise CBM decisions based on failure probabilities.

A comprehensive report on solar PV O&M, conducted by EPRI (2010), highlighted the fact that if owners and Asset Managers of utility scale PV assets want to reduce operational downtime and increase production in a cost-effective manner, a best-of-breed O&M practice needs to be adopted. Their report found that solar PV facilities require a combination of continuous monitoring, inspection, and scheduled preventive maintenance in addition to breakdown calls. It is mentioned that several maintenance approaches are taken such as PM, CM and CBM all of which have positive and negative characteristics. The view taken by Alectris [Online] (2014) is that there should be a balance of these maintenance approaches. Another key aspect is the decision to develop in-house capability or follow an outsourced model. The decision is generally based on context-specific business and management motivations. Cases can be found where large utilities have elected to integrate the maintenance of their PV facilities in-house as they found it could offer long-term cost reductions (EPRI, 2010). The report by EPRI (2010) also highlights the fact that the O&M space in the PV market is still developing and evolving and new practises emerging based on gaining more understanding in terms of what is required from a maintenance perspective. An initial search for literature on the implementation of more sophisticated maintenance techniques for solar PV could not be found, indicating a potential research gap.

In summary, the SA RE market has experienced considerable growth and is set to continue when considering the vision of the IRP 2010-2030. Market competition and low tariffs have reduced profits and resulted in companies seeking ways to reduce budgets and often vertically integrating their supply chains in order to do so. Balance sheet financing has been another mechanism by which costs of capital could be reduced in order to be more competitive. All these factors affect the market landscape, driving consolidation and as a result has been IPPs with large multi-technology renewable power plant portfolios.

The market is, however, faced with challenges such as the lack of information sharing and skills transfer from foreign OEMs. Skills (competency) within the RE sector are required to develop effective ACPs for REPPs which pose a major challenge to the industry as maintenance is a critical aspect which will enable the plant to operate successfully over its lifespan.

Understanding maintenance requirements is especially important in the next five to 10 years, after which many projects could have their O&M contracts renewed or terminated. In the event that these contracts are terminated, it could be in the interest of stakeholders to take responsibility for O&M activities as it could prove more cost effective and result in an increase in performance. In the event that contracts are renewed or end of warranty periods are reached, it would be beneficial if Asset Owners are capable of understanding maintenance requirements and costs that can strengthen negotiating positions. If Asset Owners or Asset Managers do not develop internal maintenance management capabilities for RE assets it will result in sustained high O&M costs and dependence on international contractors and delay the development of local technical and managerial skills for these assets.

Furthermore, organisations have realised that in order to adequately manage the maintenance process it would need to be integrated into the organisational strategy as it interacts with other business functions and leads to adopting good AM principles (Pintelon and Gelders, 1992, 301). However, there is a challenge due to the ISO 55000 series of standards and other literature supporting the ISO 55000 series of standards such as the IAM, *Asset Management – An Anatomy*, and GFMAM *Landscape* documents are still relatively new and only offer very high-level insight into implementing a AM standard or asset maintenance related activities (International Standards Organisation 2014*a*; GFMAM 2014; IAM 2015*a*). Practical application of the AM standard related to technology-specific Asset Care strategies and activities is thus at the discretion of the AM team.

Key activities and areas in a maintenance management strategy, namely optimisation models, approaches, scheduling, performance measurement, information systems and policies have been identified while touching on the requirement to having an overarching AM framework.

The decision on which maintenance strategies and activities to deploy for specific physical assets technologies such as wind and nuclear, has received some attention. However, literature on developing ACPs for utility scale solar PV plants is limited. The ISO 55000 series of standards requires an integrated approach to AM and although many authors have attempted to develop maintenance management frameworks, attention is generally focused on the maintenance strategies and it is not clear how these strategies are geared towards RE technologies or integrated into other AM subjects.

According to Prasad Mishra *et al.* (2006, 141) the adoption of a sound framework, in order to provide the required conceptual and theoretical details of best practices to be followed, is one of the requirements to developing a world-class maintenance system in an organisation. Entrenching a model in order to drive maintenance activities that are embedded in the general management or AMS of an organisation has thus also become a research topic due to the fundamental requirement to obtain effectiveness and efficiency in an AMP and to realise organisational objectives. This has led to demarcating, focusing and developing the research idea regarding the need to understand what a maintenance management strategy for different RE assets would consist of and what overarching management frameworks could be used to manage these functions within a larger corporate AM strategy.

The next section discusses the problem statement and research questions for this study.

1.2 Research Problem Statement and Research Questions

The introduction in section 1.1 identified key factors in the SA RE sector which needed to be considered, such as the requirement to use more modern maintenance philosophies, the dearth of skills (competency), continuous improvement requirements of the ACPs and competency levels and the complexity of management and ownership structures in the SA RE sector.

The problem is that there is no framework and supporting business processes for managing ACPs, continuous improvement and competency in a multi-technology REPP Asset portfolio, that are aligned with requirements of an AM standard such as the ISO 55000 series of standards and understand the degree to which organisational functions can be centralised or decentralised.

In order to solve the research problem, the investigation will focus on the following selected research questions:

1. What philosophies, techniques and models within the maintenance field can be adopted to develop ACP for a portfolio of multi-technology REPPs?
2. What elements or characteristics should the proposed framework and supporting business processes have to ensure that they are aligned with an overarching AM framework and maintain the line-of-sight?
3. What characteristics of the proposed theoretical framework can be centralised and which need to remain decentralised?
4. What are the scarce competencies required to assist in managing ACPs for REPPs and what can be done to address the competency issue?
5. What could a theoretical management framework look like that can be used to manage ACPs for a multi-technology portfolio of REPPs?

Through addressing the research problem and answering the research questions there is a real opportunity to contribute to the theory and practice of AM management and maintenance management in the SA RE sector.

1.3 Research Objectives

The introductory background and the problem statement direct the research objectives which guides the manner in which the research study is executed. The primary objective of the research study is as follows:

Develop a ISO 55000 series aligned Central Management Framework (CMF) for ACPs within a multi-technology portfolio of REPPs in the SA RE sector.

The research objective aims to address the needs that were presented in the problem statement. The research study builds on a series of research objectives in order to answer the posed research questions. The primary objective of the research can systematically be addressed through manageable sub-tasks. The objectives are summarised in Table 1.1.

Seq	Objective	Chapter
1	Review and establish the key or fundamental concepts in the maintenance field and identify philosophies used to develop maintenance plans	2
2	Review and establish key concepts in existing maintenance management frameworks and within the discipline of AM	2
3	Review the RE sector in SA	2
4	Contextualise the synergy between key elements within the realms of maintenance, AM and the SA RE sector	2
5	Devise a well-founded research methodology	3
6	Construct an ISO 55000 series-aligned CMF for ACPs in the RE industry and determine a suitable philosophy to develop ACPs for RE power plants in SA	4
7	Determine which of the 39 GFMAM AM subjects are embedded within the framework to maintain alignment with ISO 55000	4
8	Determine the skills required to develop and manage ACPs for REPPs and the extent to which functions can centralised or decentralised	5
9	Validate the CMF via face and user validation in line with the required framework features and success criteria	5
10	Draw conclusions and make recommendations regarding the CMF	6

Table 1.1: Summary of research objectives

Chapter 2 pursues objectives 1 to 4. These objectives are to review the key concepts related to the maintenance field, AM and the RE sector in order to establish the basis of the research. Furthermore, other objectives are pursued by understanding philosophies that can be used to develop ACPs and a review of typical maintenance management frameworks. The synergy between all the maintenance, AM and RE is contextualised as part of the base framework development. A literature review of the mentioned domains serves this purpose.

Objective 5, addressed in Chapter 3, is to formulate a methodical approach to undertaking the research. The research approach is constructed on the introductory findings related to the maintenance field, AM field and key issues in the SA RE sector.

Chapter 4 covers objectives 6 and 7 and aims to propose a CMF and supporting business processes for the management ACPs in the SA RE sector by synergising outcomes of the previous objectives. Furthermore, the relevant 39

AM subjects will be associated in the framework to demonstrate alignment with the ISO 55000 series of standards.

Objectives 8 and 9 of Chapter 5 relate to the first fieldwork, data collection and analysis activities. The aim is to understand the competency requirements of managing ACPs for the RE industry and to which extent organisational functions can be centralised. Furthermore, the final objective of the research is to validate the model through use of face and user validation in the RE sector in SA.

In chapter 6 conclusions are drawn regarding the contribution of the CMF, supporting business processes and the discipline of AM in the SA RE sector, thereby addressing the last research objective (14).

Achieving the research objectives will assist Asset Managers, owners and operators or REPPs in the SA RE sector to understand the philosophies or techniques that can be used to manage ACPs and competencies for REPPs. In the case where multiple assets are managed by a single entity an opportunity could be identified to centralise functions to improve efficiency and performance in the maintenance system. The centralised management framework will provide SA RE sector Asset Managers, owners and operators with a framework and supporting business processes to develop, execute and optimise ACPs for a multi-technology portfolio of REPPs while remaining aligned with the requirements of an AM framework such as the ISO 55000 series of standards.

1.4 Research Design and Methodology Overview

The research is empirical and in the form of a qualitative exploratory study. Existing textual data is collected and analysed in the form of a literature study order to establish the fundamentals in the maintenance, AM and RE sector in SA. The initial proposed management framework is developed based on synthesising the findings in the literature review into a structured CMF and supporting business processes.

The validation process is a combination of face and user validation using semi-structured interviews conducted with selected experts involved in organisations that operate in the field of O&M, AM, and the SA RE sector. Information and insights gained from the qualitative analysis of the semi-structured interviews will be used to validate the CMF.

1.5 Importance of the Research Problem

The research will be of relevance to RE Asset Owners, Asset Managers, maintenance managers and practitioners, RE plant managers, operations managers, general management and other stakeholders that have an interest in the O&M activities, AM and asset performance (financial, technical, etc.). It will be of particular interest for these stakeholders in the SA RE sector who currently manage assets and have full scope O&M agreements with foreign OEMs which could end after the contract period. OEMs have been found to use basic maintenance philosophies which are not optimised for performance and cost and therefore it could be in the interest of Asset Managers, owners and operators to take responsibility for the operations and maintenance in order to improve performance and revenue.

In order to achieve this it is important to understand how to manage[1] ACPs for these RE assets and which competencies are required. Understanding which organisational functions can be centralised can also provide cost and performance optimisation and contribute to overall efficiency, skills leverage and revenue increase. The importance of this lies in uncovering the business processes and competency required to maintain and manage RE assets in the SA context. This will enable more control and improved performance management of the technology as well as the associated business, commercial and technical consideration for RE assets.

1.6 Limitations and Assumptions of the Study

In exploring new areas of research it is necessary to state the delimitations and disclose the limitations. The previous sections outline the theoretical position of the thesis. In this section the delimitations, which are the explicit boundaries for the study, are set, and the limitations or conditions outside the researcher's control are stated.

- This research begins after the ISO 55000 series of standards were published and uses this as base for the AM framework.
- It focuses on the RE sector in SA.
- The study is primarily concerned with the management of ACPs and does not consider all the other aspects involved within a complete maintenance management framework or the entire discipline of AM.
- Although the CMF is intended as a general framework it has only been intensively studied within the wind and solar PV farm domains in SA.

[1] The management of APCs refers to the framework and business processes that relate to the development of maintenance plans, planning scheduling, work order execution and closure or developed tasks, with consideration for continued improvement of ACPs and associated competency requirements.

- The proposed CMF acts as a guide and is not prescriptive and does not provide specific solutions to problems, but is rather a guide to the ACPs development and management process.
- The research also focuses on understanding key management and operational areas which can be centralised within a specific type of AM environment where a single entity is responsible for multiple assets and can centralise resources and functions across all the assets under management.

1.6.1 Limitations

Developing detailed ACPs for specific technologies requires years of expertise and access to detailed technical, operating, maintenance procedures and information. Access to this expertise and information is limited due to the confidentiality clauses as well as the potential unwillingness of OEM contractors to supply detailed information. The lack of public information available regarding ACPs in the SA RE sector poses a challenge. The RE plants of round one of the REIPPPP have only been in operation for about 18 to 24 months and thus very little O&M experience and data is available. Stakeholders are not interested in gaining the knowledge and insights into AM and maintenance and would prefer to outsource this function. Time constraints are a limitation in terms of validating the effectiveness of the proposed CMF in practice.

1.6.2 Assumptions

Most REPPs in SA are still under warranty with all the equipment in a fairly new state. Asset owners, managers and operators follow the basic OEM recommended maintenance strategies. The above-mentioned delimitations and assumptions were considered during the execution of the study.

1.6.3 Ethical implications of the Research

As reflected in the ethics application, the research has no ethical implications. The research complies with Stellenbosch University's guidelines on ethical aspects of scholarly and scientific research.

1.7 Thesis Outline

The first two chapters of the thesis provide the introductory background and literature review as part of the initial data analysis. Chapter 3 follows with research design and methodology. Chapter 4 commences with construction of a proposed framework and supporting business processes. Data collection and analysis continue in Chapter 5 to refine the framework and supporting business processes where after the validation is completed. Chapter 6 follows by conclusions and recommendations. Figure 1.2 illustrates the road map and Chapter sequence of the thesis.

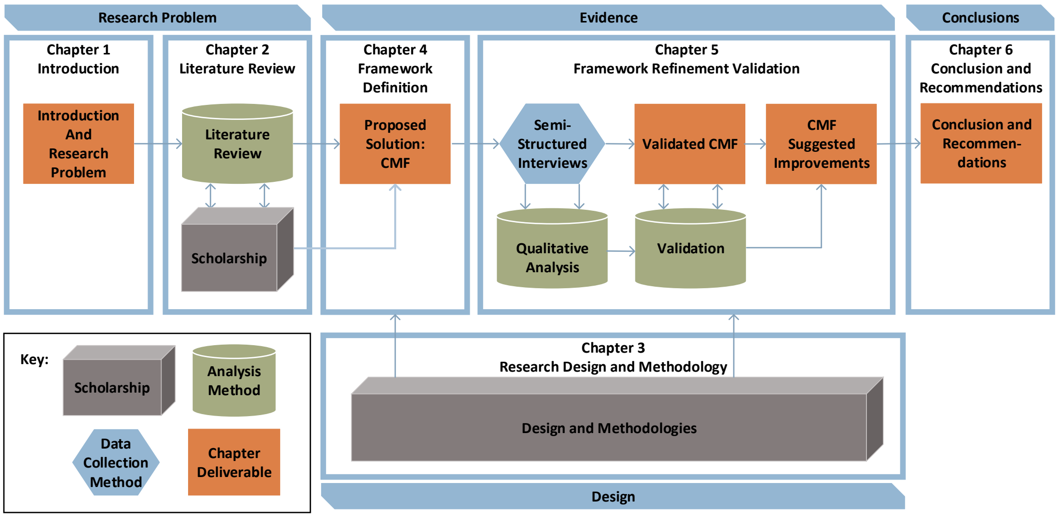


Figure 1.2: Thesis road map

Chapter 1: Introduction

Chapter 1 introduces the research study. First, the theoretical background to the study is provided, which leads to problem statement and research questions. This is followed by a discussion of the research objectives, scope and overview of the research design and methodology. The chapter is concluded by presenting the research delimitations and limitations and the thesis outline.

Chapter 2: Literature Review

Chapter 2 entails a comprehensive review of literature on the scholarship that is relevant to the research. The three most dominant fields which are studied in this chapter are AM, maintenance and key aspects of the SA RE sector. The chapter concludes with the identification of areas of integration and synergies between these relevant fields providing a base for the remainder of the research process.

Chapter 3: Research Design and Methodology

Chapter 3 presents the research design and methodologies and starts with an overview of the nature of science and methodology. The research approach is presented through explaining the philosophical worldview, research design and research methods which are used to study the problem. The chapter concludes with the scientific reasoning used in the thesis.

Chapter 4: Proposed Solution
Chapter 4 provides a proposed CMF and supporting business processes as a solution to the problem. Each element of the CMF and business processes is described regarding its specific objectives and how it relates to the overarching AM framework and general framework features.

Chapter 5: Validation
Chapter 5 entails data collection using semi-structured interviews with expert AM and maintenance practitioners and includes owners and operators of multi-technology portfolios of RE projects in the SA RE sector. The field data is analysed to understand some of the competency challenges and the extent to which organisational functions can be centralised. Lastly the CMF and supporting business processes are validated using a combination of face and user validation.

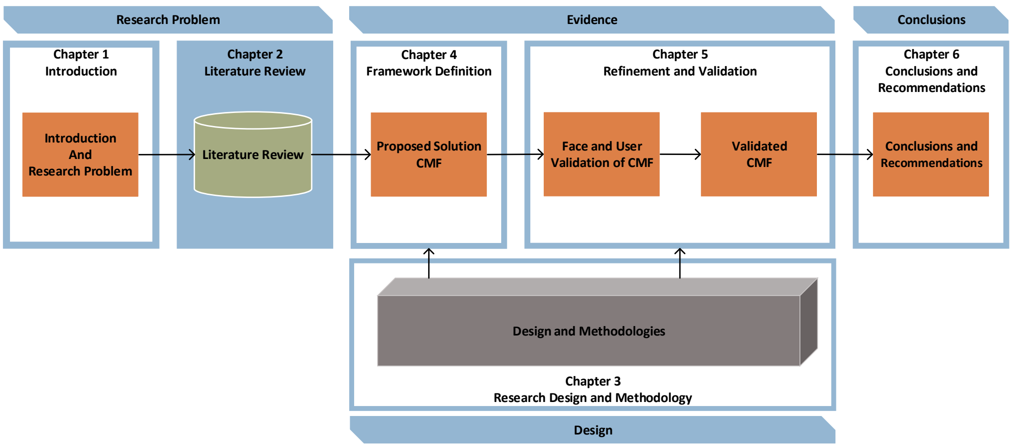
Chapter 6: Conclusion
In Chapter 6 the conclusions of the study are presented and recommendations are made regarding future research opportunities.

The current chapter introduced the research and the thesis roadmap was outlined. The following chapter covers the details of the research design and methodology.

Chapter 2

Literature Review

In great literature, I become a thousand different men but still remain myself. – C.S. Lewis, An Experiment in Criticism



The purpose of this chapter is to review the present literature that relates to the problem statement and objectives. The research problem is embedded within the synergy of the AM and maintenance management disciplines. The first part of the chapter reviews the scholarship of AM, while the second part reviews the maintenance management body of knowledge. The third part of the chapter concludes with a review of the RE sector, which serves to highlight some key industry challenges.

2.1 Asset Management

The scholarship related to AM serves as the initial foundation of the research. A brief history of AM is presented followed by the introduction of key concepts such as assets; asset classification; ALC; AMS; and key documents within the AMS such as the AM policy, SAMP, and AMPs; which leads to a definition of AM. The latter subsections review the GFMAM 39 AM subjects.

2.1.1 Asset Management Landscape

AM thus cuts across numerous aspects of an organisation with Woodhouse, J. [Online] (2001, 1) mentioning that AM consists of individual meliorations bound together by a common understanding, and collection of tools and processes. According to Amadi-Echendu *et al.* (2007, 117), since the early beginnings of AM in the 1990s, arguments have been made to have the discipline of AM adopt an interdisciplinary and a synergistic approach to aspects such as ALC, maintenance, risk, reliability, performance, quality, efficiency, finance, procurement and sustainability (Van der Lei *et al.* 2012, 117; Woodhouse, J. [Online] 2001; Campbell *et al.* 2010, 15).

During the first few years after the turn of the century the need to consider Asset Life-Cycle Management (ALCM) was highlighted by scholars in order to address inefficiencies within the existing AM models as well as incorporate sustainability aspects with Woodhouse (2000, 3) and Amadi-Echendu (2004, 1157) mentioning that industries were moving towards a more holistic approach to AM. In support of this Schuman and Brent (2005, 566) propose an ALCM model which integrates existing frameworks and practices such as project management, systems engineering and operational reliability.

The practice of ALCM has developed in sophistication over the past 30 years and evolved into its own discipline. Combined with the need to develop strategies to reduce risks to business-critical assets the BSI developed the PAS 55 for Physical Asset Management (PAM) first emerged in 2002 and was published in 2004 (Tywoniak *et al.* 2008, 1561; Woolpert Inc. [Online] 2012, 1561; Campbell *et al.* 2010, 455). The PAS 55 was the first attempt at clarifying and standardising the meaning of physical AM systems, after calls from industry to develop a unified view on what AM means in practice. The PAS 55 originated from a joint project by the BSI and the IAM and provides a definition of PAM that considers an optimised combination of performance, maintenance, capital investments, maintenance, resources, risks and sustainable development with a LC perspective (Tywoniak *et al.* 2008, 1561; Campbell *et al.* 2010, 455).

Industries such as mining, manufacturing, utilities and transport widely adopted PAS 55 and as a result the standard was accepted as a platform to develop the ISO 55000 series of international standards that was published in January 2014 and supersedes the PAS 55 documents (Hastings 2015, 5; Institute of Asset Management (IAM) [Online] 2014; Kersley and Sharp 2014, 3). ISO 55000 series of standards consist of ISO 55000 (introduction to AM), ISO 55001 (the AM standard) and ISO 55002 which provides interpretation of the requirements set out in ISO 55001 (International Standards Organisation 2014*a*; International Standards Organisation 2014*b*; International Standards Organisation 2014*c*; Kersley and Sharp 2014, 3). The ISO 55001 has rapidly been adopted by organisations who are already PAS 55 certified and organisations who are eager to benefit from good AM practices (Kersley and Sharp, 2014, 3).

The GFMAM, consisting of a number of maintenance and AM organisations around the globe, was established in 2010 with the objective of aligning the Asset Management Body of Knowledge (AMBOK) through a collaborative process. The GFMAM published the *Asset Management Landscape* document in November 2011, which is an attempt to build a common perspective or collective view on the discipline of AM.

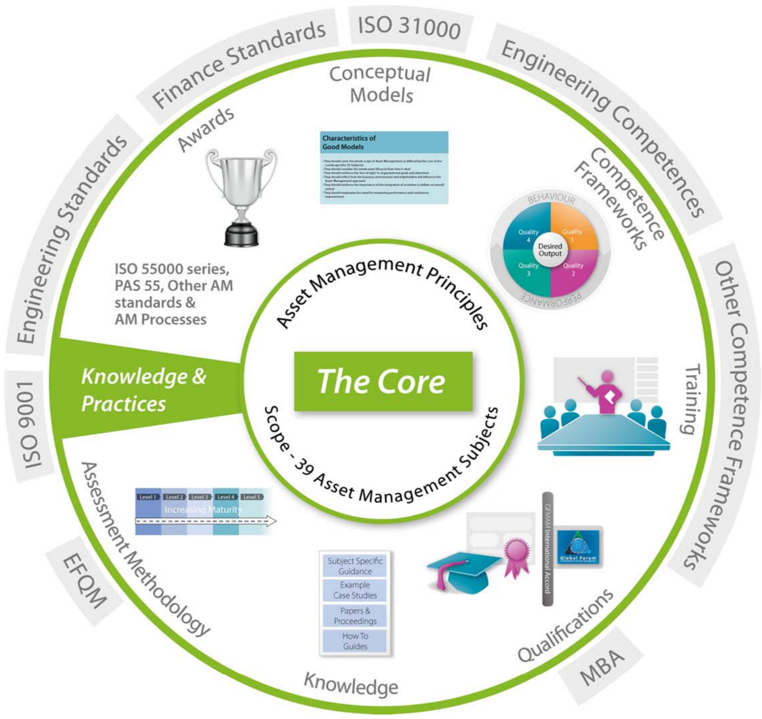


Figure 2.1: Traditional functional and activity-centred organisation (Adapted from GFMAM (2011, 6))

The *Asset Management Landscape* consist of three key areas namely the **Core**, **Knowledge and Practices** and **Support** and is represented by figure

2.1 (GFMAM, 2011, 6).

The core of the *Asset Management Landscape* framework includes 39 subjects, describing the scope and discipline of AM, and was developed based on an international review and consensus process considering AM models and assessment methodologies (GFMAM 2011, 7; IAM 2015*b*, 4).

The GFMAM members incorporate the *Asset Management Landscape* into their respective AM frameworks where the 39 subjects are used to develop a universal approach to AM and its definitions through an international accord. One such member is the IAM that published the first edition of their influential *Asset Management – An Anatomy* in February 2012 after their annual conference in June 2011 (GFMAM 2014, 4; IAM 2011, i). The second edition of the IAM *Asset Management – An Anatomy*, was published in July 2014 and aligned with the ISO 55000 as well as the GFMAM *Asset Management Landscape* (IAM, 2014*a*, i). IAM (2011, 3) and IAM (2015*a*, 3) notes that the BSI PAS 55:2008 specification lists 28 requirements while the ISO 55001:2014 lists 24 clauses specifying 71 "shall statements" requirements that an organisation needs to meet in order to exhibit prudent AM practices and a robust AM system, often leading to confusion when discussing the 39 subjects described in the *Asset Management – An Anatomy* and the GFMAM *Asset Management Landscape* (International Standards Organisation 2014*b*; British Standards Institution 2008*b*). The difference is that ISO 55001 and PAS 55-1 is a check-list of requirements on the organisational AM system while the 39 subjects, arranged in six subject groups, is a description of the AMBOK in its entirety (IAM 2014*c*, 2; GFMAM 2014; British Standards Institution 2008*a*).

Emphasis is placed on the fact that knowledge and competency throughout the AM discipline cannot be gained through merely being familiar with the management system standard. Although it is important to have knowledge of the PAS 55 and ISO 55000 series, it is not the entire picture. It is critical to comprehend the entire discipline which is represented by the 39 subjects; however, a person's responsibility within an organisation can determine the level of knowledge required (IAM 2011, 2; IAM 2014*a*, 3). In order to maintain its application across many different types of organisations the ISO 55000 series documents explain the requirements of an AM system, but does not specify how this is achieved – there is still a need to have applicable knowledge and interpret the standard in order for it to be effectively utilised (IAM, 2014*a*, 3).

2.1.2 Defining Asset Management

AM concepts have developed over time and stem from the financial services industry that has been using the term for decades to describe the management of risk and reward within financial portfolios. The oil and gas industry in the

North Sea came to the understanding that managing operations from a LC view offered substantial benefits in all areas of business following the Piper Alpha disaster;[1] so did the public sector in Australia and New Zealand, who were experiencing a lack of service delivery and poor financial performance (IAM, 2014*a*, 7). The result was a collective understanding that there needed to be a more defined scope of what good AM entails, which would include aspects such as risk, cost, performance, resources and LC.

The concept of AM is widely interpreted within industry and the meaning can even evolve over time throughout a single organisation (Morton, 1999). Vanier (2000, 40), states that the AM concept is challenging in its adoption as a philosophy, and its implementation, as the meaning of AM is interpreted differently by different people, this view is shared by Wijnia (2009, 2). The ambiguity around AM would seem to stem from the lack of understanding and identification of the AM activity, the compartmentalised approach to technical areas (aviation, civil works, defence, etc.) due to education and professional specialisation, and the context-specific definitions (Hastings 2010, 2; Hastings 2015, 4; Amadi-Echendu *et al.* 2007, 118). Woodhouse, J. [Online] (2006, 12) shares a similar view and states that there is a tendency to create silos of specialism. Woodhouse, J. [Online] (2003) notes six distinct different interpretations and uses of the term AM within organisations such as the financial services, company management boards and analysts, equipment maintenance managers, software vendors, information systems, the owners and operators of plants or infrastructure.

The term AM is expansive and can have industry-specific meanings. Galusha (2001, 37) discussed AM from an Information Technology (IT) perspective and tries to highlight the importance of knowledge and competency management. Publications related to AM can be found in numerous sectors such as construction and facilities management (Robbens, 1995, 4); electrical utilities (Morton, 1999, 233) (with Vetter *et al.* (2000, 241) and Kostic (2003, 275) advocating complex software systems to facilitate AM); roads and transportation (Beauvais *et al.* 2003, 269; Wittwer *et al.* 2002, 87); hospitality (Bridge and de Haast, 2004, 251); water management (Johnson, 2003, 111); and irrigation (Moorhouse, 1999, 169).

Gaining a greater understanding of the concept called AM is beneficial. Many definitions of AM exist within literature provided by authors such as Schneider *et al.* (2006, 643) and Hastings (2010, v) with Davis (2007, 26) providing an engineering contextualised definition and states that AM is:

[1]Accident on an offshore oil platform, in July of 1988, that cost the lives of 167 people and billions of dollars in damage (Pae, 1993, 165).

> *A continuous process improvement strategy for improving the availability, safety, reliability and longevity of plant assets, i.e., systems,facilities, equipment and processes.*

However, Tywoniak *et al.* (2008, 1154) provide a definition which is based on a general consensus over a spectrum of industries and state that: "Asset management is the process or cycle in which assets are put 'through' in order to create a product or provide a service at optimum level."

ISO 55000 intentionally provides a very general definition to allow the Asset Manager to apply the principles to whatever form the asset takes and determine how to derive value (IAM, 2014*a*, 6). ISO 55000 defines AM as (International Standards Organisation, 2014*a*, 14):

> *the coordinated activity of an organisation to realise value from assets*

The definition provided by ISO 55000 is then qualified by the following notes (International Standards Organisation, 2014*a*, 14):

- *Note 1 to entry: Realisation of value will normally involve a balancing of costs, risks (3.1.21), opportunities and performance (3.1.17) benefits.*
- *Note 2 to entry: Activity can also refer to the application of the elements of the asset management system (3.4.3).*
- *Note 3 to entry: The term "activity" has a broad meaning and can include, for example, the approach, the planning, the plans and their implementation.*

According to IAM (2014*a*, 5) the discipline of formalised AM is maturing and organisations are coming to the realisation that AM is increasingly less about working on assets but demands that assets are used to derive value from an asset in pursuit of organisational objectives (IAM, 2014*a*, 5). Furthermore, the ISO 55000 series of standards has assisted in further converging how AM is defined by the AM community (IAM, 2014*a*, 5).

The definition of AM provided the ISO 55000 is used in this study as it is currently the authority on AM.

Organisations around the globe are thus recognising that AM is a discipline that is relevant and can offer significant potential improvement in performance.

The discipline of AM evolved from the maintenance of physical equipment and infrastructure to encompass a holistic set of practices and capabilities that could increase the value extracted from all asset types over their entire LC (IAM, 2015*b*, 4).

The ISO 55000 states that AM can be understood as a means of balancing costs, opportunities and risks in order to achieve organisational objectives and acquire the best value from assets (International Standards Organisation, 2014*a*, 2). AM is based on the following four fundamentals (International Standards Organisation, 2014*a*, 3): Value, Alignment, Leadership and Assurance.

2.1.3 Asset Management Concepts

The definition of the AM has evolved to include a more comprehensive view and includes a greater focus integrating wider organisational objectives. The broadening definitions could mean that the discipline of AM is gaining in influence in areas such as general management, operations, financial capital and human capital (Amadi-Echendu *et al.*, 2010, 4). The following sections review key terms found within the AM literature and the latest ISO 55000 AM series of standards.

2.1.3.1 Assets and Asset Types

Taking a step back and considering the definition of the of the AM word pair, the Oxford English Dictionary (OED) defines an *asset* as (Oxford, 2010):

> *property owned by a person or company, regarded as having value and being available to meet debts, commitments, or legacies.*

The definition provided by the OED is very broad and considering the definition of an asset within an AM perspective the definition according to ISO 55000, which supersedes the PAS 55, and is regarded as the relevant authority, defines an asset as (International Standards Organisation, 2014*a*, 13):

> *item, thing or entity that has potential or actual value to an organisation.*

The OED definition is broad as it refers to an asset as more than merely a physical item as it attributes value to a legal entity, but PAS 55 attributes value more specifically to a physical asset. The definition of an asset is then once again broadened by the ISO 55000 definition which is also highlighted by

Zhao *et al.* (2014, 5) who state that the target scope of PAS 55 is more focused on physical assets while ISO 55000 has been designed to be applicable to any asset type.

The concept of asset type is introduced in PAS 55 as it defines five categories of assets that need to be managed in pursuing the OSP. The PAS 55 perspective regards AM as focusing on physical assets with interfaces to the four other asset types, namely financial, intangible, information and human assets (British Standards Institution, 2008*a*, vi). Prior to the use of asset types within PAS 55 other authors defined asset classes, with McGlynn and Knowlton (2011, 12) and Barry (2011*a*, 2) introducing the plant and production, infrastructure, real estate and facilities, mobile assets and information asset classes.

As ISO 55000 is the de facto AM standard this study will consider its definition of an asset which is then qualified by the definition of value (International Standards Organisation, 2014*a*, 13):

> *Value can be tangible or intangible, financial or non-functional, and includes consideration of risks and liabilities. It can be positive or negative at different stages of the asset life. Physical assets usually refer to equipment, inventory and properties owned by the organisation. Physical assets are the opposite of intangible assets, which are non-physical assets such as leases, brands, digital assets, use rights, licences, intellectual property rights, reputation or agreements.*

ISO 55000 then continues to define and qualify asset types as (International Standards Organisation, 2014*a*, 13):

> *The grouping of assets having common characteristics that distinguish those assets as a group or class.*

> *EXAMPLE: physical assets, information assets, intangible assets, critical assets, enabling assets, linear assets, Information and Communication Technology (ICT) assets, infrastructure assets, moveable assets.*

2.1.3.2 Assets Life-cycle

The concept of assets and value were introduced in section 2.1.3.1 and is an important departure point for the following discussion.

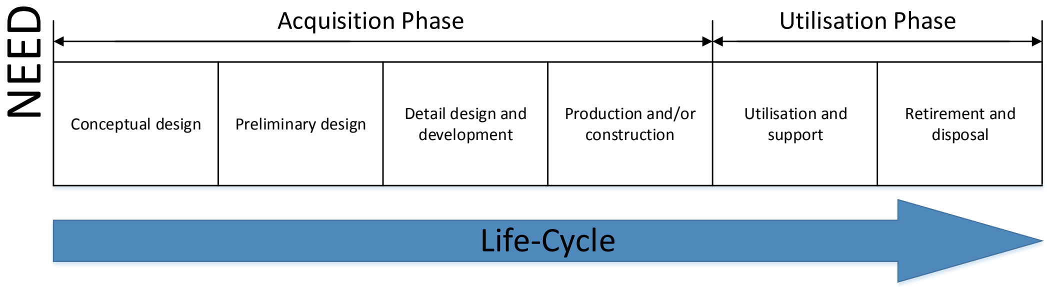


Figure 2.2: Traditional asset life-cycle (Adapted from Blanchard and Fabrycky (1998))

An asset should have value to an organisation and according to Schuman and Brent (2005, 567) value can be increased by applying AM processes across the entire life-cycle (LC) of the asset.

Life-Cycle Cost (LCC) was initially conceived in the 1960s (Sinisuka and Nugraha, 2013, 5), with the traditional system LC consisting of two phases, the acquisition phase and the utilisation phase as seen in figure 2.2. Asset LC is fundamental to the AM discipline, widely used and defined within literature as consisting of the following basic phases, which can differ depending on the context (GFMAM 2014, 4; IAM 2014*a*, i; Amadi-Echendu 2004, 1157; Hastings 2015, 12; British Standards Institution 2008*a*, 4; British Standards Institution 2008*b*, 14; International Standards Organisation 2014*a*, 13; Schuman and Brent 2005, 572-577; Jooste 2014, 24):

1. Conceptual Design
2. Preliminary Design
3. Detailed Design and Development
4. Production and Construction
5. Utilisation and Support
6. Retirement and Disposal

Assets have the ability to create and destroy value at any stage of their LC; however, understanding the LC is more comprehensible at the lower levels of asset granularity. Identifying the interdependent LC stages, as described above and depicted in figure 2.2, becomes more challenging as the system context in which the asset is creating value increases in complexity (Amadi-Echendu 2004, 1556; IAM 2014*a*, 10).

2.1.3.3 Asset Management System

The establishment of an AMS is an important strategic decision for an organisation. ISO 55001 specifies the requirements of an AMS, but does not specify the design of the system. However, ISO 55002 provides guidance on the design and operation of an AMS (International Standards Organisation 2014*b*;International Standards Organisation 2014*c*).

The departure point for the development of a AM policy, SAMP and AMP is the organisational plan which also drives the LC activities across the organisation's portfolio of assets and asset systems (British Standards Institution, 2008*b*, xi). An integrated AMS is critical to an organisation that relies on physical assets in order to deliver products or services as well as support in delivering the organisational plan and meet expectations of stakeholders (British Standards Institution, 2008*b*, x, xi).

The key elements of an AMS according to ISO 55001 are (International Standards Organisation, 2014*b*, 5): context of the organisation (ISO 55001:2014, Clause 5), leadership (ISO 55001 Clause 5), planning (ISO 55001 Clause 6), support (ISO 55001 Clause 7), operation (ISO 55001 Clause 8), performance evaluation (ISO 55001 Clause 9), and improvement (ISO 55001 Clause 10).

ISO 55000 defines an AMS as (International Standards Organisation, 2014*a*, 15):

> ***management system*** *for asset management whose function is to establish the asset management* ***policy*** *and asset management* ***objectives****.*

Stakeholders are seeking the stability, safety, continuity and financial performance that can be delivered by establishing an AMS and therefore regard an AMS as a requirement opposed to an option (British Standards Institution, 2008*b*, xi). AM strives to support the operations of organisations. This support process requires an AMS which includes elements across all activities like information systems, legal services, financial services, maintenance, planning and logistics (Hastings, 2015, 11). According to Woodhouse, J. [Online] (2006, 13) an AMS is the way in which an organisation delivers its business objectives and provides a clear and logical perspective on how the organisation intends to convert intentions into practical activities to be carried out, how and by when. AM requires accurate asset information and Gao *et al.* (2010, 160) states that the performance of an AMS can be greatly impacted by the quality of data.

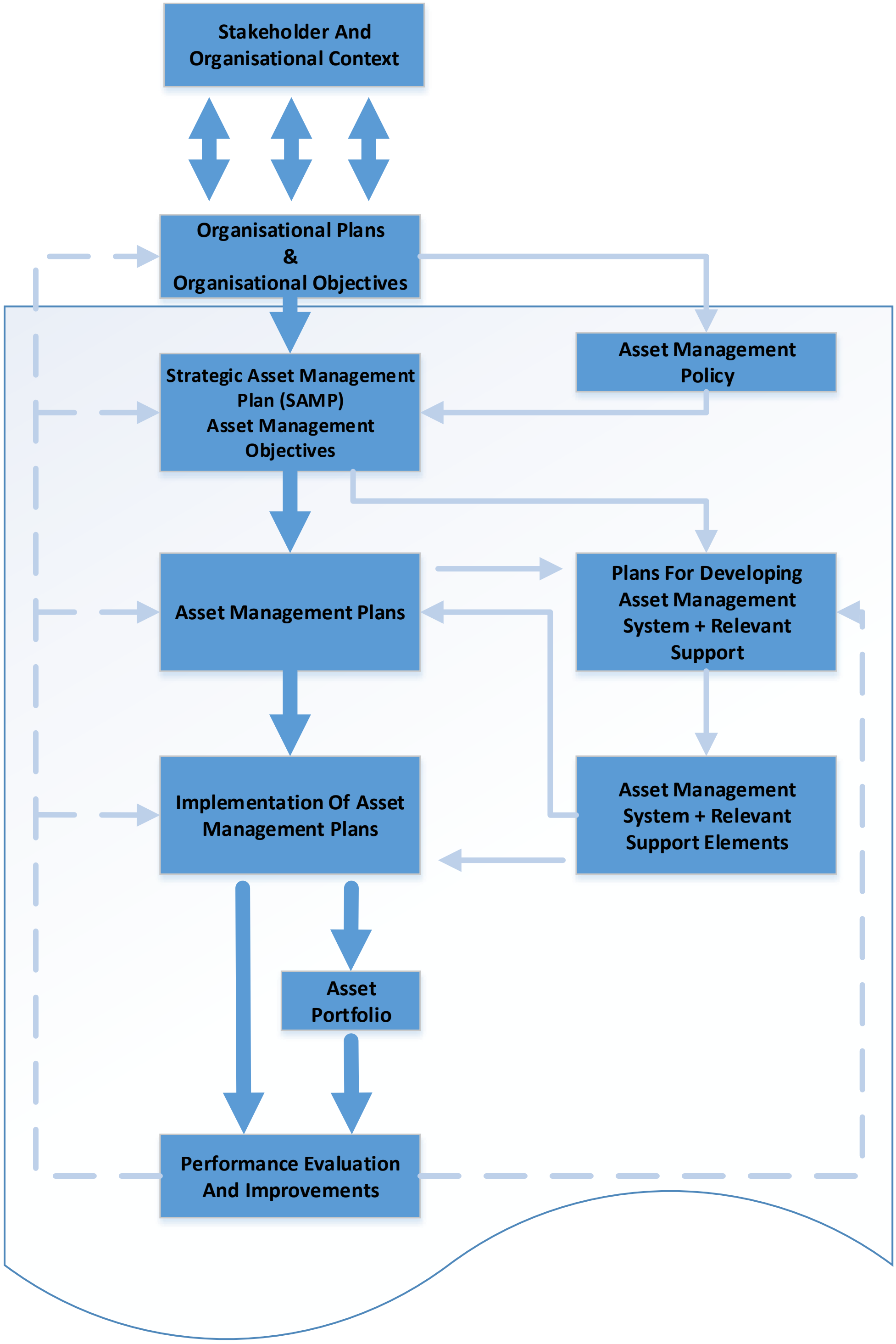


Figure 2.3: Elements of an asset management system (Adapted from British Standards Institution (2008*a*, xii))

However, an AMS is more than an information management system. AM interacts with many functions of a cross-functional organisation (International Standards Organisation, 2014*a*, 5).

The interdependencies of numerous elements of an AMS mentioned up to this point are visualised by figure 2.3. The ISO 55000 series notes that an AMS consist of interrelated elements which are used to establish policy, strategy and objectives whereby the objectives are attained via the implementation and execution of plans (British Standards Institution, 2008*a*, 3).

The requirements of a organisation with regard to its AMS are listed by (British Standards Institution 2008*b*, 2,15; British Standards Institution 2008*b*, 2; British Standards Institution 2008*b*, x; IAM 2014*a*, 12; Too 2010, 57). The organisation is required to:

- establish, document, apply, maintain and continuously improve an AMS in accordance with a AM standard;
- define and clearly document the scope of its AMS ;
- ensure that the AMS has the required level of depth, detail and coverage to meet the requirements of an AM standard;
- choose whether to apply the boundaries of an AMS to the organisation as a whole or to specific operational units within an organisation;
- ensure that the AMS includes the complete portfolio of assets that are required to deliver the OSP;
- ensure that processes and system such as health and safety management, quality and environmental are in place to have an effective AMS ;
- establish a common terminology regards to assets and their components; and
- rigorously manage documents related to its AMS in order to ensure that the documents are suitably based on a quality management system.

Assets can be identified at various levels, or hierarchy, as seen in figure 2.4, within an organisation. The identification of assets can range from discrete pieces of equipment, complex systems, sites or asset portfolios (British Standards Institution, 2008*b*, x).

Benefits of an AMS are noted by the International Standards Organisation (2014*a*, 5,6) and IAM (2014*a*, 14) as providing the organisation with a structured approach to develop, coordinate and control activities actioned on and by assets during the entire LC in order to align activities with organisational objectives; improved financial performance due to enhanced data and linkages; Human Resource (HR) improvement due to the development of competency frameworks, training and development programmes; supporting the sustainability of long term decision making; and integrating the SAMP with long-term financial goals while meeting short-term activity and financial needs.

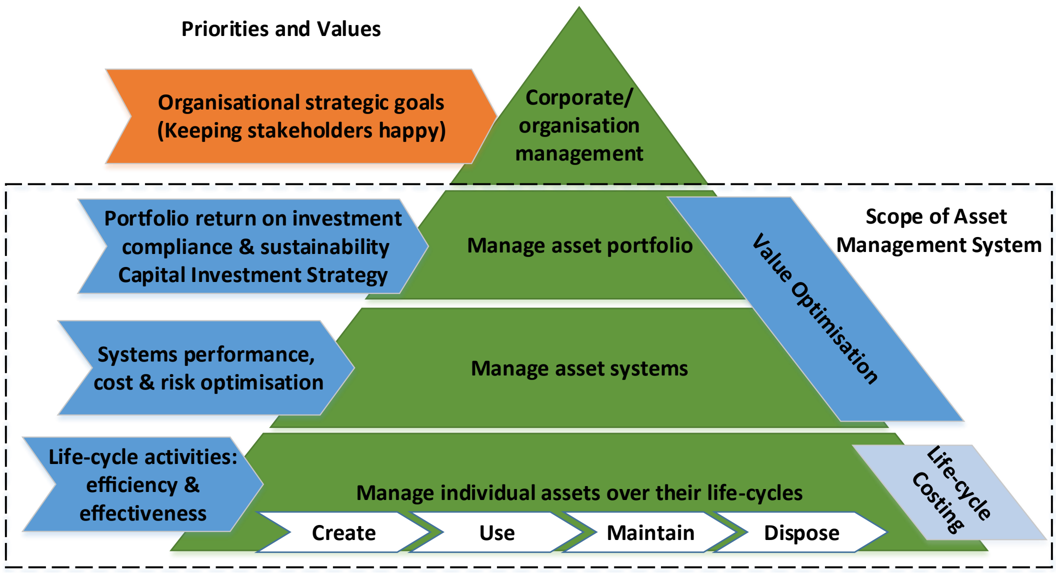


Figure 2.4: The various levels of assets and their management (Adapted from British Standards Institution (2008*a*, vii) and IAM (2014*a*, 29))

The AMS is designed to assist and support in delivering the OSP and fulfil stakeholder expectations (British Standards Institution, 2008*b*, xi). The connection between organisational objectives and strategy needs to be reflected in the daily activities of all departments. Literature refers to this as having "Line-of-Sight" as it enables people to understand why tasks are being performed and not just how they should be performed (IAM, 2014*a*, 14).

Care should be taken to not confuse an enabler such as a Computerised Maintenance Management System (CMMS) with that of a AMS. The relationship that exists between the AMS and other key concepts with the discipline of AM can be seen in figure 2.5 as described by ISO 55000 (International Standards Organisation 2014*a*, 4; IAM 2014*a*, 11).

Developing and implementing an AMS typically requires significant resources in terms of time and costs. However, the benefits of an AMS can be accrued even though the AMS is not in full operation. Early identifiable opportunities in the areas of risk and improving processes can be quick wins and assist in gaining stakeholder support (International Standards Organisation, 2014*a*, 5). The ISO 55000 series describes a management system for AM (see figure 2.5) and defines the requirements for best practices; however, it does not specify the required activities. The framework provided by the ISO 55000 series provides the structure to facilitate the consistent and efficient achievement of the organisational goals by managing its assets through a controlled process (IAM, 2015*a*, 11).

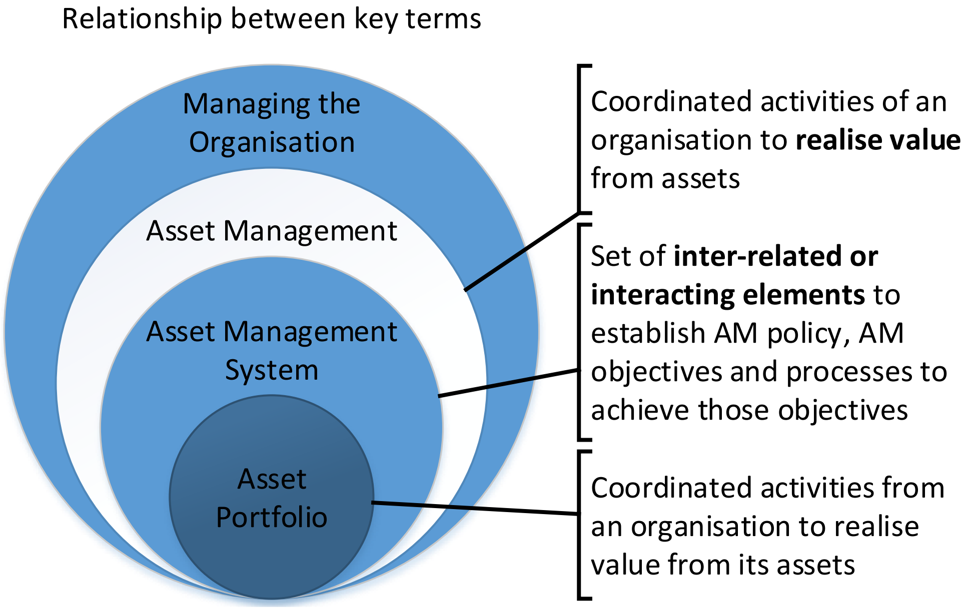


Figure 2.5: Relationship between key AM terms (Adapted from IAM (2014*a*, 11))

One of the requirements of an AMS according the ISO 55000 series is the "Plan-Do-Check-Act" methodology which requires performance measurement at numerous levels of the AMS (IAM, 2014*a*, 63). All the elements of an AMS should be regarded as a repository of tools which includes policies, plans, processes, data and information systems integrated in such a manner that it assures the sustainable achievement of organisational objectives (International Standards Organisation, 2014*a*, v).

2.1.3.4 Organisational Strategic Plan

The OSP is regarded as the long-term plan that encapsulates the vision, mission, values, objectives, policies, stakeholder requirements and risk management of an organisation (British Standards Institution 2008*a*, 4; IAM 2014*a*, 70).

The vision and mission statements serve to promote internal and external communication and motivation as well as assert leadership (Klemm *et al.*, 1991, 76). These statements are strategic and frequently descriptive of the identity of an organisation outlining why an organisation is in business and what it seeks to accomplish (Cady, S.H., Wheeler, J.V., DeWolf, J. and Brodke, M. [Online], 2011, 65). Providing clear and understandable vision, mission and values helps members of an organisation to understand who they are, where they are heading, and how they will get there. This process also ensures that the correct work is undertaken and in so doing increases productivity (Cady, S.H., Wheeler, J.V., DeWolf, J. and Brodke, M. [Online], 2011, 65).

The direction and AM activities of the organisation are driven by the objectives and context of the business and the organisational strategies should also be clearly defined and documented (International Standards Organisation, 2014*a*, 7).

The deployment of policies, and nurturing a shared vision and mission can help develop focus within an organisation and support reaching strategic goals (Voss, 1995, 7). According to Andrawus (2008, 61) this process also helps to unify divergent stakeholder requirements and overarching business objectives, while the overall business objectives need to be defined in such a manner that it upholds the values and stakeholders' requirements. Andrawus (2008, 61) also states that this process can sometimes result in conflicting objectives and this variability needs to be managed by translating organisational objectives into very concise and effectively communicated functions.

Risk assessment and management assist the organisation to deliver on the OSP and extract as much value from the assets as possible. Risk management should provide the organisation with a consistent methodology for assessing and managing uncertainty to optimise AM decision making. The organisation needs to understand how risk related to assets and AM can be combined within a corporate governance framework (IAM 2014*a*, 59; GFMAM 2014, 43). Establishing a view on asset criticality informs the AM strategy and decision-making processes followed by the organisation. Critically, assignment of an asset requires the organisation to assess the potential impact failure would have and is influenced by the vision, mission, values as well as other business policies, key stakeholder requirements, goals and risk management criteria (IAM, 2015*a*, 59). The ISO 31000, Risk Management Principles and Guidance, provides guidance on good practice approaches to Risk Assessment and Management (IAM 2014*a*, 59; GFMAM 2014, 43). Furthermore, the portfolio of assets that are relevant to the vision, mission, values as well as other business policies, key stakeholder requirements, goals and risk should be clearly defined.

2.1.3.5 Asset Management Policy

The importance of having alignment between the OSP and the rest of the AMS is reiterated throughout the literature. Alignment (Line-of-Sight) is important and should be established in such a way that the staff on the ground are able to link their daily tasks, via a clear path of plans, objectives and strategy statements, to aspects of the OSP. In order to achieve this alignment there needs to be a clear AM decision-making framework created by the AM policy (IAM, 2014*a*, 20).

Dunn, S. [Online] (2015, 1) states that top management involvement and support is required with the development of the AM policy to ensure that it is aligned with the overall business objectives. Some of the requirements of the AM policy are stated in section 2.1.4 but are echoed by Clause 5.2 of ISO 55001 International Standards Organisation (2014*b*, 3) and Dunn, S. [Online] (2015, 1) stating that an AM policy needs to commit to:

- being appropriate for the business;
- providing a framework for AM objectives;
- complying with any mandatory regulatory and legal requirements;
- continuously improving the AMS ;
- keeping documentation available and well communicated;
- providing resources to achieve AM objectives;
- utilising decision-making support tools when making asset-related decisions;
- reporting on the performance of its AM activities;
- measuring and reporting on asset and AM performance; and
- maintaining long-term sustainability of AM.

An AM policy needs to be short and concise and depending on the organisation can range from one to a few pages. The AM policy should be high level with the detail of AM contained within the SAMP, AMPs and other related policies, procedures and plans. The AM needs to be visible within the organisation (main reception, board room walls, site offices, etc.). The AM needs to provide useful guidance regarding AM or any other decisions related to assets that are part of the AMS (Dunn, S. [Online] 2015, 2; IAM 2014*a*, 20)

According to Dunn, S. [Online] (2015, 3), it is important how an AM policy is developed, and should be developed in a top management workshop environment. The top management team needs to have a clear understanding of the key fundamentals, principles and scope of AM in order for the workshop scenario to be successful. Ideally an AM policy should have similar length and detail to other organisational policies indicating the equal importance of all these documents. After the AM has been developed it needs to be effectively communicated to the rest of the organisation and it needs to be made clear that the AM policy is the core of AM decision making. The AM policy can be communicated during an induction, team briefs or at the start of meeting. All members of the organisation need to be fully aware of the implications the AM policy has for the decisions they make regarding the assets that they are involved with (Dunn, S. [Online] 2015, 3; IAM 2014*a*, 20).

2.1.3.6 Strategic Asset Management Plan

The AM policy and organisational strategy are key inputs into the SAMP. The purpose of a SAMP, also commonly known an AM strategy, is to document and define the objectives an organisation needs to achieve as a result of its AM activities, as well as outline the time frame in which these objectives should be reached while remaining aligned with organisational objectives, AM policy and how the AMS should support this process (IAM 2014*a*, 19; GFMAM 2014, 14; International Standards Organisation 2014*a*, 8; British Standards Institution 2008*b*, x). In ISO 55001, the strategy for managing assets and the strategies for improving AM are separated into discrete requirements and that lead to changing the PAS 55 term AM strategy, into SAMP (Zhao *et al.*, 2014, 5).

ISO 55000 defines the SAMP as (International Standards Organisation, 2014*a*, 8):

> *documented information that specifies how organisational objectives are to be converted into asset management objectives, the approach for developing asset management plans, and the role of the asset management system in supporting achievement of the asset management objectives*

There are numerous factors that need to be taken into consideration when developing a SAMP, namely demand requirements, asset performance requirements, organisational AM capability related to human capital, information systems and resources as well as how the organisations endeavours to pursue organisational goals by developing its AM capabilities. It is important for an SAMP to have objectives which are clearly specified, can be measured, realistically achievable with a defined time-line and should clearly be communicated to management and staff (IAM 2014*a*, 19; Barry 2011*b*, 313).

Davis (2007, 26-34) makes the point that an AM strategy should not merely apply to the maintenance department but should be integrated into the organisation as a whole. The author also states that the development, implementation and improvement of PAM should be included within the core of the AM strategy and planning. Davis (2007, 26-34) also lists various ways in which an organisation is supported by an AM strategy through enabling the organisation to know what assets it owns and who is responsible for the assets; where the assets are located; be cognisant of the condition of the assets; gain more insight into asset operations; dictate the requirement to develop formal ACPs to facilitate asset performance and reliability; and operate assets in the most cost-effective manner while extending their life span.

Similarly, a number of these points are mentioned in ISO 55002; however in addition the SAMP should (International Standards Organisation, 2014*c*, 2):

- clearly document the relationship that exists between the AM objectives and the organisational objectives;

- consider the expectation of stakeholders;
- consider that the time frame required certain activities might not be aligned with the organisational planning horizon;
- ensure two-way communication between the SAMP and the organisational plan; and
- ensure that the organisational objectives and AM activities are not developed in isolation.

According to Yates, S. [Online] (2015a), the SAMP has the role of capturing the AM objectives that link organisational objectives to lower-level plans. The SAMP needs to be driven by the greater ISO 55002 compliant AM planning process which can be seen in figure 2.6.

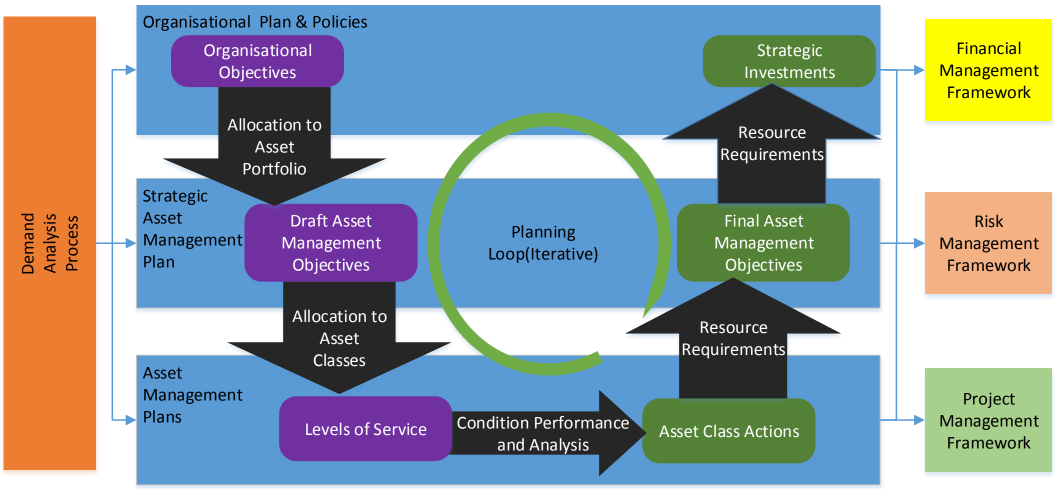


Figure 2.6: ISO 55001 compliant planning process (Adapted from Yates, S. [Online] (2015a, 1))

An ISO 55001-compliant planning loop is an iterative process that will produce AM objectives which are linked to organisational objectives and is informed by demand and stakeholder requirements while remaining consistent with asset portfolio and the AMS capability, condition and performance (Yates, S. [Online], 2015a, 1). AM objectives are the results, goals, targets, aims, outcomes or purpose to be obtained through AM activities. AM objectives are applicable to the asset as well the tools used to manage them like the AMS. Furthermore, objectives can be applicable to different disciplines and at different levels (project,strategic, organisational) (Yates, S. [Online] 2015a, 1; International Standards Organisation 2014a, 11).

According to the IAM (2014a, 20) the second stage of building the Line-of-Sight initiated by the AM policy is the AM objectives and strategies. AM objectives need to be supported by strategic actions that will deliver the AM objectives. These AM strategies need to sufficiently resourced and delivered with clear time lines and responsibilities. AM strategies could, for example, be to implement RCM in order to deliver detailed maintenance plans, or procure and operational a CMMS system to manage maintenance plans. These AM strategies also do not have to link to a single AM objective (Yates, S. [Online], 2015*a*, 1). The combination of AM strategies and objectives provides the direction for lower level planning. A good quality SAMP will be able to deliver the right information to the right people at the right time (Yates, S. [Online], 2015*a*, 1). ISO 55002 provides guidance on the implementation of ISO 55001 and makes some comments on what the contents and structure of the SAMP should do (International Standards Organisation, 2014*c*, 2-5):

- document the manner in which the AM policy principles are applied;
- document the framework for achieving AM objectives and the AM objectives relationship to the organisational objectives;
- be scaled to match the size and complexity of the organisation;
- consider stakeholder needs;
- outline the scope of the AMS ;
- determine methods, criteria and processes for prioritising, decision making, ALC management; and
- plan and review horizons, schedules and methods.

The IAM (2014*a*, 21) highlights that asset-intensive organisations have a major challenge in keeping the developed AM strategy aligned to the AM policy and that an AM strategy needs to be Specific, Measurable, Achievable, Realistic and Time-bound (SMART). The AM strategy also does not need to be delivered as a single document but could be operated into smaller documents which are all aligned with the organisational working culture. Cascading of AMPs could be used within large organisations as well in cases where complex asset portfolios exist. In addition to the AM strategy or SAMP being a high-level plan outlining organisational objectives it should also be at the core of developing AMPs (i.e. in establishing what to do) which will dictate the activities carried out at asset level and should also be SMART (International Standards Organisation, 2014*a*, 8).

The ISO 55000 series provides significant latitude regarding the content and structure of the SAMP (Yates, S. [Online], 2015*a*, 2).

2.1.3.7 Asset Management Plan

Key elements or themes observed within the literature up to this point include topics such as top management, LC consideration, organisational objectives, risk management, value, decision making, performance measurement, monitoring and maintenance. All the these themes are core elements within the

PAS 55 and the ISO 55000 series of standards. The ISO 55000 notes that organisational objectives need to be transformed into AMPs by the use of planning and decision-making processes that consider risk and information (International Standards Organisation, 2014*a*, 3). PAS 55 echoes the need for top management support by noting that top management should ensure resources are available to deliver AMPs and related activities such as monitoring and performance measurement (British Standards Institution, 2008*b*, 19). The entire ALC and all asset types should be addressed by AMPs (British Standards Institution, 2008*b*, 36). Vanier (2000) introduces the view that AM should assist in obtaining organisational objectives while delivering value to stakeholders and proposes a "six What" methodology for implementing a AMP which is the term used in the PAS 55 and ISO 55000 standard (British Standards Institution 2008*a*, 2; International Standards Organisation 2014*a*, 14).

ISO 55000 also defines an AMP as (International Standards Organisation, 2014*a*, 14):

> *documented information that specifies the activities, resources and timescales required for an individual asset, or a grouping of assets, to achieve the organisation's asset management objectives*

An AMP defines the activities, required resources and time-scales related to a asset or grouping of assets.[2] The intent of the AMP is really to write down the things that need to be done in order to achieve or deliver the AM objectives (Yates, S. [Online], 2015*b*, 1). The AMP needs to be derived from the SAMP and could be a subsidiary plan to the SAMP (International Standards Organisation, 2014*a*, 14).

The ISO 55002 standard requires that all decision criteria, processes and methods for managing assets be documented. However, there is no specific requirement to have this as part of the AMP. On the other hand the ISO 55002 guidance does state the requirement to have an iterative planning process which will enable the organisation to strike the balance between its objectives and available resources (Yates, S. [Online] 2015*b*, 1; International Standards Organisation 2014*c*, 10).

The content of the AMP needs to reflect the outcomes of a thorough AM planning process. This lower-level planning process needs to be integrated with other organisational planning activities and is a requirement of the ISO 55001 standard (Yates, S. [Online] 2015*b*, 1; International Standards Organisation

[2] Assets can be grouped by asset type, asset class, asset system or asset protfolio (International Standards Organisation, 2014*a*, 14).

2014*b*, 4). ISO 55001-compliant planning process has been presented in figure 2.6.

A detailed breakdown of AM objectives needs to be completed and specific objectives assigned to specific assets or asset classes. This is also called the “level of service” of these specified assets or asset groupings. The ISO 55001 standard (International Standards Organisation, 2014*a*, 15) defines the “level of service” as “parameters, or combination of parameters, which reflect social, political, environmental and economic outcomes that the organisation delivers”. It further notes that: “The parameters can include safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost and availability.” For example, detailed information regarding the performance and condition of an asset group can assist in a gap analysis and identify improvement initiatives and the actions required to complete them. These initiatives combine into coordinated projects that can span multiple asset classes as strategic organisational programmes. At the start of each planning phase the available resources are weighed against the required resources and balanced under the iteration. The final outputs of the planning process are tracked and delivered via other frameworks that are key to the organisation such as budgets, project and risk management (Yates, S. [Online], 2015*b*, 1).

Asset Management Plans should be short, visual (tables, graphs) and use references to other documents, data sources and plans. It is recommended that the AMP should be around eight pages per asset class and based on a recommended format for an AMP should include (Yates, S. [Online], 2015*b*, 1):

- Asset Class information
- Owners and Stakeholders
- Current and Desired Levels of Service
- Life Limiting Factors
- Health, Safety and Environment
- Life-Cycle Strategies
- Budget
- Risks and Actions

It is argued that AMPs can assist in improving the performance as well as offer strategic benefits to organisations which results in good financial performance. Furthermore, the AMP could assist the organisation to establish a relationship between its AMS (as described in the ISO 55000 series) and a range of very specific, AM requirements of a technical nature (International Standards Organisation, 2014*a*, 5). The ISO 55000 standard also states that an AMP is derived from, contained in or be a subsidiary of the SAMP (International Standards Organisation, 2014*a*, 14).

2.1.3.8 Asset Management Maturity

The convergence by industry on what good AM represents is discussed in section 2.1.1. The consistency between different industries on what good AM entails is surprisingly consistent, according to IAM (2015*a*, 35).

According to Mahmood *et al.* (2012, 2) an effective manner of managing resources and supporting the continuous improvement of AM performance is the adoption of a capability maturity model, that can be defined as a way of assessing the various stages of business process development within an organisation and used to improve processes using a pre-defined set of levels (Mahmood *et al.*, 2012, 2).

Hillson (2003, 299) states that the core purpose of utilising a maturity framework is to understand the existing capability, strengths and weakness while determining gaps for improvement. These frameworks are collections of the best practices that can guide organisations to improve their effectiveness, efficiency and quality. Maturity models can be regarded as a set of structured levels that describe how effective various processes within an organisation can sustainably achieve desired outcomes (Mahmood *et al.*, 2012, 2).

Network Rail in the United Kingdom have used AM maturity, aligned with the IAM (2015*b*) maturity guidelines as a means of driving improvement within its AM capability (Kersley and Sharp, 2014, 1). The intelligence gained during the maturity assessment guides target trajectories, improvement programmes for AM capabilities and monitors the progress over time (Kersley and Sharp, 2014, 1).

The organisational development in terms of AM capability can be described as a function of the AM maturity through a development path leading from basic awareness ("Innocence") of the importance of AM through to the point where the AM practices and processes can deliver sustainable good performance ("Excellence") (Kersley and Sharp, 2014, 3).

Compliance with the ISO 55001 standard can be measured against a qualitative maturity sale (IAM, 2015*b*, 1). The generic maturity scale ranges from "Innocence" to "Excellence" accompanied by qualifying attributes and example symptoms of what could be expected of an organisation on each of the 39 AM subject areas of the GFMAM *Asset Management Landscape* (IAM, 2015*b*, 4).

A maturity scale is also useful to diagnose and prioritise the development of new capabilities, benchmarking, demonstrating progress or competency, and it fosters continuous improvement.

The IAM (2015*b*, 4) maturity scale and guidance for AM has six levels

("Innocent", "Aware","Developing", "Competent", "Optimising","Excellent") and considers both the maturity of the AMS (how it conforms to the requirements of ISO 55001) and the maturity of the AM practices (covering the 39 subjects) (IAM, 2015*a*, 35). The "Developing" and "Optimising" state recognises that there is development in progress. Obtaining a level 3 or "Competent" state shows compliance with the ISO 550001 requirements and that the organisation is competent and managing the assets in a manner where activities are coordinated, aligned, integrated and managed from a LC perspective (Kersley and Sharp 2014, 3; IAM 2015*b*, 7). The "Optimising" and "Excellent" states are context-specific stretch targets and often temporary, as what is regarded as best practice will evolve (IAM, 2015*b*, 7). These states should be considered on a cost-benefit basis and justified or motivated by the business requirements (Kersley and Sharp, 2014, 3).

Displaying AM maturity transcends simply conforming with the ISO 55001, and in certain cases organisations would opt to develop AM capability beyond that required by the ISO 55001 to obtain their organisational objectives. AM as a discipline is evolving continuously and influenced by innovation, learning and new technology. The ever-changing trends continuously challenge what is regarded as best practice (IAM, 2015*a*, 35).

An organisation can obtain a certificate of conformance by demonstrating a desired level competence and good practice in AM. Using accredited assessors will deliver the most value to the certification process (IAM, 2015*a*, 35).

2.1.3.9 Competency Management

Competency frameworks provide a platform to integrate HR activities such as training and performance management by creating a coherent approach towards managing people within an organisation (Lucia and Lepsinger, 1999). Management based on competency has become a critical part of managing organisations effectively and competency management systems enable organisations to manage and develop skills of employed staff, recruit the most competent candidates and develop effective succession plans (Draganidis *et al.*, 2003, 1).

Competency is defined by Draganidis and Mentzas (2006, 52) as "a specific, identifiable, definable, and measurable knowledge, skill, ability and/or other deployment-related characteristic (e.g. attitude, behaviour, physical ability) which a HR may possess and which is necessary for, or material to, the performance of an activity within a specific business context".

Empowering the modern workforce to improve effectiveness, innovation and provide a competitive advantage can be linked to skills management and the ability to leverage internal knowledge (Houtzagers 1999, 27; Hellström *et al.*

2000). Managing skills can also save organisations money through effective resourcing (Homer, 2001, 59).

Organisations need to understand and analyse the business processes driving the OSP and core activities to achieve the strategic goals and should regularly assess the internal skill sets and resources required to sustain performance (Houtzagers 1999, 27; Homer 2001, 59; May 1999, 336).

Competency-focused approaches are a critical tool to manage functions within the organisation such as performance appraisals and succession planning and is important to identify behaviour, skills, knowledge and capabilities to fulfil future staffing requirements in alignment with the OSP (Draganidis *et al.*, 2003). Furthermore, individual and organisational competency plans can be focused to close the gaps between the competency required by the organisation and those available (Draganidis *et al.*, 2003).

An organisation needs to ensure that it has the required competent people in order to sustain a successful organisation (IAM, 2014*a*, 56). Mapping the organisational and employee skill gap analysis with suitable learning objectives is key to developing appropriate learning paths and competencies of the organisation and employees (Draganidis *et al.*, 2003, 1). Good competence does not imply good performance as competence will deteriorate if not practised, and competent people might have difficulty performing in a dysfunctional team. Organisations need to ensure that there are sufficient competent people to perform the activities that drive success (IAM, 2014*a*, 56).

Management teams of AM organisations need to understand what workforce competency requirements will be dictated by the AM objectives and strategies and competency requirements should be clearly defined for all levels of the organisation (IAM, 2014*a*, 56).

Vakola *et al.* (2007, 261) present an approach towards modelling competencies. However, a single formula or guidance for competency management systems does not exist and organisations should adopt a framework which they consider as developing the competencies of individuals and the organisation (IAM, 2014*a*, 56). According to May (1999, 337) the development of a competency structure is a key step towards developing an organisation capable of dealing with rapid change. Draganidis and Mentzas (2006, 56) state that a competency framework should be managed by a structure which is able to the review the effectiveness of the framework that enables the organisation to accomplish the business objectives and strategies. The framework should enable management to develop coherent development training that will deliver the required competencies. The authors also note that the adequacy of the competence framework will be tested every time the organisation is faced with threats or opportunities. In the event that a weakness is detected within the competency framework it should be addressed through a review process (Draganidis and Mentzas, 2006, 56).

According to the IAM (2014*b*, 3), their "Competency Requirements Framework" is generic and applies to human resources in AM roles in any organisation and industry, is consistent with and supports leading competency frameworks and requirements from PAS 55 and the ISO 55000 series, and mapped to the GFMAM 39 subjects in the AM Landscape and the IAM *Asset Management – An Anatomy*.

2.1.4 Asset Management Subjects

The 39 AM subjects, touched on in sections 2.1.1 and 2.1.3, mention that a group of international partners within the GFMAM have been working together to arrive at a common definition and interpretation of the 39 subjects that form the core of the *Asset Management Landscape* (IAM 2014*a*, 15; GFMAM 2014, 2).

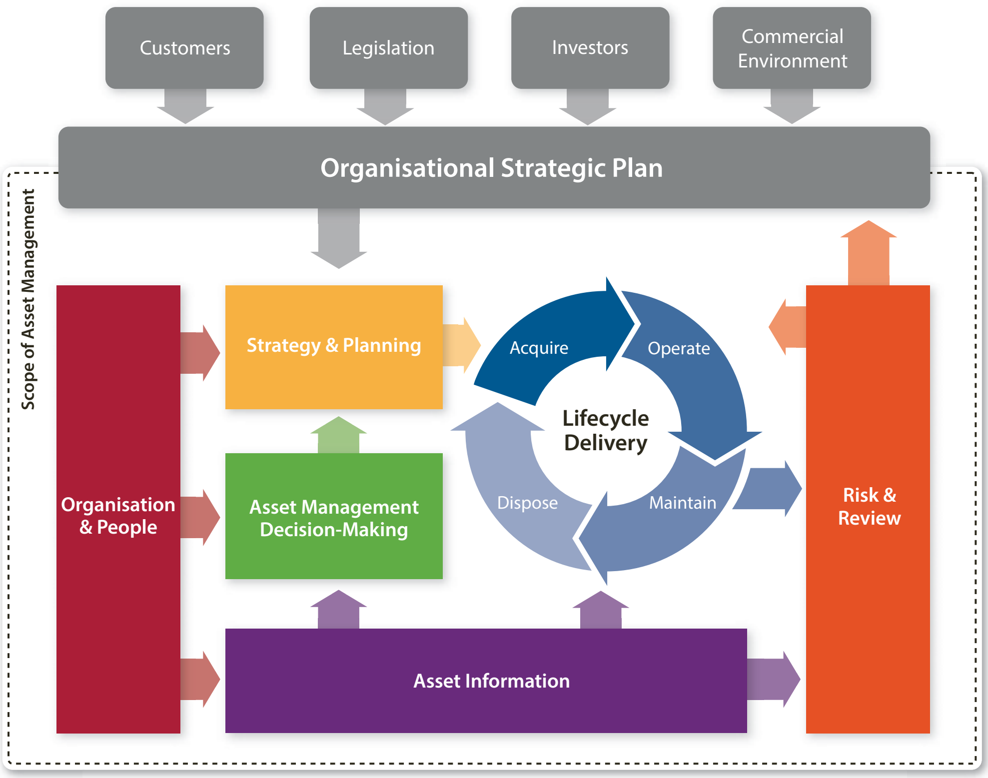


Figure 2.7: The IAM conceptual model (Adapted from IAM (2014*a*, 17))

One of these international partners is the IAM who have developed a conceptual model linking the 39 subjects (see figure 2.8) to the six subject groups as seen in figure 2.7 (IAM, 2014*a*).

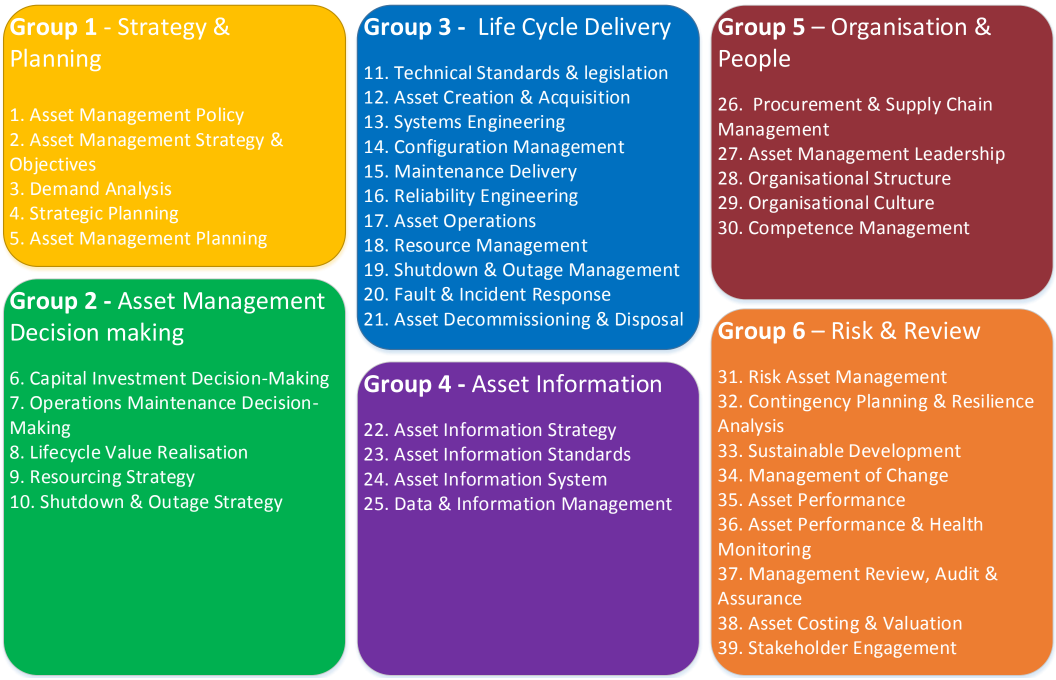


Figure 2.8: 39 Asset management subjects (Adapted from IAM (2014*a*))

A critical aspect to understand is that the entire scope of AM is intended to be encapsulated within the 39 subjects. Any person intending to become a competent person within the field of AM will need to understand the entire breadth of all the 39 subjects in addition to expert knowledge in any one of the subjects (IAM, 2014*a*, 15).

The six groups (as seen in figure 2.8) that span the 39 subjects are:

- Strategy and Planning
- Asset Management Decision Making
- Life-Cycle Activities
- Asset Information Maintenance
- Organisation and People
- Risk and Review

The AM subject related to each group can also be seen in figure 2.8. The AM subjects are a detailed representation of the four AM fundamentals discussed in section 2.1.2 as per the ISO 55000 standard (International Standards Organisation, 2014*a*, 3). The AM subjects are elaborated on in the IAM (2014*a*) in their publication *Asset Management – An Anatomy* as well as the GFMAM (2014) *Asset Management Landscape* Second Edition.

According to Edwards and Lloyd (2010, 3) many of the 39 subjects are not new, but the integration of the 39 subjects is what AM aims to achieve. Prudent and effective AM is when all the AM subjects are aligned towards to the overall business objectives and strategy. This alignment is typically referred to as the "Line-of-Sight" stretching from policy and strategy right down to LC delivery activities (Edwards and Lloyd, 2010, 3). The conceptual model developed by the IAM, as seen in figure 2.7, attempts to integrate the 39 subjects and align them to the OSP which is dependent on stakeholder requirements. The GFMAM subjects applicable to the study are identified and summarised in appendix A.

The 39 subjects that are regarded as relevant to the study are outlined in appendix A. The following section will review the six subject groups to understand their focus within the AMBOK.

2.1.4.1 Strategy and Planning

As mentioned in section 2.1.3.6, the **Strategy and Planning** group within the *Asset Management Landscape* 39 subjects contains the core AM activities required to establish AM within an organisation (GFMAM 2014; IAM 2014*a*, 19). The elements subjects within this group are (GFMAM 2014; IAM 2014*a*, 19):

- Asset Management Policy
- Asset Management Strategy and Objectives
- Demand Analysis
- Strategic Planning
- Asset Management Planning

According to Simmons (2000) there is a need for any business to understand the market it operates in and the resources that are available. Understanding this will enable business to make informed decisions regarding where resources should be focused. Therefore the ISO 55000 standard is very explicit on the requirement to consider internal and external contexts when reviewing its AMS (International Standards Organisation, 2014*a*, 7).

Stakeholder consideration also plays a significant role in determining organisation objectives and decision making (International Standards Organisation, 2014*a*, 7). Wheelhouse, P. [Online] (2009, 15) states that all stakeholders have an interest in the reliable and optimal performance of plant and equipment while maintaining a balance between other factors such as costs and safety.

Strategy and Planning are core elements required when establishing AM within any organisation (IAM, 2014*a*, 19). There are core AM activities that an organisation needs to undertake to develop and implement AM, while considering the business and organisational objectives. The AM strategy needs to (IAM, 2014*a*, 19):

- record how the organisations objectives will be converted into AM objectives;
- establish the approach for developing AM plans; and
- and provide a clear guideline of how how the AMS will support obtaining the AM objectives.

Strategy and Planning also creates the framework for AM and provides the Line-of-Sight for ground personnel to trace their daily activities all the way back to the OSP through plans, objectives and strategies (IAM, 2014*a*, 14). Keeping the AM policy relevant requires continuous development, consistency in the OSP, risk management practices, compliance to laws and regulations, and appropriateness to the nature and scale of the organisation (IAM, 2014*a*, 14).

AMPs should also provide clarity on how the organisation will utilise assets to achieve AM objectives while considering time-scale and the ALC such as acquisition, maintenance, operation and disposal. Furthermore, *Strategy and Planning* should also consider the current and future requirements from the assets and how these can be delivered over the ALC. AM strategies and objectives are often considered over the lifetime of the asset which could be over 50 years in the case of large infrastructure projects. Integrating *Strategy and Planning* activities with Asset Management Decision-Making activities is thus important to consider long-term uncertainties. The operating environment could change due to factors like legislation, required level of service, deteriorating equipment, technology advances, and their impact needs to be understood from a risk, cost and level of service perspective (IAM, 2014*a*, 19).

The AM strategy should be geared towards long term-considerations for the management of physical assets. The AM strategy should also provide guidance regarding the long-term maintenance and investment plans that will inform resourcing required to deliver consistent outcomes. The AMS needs to be considered in parallel and should also be able to consistently deliver the required AM objectives and plans.

Starting the development and following through to the review of AMPs, the organisation should consider who will be responsible, who needs to read the information, what these persons need to know, the asset environment and interdependencies, current condition and performance, and future intended outcomes and the funding and resources that are available (International Standards Organisation, 2014*c*, 11). According to Burns (2010) AM strategy is a three-stage decision-making process:

1. Where does the organisation want to go? The organisational focus should be on vision and values in a long-term perspective. Organisational goals will be proven against future scenarios and consequences in search of the best-suited vision.
2. How does the organisation get there? This stage is about creating structure. Creating structure where all the organisational elements work in harmony towards a common vision is important. Activities should be dictated by decision making.
3. How is the organisation doing? This requires continuous monitoring of outcomes and realignment with values if required with a long-term focus. The top management of the organisation needs to determine the overall goals and strategy and direct the activities of ground personnel.

Woodhouse (2010) states that in creating the Line-of-Sight within an organisation there should be clear understanding why activities are undertaken and that it is insufficient simply to document what needs to be done. Taking this approach provides stakeholders with a clear understanding of reasons and consequences for taking or neglecting to take action. Having good alignment also creates the opportunity for ground personnel to use their valuable experience to contribute to the overall planning process (Woodhouse, 2010).

2.1.4.2 Asset Management Decision-Making

The *Asset Management Decision-Making* group within the *Asset Management Landscape* 39 subjects can assist in the analysis of selecting the optimal combination of activities required to achieve specific objectives. The elements within this group are (GFMAM 2014; IAM 2014*a*, 26):

- Capital Investment Decision Making
- Operations and Maintenance Decision Making
- Life-Cycle Value Realisation
- Resourcing Strategy
- Shutdowns and Outage Strategy

Organisations have experienced a significant change in the global economic climate over the years, which has often led to cost cutting and downsizing as an approach to remaining in business. However, Burns (2010) does not consider cost cutting as the best strategy and challenges managers to leverage increased effectiveness as opposed to reducing cost. The author further notes that emphasis should be placed on more strategic spending as opposed to less spending, while considering the future operational environment and potential new products. Business, processes and technology are continuously changing and the future is increasingly diverging from being a reflection of the past (Frankel, 2008*a*, 13). This trend requires that organisations are able to effectively manage change and Frankel (2008*b*, 12) proposes key factors and organisation needs to consider when trying to plan for the future:

- development in technology and internally used technology;
- underlying economic markets;
- capability and state of competitors;
- capability and state of the organisation;
- competitiveness of processes and products;
- organisational resources related to manpower, competency, finances, technical and other needs;
- resources of competitors;
- internal and external threats to the organisation;
- cross impact; and
- external developments on the political, regulatory and non-technical front.

Frankel (2008*b*, 12) further provides characteristics of good AM decision-making:

- There is a clear understanding of who is responsible for what.
- There is a good understanding of the decisions that enable the organisation to operate effectively.
- There are well-defined precision trees.
- There is respect for the opinions of others irrespective of where they fall within the hierarchy.

Considerations for whole-life management

The concept of whole-life management represents the shift away from procurement based on the lowest price towards procurement considering the "optimum trade-off that can be achieved between social, environmental and economic objectives" (Lloyd, 2010, xiii). Approaching AM from this perspective should be a natural part of AM decision-making for long-term decisions. Analysing the risks and costs starting at inception all the way to the disposal of an asset can mitigate the risk of choosing the most costly option. Good AM should therefore consider all the costs associated with an asset over and above the acquisition cost such as O&M, training, etc. Considering this approach will create economic benefits and facilitate the process of justifying strategic organisation plans facing multiple stakeholders with competing objectives. Using techniques such as FMEA, RCM and Risk Based Inspections, managers could gain an understanding of how different activities have an impact on costs over different time horizons (IAM, 2014*a*, 28). According to Edwards and Lloyd (2010) an organisation could realise reductions of up to 30% in Operational Expenditure (OPEX) should risk-based techniques be used in AM decision-making.

Fostering whole life management also engages employees to think in the long term when faced with decisions and consider the value derived from assets opposed to their costs (Hawkins, B. [Online], 2013). One of the challenges that face whole-life management is the annual cyclic nature of the budgeting process, performance reporting and planning within organisations, which creates internal conflict regarding funds, and different departments often working in silos (Edwards and Lloyd, 2010, 212).

Life Cycle Cost analysis

LCC analysis attempts to ensure that all relevant costs are identified and that costs incurred throughout the life of the asset are considered through key stages such as planning, budgeting and acquisition (Hastings, 2010, 198). LCC is an optimisation method used to identify cumulative costs of competing options in order to make the most appropriate economic decisions. Using templates to determine whole-life cost optimum renewal points and what the associated cumulative costs are can be useful.

Undertaking a LCC analysis has a more significant purpose than mere cost control, but serves as a key planning tool to enable optimised decision-making. The best results of an LCC analysis are achieved during the planning stage of a system. Edwards and Lloyd (2010) notes that the ability to influence the total costs over the LC decreases over time. The author further states that 80% of the complete LC costs are incurred during the O&M phase and already committed during the design stage. An example is highlighted by Pilling (2010) who notes that Network Rail obtained significant positive results from introducing a formalised AM approach and saving 178 million British Pounds (8% of annual O&M budget) between 2007 and 2008. LCC analysis provides organisations with the opportunity to understand the need for O&M and select competing options that will provide the most efficient LCC. Furthermore, it should be understood that LCC only considers economic factors and does not consider other factors such as risk (Markeset and Kumar, 2000).

2.1.4.3 Life Cycle Delivery

The previous section on *Asset Management Decision-Making* considered trade-offs that need to be made by Asset Managers. The *Asset Management Life Cycle*, however, is the area where the majority of the expenditure is incurred and offers many opportunities to introduce efficiencies by using good AM (IAM, 2014*a*, 35). The elements within this group are (GFMAM 2014; IAM 2014*a*, 35):

- Technical Standards and Legislation Decision-Making
- Asset Creation and Acquisition
- Systems Engineering
- Configuration Management
- Maintenance Delivery
- Reliability Engineering
- Asset Operations
- Resource Management
- Shutdowns and Outage Management
- Fault and Incident Response
- Asset Decommissioning and Disposal

The various LC stages are discussed in section 2.1.3.2 and the activities within each of these LC stages should not be considered in isolation. There should be a key understanding of what resources are required during each stage of the LC and as an example maintenance considerations should be incorporated during the design stage to understand the implications (IAM, 2011, 35).

Reliability Engineering

Reliability engineering should be a continuous process that should be prevalent in all LC stages to optimise costs. Reliability engineering aims to ensure that assets are able to meet their requirements by identifying reliability challenges early and applying mitigating steps. Common tools used by reliability engineering is the Failure Mode and Effects and Criticality Analysis (FMECA). However, reliability engineering does not provide reasons for why failures occur, but identifies which failures might occur and on what systems. The discipline of reliability engineering is also well established (GFMAM 2014, 28; IAM 2014*a*, 42).

Holistic Thinking

Engineers will always aim to derive value for stakeholders, but AM engineers think differently about how to achieve this. The discipline of AM requires that there is alignment between the overall OSP and all technical and financial decisions, plans and activities. The alignment requires that compartmentalisation of different aspects, like mechanical, electrical, construction and environmental, needs to be broken down and a more holistic view needs to be taken.

Lloyd (2010, xiii) states that AM is representative of an approach that managed the whole life of assets and incorporates decisions within a framework that focuses on attaining organisational goals.

- What are the most critical assets and processes?
- What needs to be known, and how should this information be captured and distributed?

Lloyd (2010, xiv) also states that the holistic thinking as opposed to compartmentalised thinking will aim to:

- incur less cost but gain more value;
- manage risk opposed to resources;
- use systems Engineering;
- consider entire systems and not only their parts;
- ensure stakeholders understand the decisions made;
- offer a whole-life perspective; and
- provide a common understanding.

According to Parnell *et al.* (2011), traditional engineers embraced systems and applied laws while engineers that practise AM challenge these systems and applied laws. There is a shift from considering outcomes, to considering systems. Woodhouse (2010, 31) consider the net output of all systems and processes working together, which is representative of the asset performance.

Maintenance

Maintenance is often referred to as AM, but the definition of an asset creates the understanding than an asset is more than just equipment and AM entails more than just maintenance. Maintenance is, however, an important part of AM with maintenance being increasingly recognised as making a significant contribution the success of an organisation. Maintenance is increasingly being regarded as a method to optimise the useful life of assets while ensuring environmental safety (Ferreira, L.A. [Online], 2012). The author further argues that in this complex and competitive business world the only way improve return on investments (ROI) is to improve on the return on assets (ROA). As an example, the asset base of a manufacturing organisation is large and AM should be a priority with a clear maintenance strategy to ensure asset performance and costs over the LC. According to the IAM (2014*a*, 40) maintenance activities can be divided into three different groups, namely inspection, testing and monitoring; PM; and CM. Ageing equipment is often only managed using CM, which is not prudent practice. Hastings (2015, 17) refers to "The Asset Death Spiral" where ageing equipment is neglected in terms of resources and maintenance, often resulting in operational disaster. This is a clear example of not following a whole-life approach.

2.1.4.4 Asset Information

Asset-intensive organisations rely on data coming from assets, information and knowledge as enabling tools when undertaking strategic AM and operational activities. The asset information group considers these requirements. The elements within this group are: (GFMAM 2014; IAM 2014*a*, 47):

- Asset Information Strategy
- Asset Information Management
- Asset Information Systems
- Data and Information

Data and information can be improved by following management approaches described by an Asset Information Strategy (AIS). The activities defined in this strategy set out how an organisational asset information meets current and future needs. Contextualising this in terms of AM, information would include an asset inventory or register; asset and asset system attributes; logical groupings of systems or equipment; safety information; historical data; operational data; and technical documents. Other key elements to consider are asset types; metadata; data attributes; intervention data and unstructured data (IAM, 2014*a*, 49).

Information flow is increasing playing a key part in day-to-day business decisions and adds value (Frankel, 2008*a*, 25). The efficient relay and information is an essential part of modern management. The continuous flow of information enables bridging the many layers of management and establishing a flat structure where employees have more responsibility to make decisions. Furthermore, staff are regarded as intellectual capital, and not just a work force, who are capable of participating and cooperating within the defined boundaries and controls of the organisation. An AIS is required to provide guidance around the criticality of asset information which will drive the structure and quality of information.

Furthermore, the information strategy should also guide the collection, sorting, storage and disposal of asset information used to support achieving AM objectives. Standards such as ISO 8000-001 can be used to provide guidance on data and information quality to support asset data and information (Edwards and Lloyd, 2010). Hawkins, B. [Online] (2013) also notes that the risks and opportunities to the organisation can be better understood through having good asset information. Systems also play a critical role in collecting, storing, processing and analysing data and asset information (IAM, 2014*a*, 50). Hastings (2015, 161) proposes a register of key assets be compiled and that employees can understand that significance of the asset and how it relates to AM and organisational objectives. The resister, ideally maintained on a computerised system, should clearly define parameters such as capability, interdependencies, age and estimated remaining life, history, issues, plans, costs and replacement costs. A CMMS could potentially provide the required functionality.

Campbell and Reyes-Picknell (2006) also note that systems can assist with identifying what the activities need to be undertaken, by analysing and reporting on activities. Systems should be customised to serve a specific asset and also consider the criticality and role of assets. Criticality can be determined by considering factors such the category of failure, the impact of failure, how easy it is to repair, mean downtime and cost of repair (Hastings, 2015, 166).

Asset knowledge is the experience, values and the insight contained within management and the work force. The reliability and the quality of knowledge has a direct impact on the quality of decision making. All knowledge that has an impact on decision making should be documented, mapped and made available within the organisation. Documenting valuable information is critical to ensure that knowledge is not lost to the organisation. Concepts which as BIM (building information modelling) will be helpful (IAM, 2014*a*, 51).

2.1.4.5 Organisation and People

The traditional way organisations operate is often challenged by AM and existing structures, roles and responsibilities can be questioned. Issues related to leadership and people should be addressed and could lead to uncomfortable experience for people. The *Organisation and People* group considers these aspects and the elements within this group are (GFMAM 2014; IAM 2014*a*, 52):

- Procurement and Supply Chain Management
- Asset Management Leadership
- Organisational Structure
- Organisational Culture
- Competence Management

The *Organisation and People* group is focused on the awareness, understanding and alignment of roles, responsibilities and competencies related to AM goals and activities. Successful AM practices require top management support (IAM, 2014*a*, 52). Hastings (2015, 15) also notes that top management commitment should address the "grey area" of AM that often exists between top management and operational management. The "grey area" should be replaced by a clear understanding and awareness of asset planning, acquisitions and development projects and assets that are in service by managers. Edwards and Lloyd (2010) states that leadership skills for middle managers and top management are important. The author further highlights the importance of adequate competence throughout all levels of the organisation and notes that all employees that are involved in delivering the AM plan should be competent, committed and motivated. Culture also plays a significant role in AM, enabling leadership and the workforce to work together to collectively achieve the desired results. Human factors are more important than tools, methods and technology (IAM, 2014*a*, 55).

(Johnson, 2010*a*) also mentions that when it comes to AM there should be clearly defined objectives of what the culture should be and how it will be established. The author further notes that there are three key characteristics of culture, namely that it related to values which are shared by all employees within the organisation, that it is stable, enduring and resistant to change, and that it has an impact on how employees behave and perform their duties.

All stakeholders are unique and have different requirements (International Standards Organisation, 2014*c*, 5). Stakeholders could be owners, employees, suppliers, customers or unions, and often have an impact on decisions. The values, needs and concerns of stakeholders need to be considered and recorded during the decision-making process. Following this approach can assist in preventing conflicts and establishing priorities while developing a set of decision-making criteria.

Multi-disciplinary AM teams are important within the discipline of AM as they break down the barriers and departmental thinking created by silos, as discussed in section 2.1.4.3. These multi-disciplinary AM teams need to have the competency in and collective knowledge of all the AM activities across the organisation. The AM policy, SAMP and AMPs should be influenced by these multi-disciplinary teams. (Hastings, 2015, 133) notes that a RACI chart is a good way of assigning responsibility, accountability, consultancy and who should be informed. According to Johnson (2010*a*) should multi-disciplinary teams be absent the possibility of functional silos forming and a lack of information sharing will increase. Establishing these teams is critical to overcoming such attitudes and silo mentality while creating a holistic approach and decision making (Johnson, 2010*b*).

Organisations often outsource elements of the AMS and should ensure that external contractors are able to demonstrate and validate their competency against the required AM activities (International Standards Organisation, 2014*c*, 13).

2.1.4.6 Risk and Review

The *Risk and Review* group considers these aspects and the elements within this group are (GFMAM 2014; IAM 2014*a*, 52):

- Risk Assessment and Management
- Contingency Planning and Resilience Analysis
- Sustainable Development
- Management of Change

- Assets Performance and Health Monitoring
- Asset Management System Monitoring
- Management Review, Audit and Assurance
- Asset Costing and Valuation
- Stakeholder Engagement

The underlying risk faced by the modern business or organisation have evolved from merely being financial and regulatory to becoming complex and inclusive of dimensions such as the environment and the social aspects (Van der Lei *et al.*, 2012, 19). Clients are also increasingly becoming aware of the environmental and social impacts their actions have, which further complicates the way risk managers view and manage risk. The current operating environment introduces some key challenges within the process of developing and establishing governance frameworks and management principles due to these new risk factors (International Standards Organisation 2014*a*, 1; Van der Lei *et al.* 2012, 19).

Edwards (2010) proposes that social anger should be included in calculating risk. The equation should be that risk is equal to severity multiplied by the frequency and the social outrage due to an incident. AM has to consider the balancing of risk with other factors such as cost and has to view each scenario as unique.

Effective control and governance of assets by organisations is essential to realise value through managing risk and opportunity, in order to achieve the desired balance of cost, risk and performance. The regulatory and legislative environment in which organisations operate is increasingly challenging and the inherent risks that many assets present are constantly evolving (International Standards Organisation, 2014*a*, 1). Organisations need to document the manner in which they manage risk as part of the requirements of the ISO 55000 series. This can consist of risk registers or other mechanisms for the management of risk (International Standards Organisation, 2014*c*, 12). Hastings (2015, 252) introduces a potential method of managing risk as seen in figure 2.9.

Significant Events

Each organisation needs to prepare for events which could have a significant impact on the organisation. These risks should have contingency plans that can enable business continuity. These contingency plans cover a set of pre-planned actions to ensure that critical parts of the organisational operation can continue and to prevent or contain injury (International Standards Organisation, 2014*c*, 8).

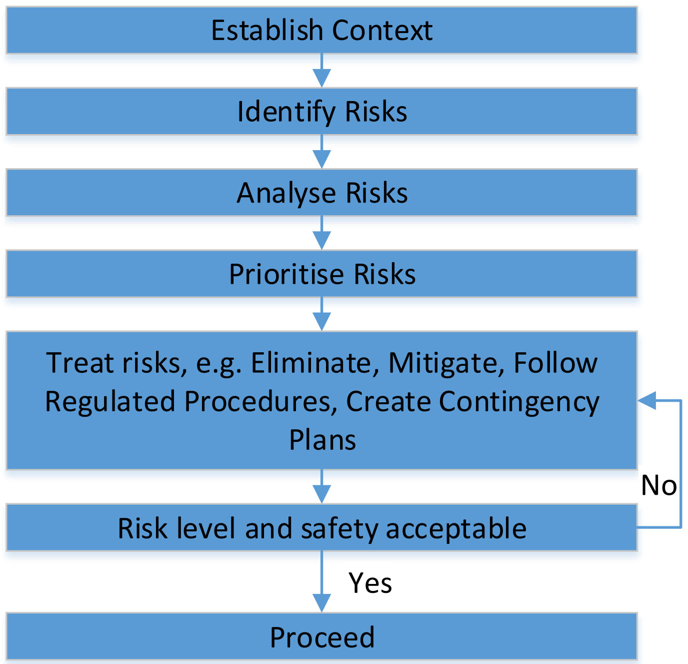


Figure 2.9: Risk management outline (Adapted from Hastings (2015, 252))

Review

Measuring the correct aspects is key to the review process. Traditional performance measures would concentrate on ROI with insufficient regard for aspects related to employees, stakeholders, the environment and society. Organisations need to consider measuring aspects which are the most important, such as production performance, and employee and customer satisfaction. Obtaining consistent good scores on these performance measures will require the organisation to continuously consider how it can improve (Campi, 1993).

Personal performance management is also part of the review process and should have the objectives of motivating, communicating and developing. Campi (1993) states that there has been a shift in thinking, where "how and why things have been done" is also considered in addition to whether targets have been achieved (Armstrong and Baron, 2005). The audit programs, review processes, and Key Performance Indicators (KPIs) need to be linked to the overarching organisational objectives. It is imperative to link performance measurement with organisational strategies and objectives (Campi, 1993). Achieving this alignment provides a basis for feedback and also provide stakeholders with assurance and management the opportunity to improve efficiency (Edwards and Lloyd, 2010).

The IAM (2015*a*) states that the performance of people towards their objectives, how effective processes are, customer feedback and continuous improvement on risk profile are all areas that should be reviewed on a regular basis.

2.1.5 Summary of Asset Management Literature

The underpinning and introductory scholarship that is relevant to the research is the discipline of AM. This section introduces the discipline of AM with a review of the history of AM up to the present landscape. Key concepts of the AM discipline are discussed and concluded by an overview of the six subject groups defined by GFMAM.

2.2 Maintenance

Maintenance is evolving into one of the critical functional areas within many types of organisations (Al-Turki, 2011, 151). Maintenance has also only recently been recognised as a profit generator. There has also been a realisation that the operating function and the maintenance function are interrelated with maintenance becoming an important part of an integrated business concept. Outsourcing the maintenance function has increased while there is a movement from failure-based maintenance to use-based or CBM maintenance. Safety, availability and reliability are prioritised and highly qualified human resources with continuous training are required. Computer-based systems have become an indispensable tool to manage various aspects such as stock management, staff, Work Orders (WOs), production data and document control. Renewed interest in LC costing also indicates that maintenance has become more and more integrated (Waeyenbergh and Pintelon, 2002, 300).

Maintenance has been part of keeping equipment operable since the industrial evolution and has become an important aspect of various industries. Maintenance has moved from a "necessary evil expense" perspective to one that contributes to the business bottom line (Sharma *et al.*, 2011, 6). Ahuja and Khamba (2008, 710) state that generally maintenance is perceived as a having a poor rate of return compared to any other items within a budget. However, by providing maintenance management the required priority costs could be reduced by one third while improving productivity. Maintenance should involve decisions made at all levels of business with the aim of achieving sustainably high levels or availability and reliability from its asset base. According to Anderson and Neri (1990) maintenance addresses very specific resources (time, people, money) and methodologies with the purpose of keeping an asset operating efficiently over its LC. Maintenance is defined by BS EN 13306:2010 as (British Standards Institution, 2010, 5):

> *combination of all technical, administrative and managerial actions during the LC of an item intended to retain it in, or restore it to, a state in which it can perform the required function.*

Maintenance practices have, however, evolved over the past few decades to become a critical area within any asset-intensive business with the development of more sophisticated strategies and tactics. The post Second World War era up to the 1970s is regarded by Moubray (2001, 2) as the *second generation of maintenance*. Increased mechanisation led to increased dependency on equipment and equipment uptime, which resulted in the application of PM at fixed intervals. The increasing cost of maintenance then resulted in the development on *maintenance planning and control* methods as well as researching methods of increasing the LC of equipment (Moubray 2001, 2; Brown, P. and Sondalini, M. [Online] 2007, 3; Murthy *et al.* 2002, 289; Dunn, S. [Online] 2007).

The *third generation of maintenance* was at a time when industry continued to change in the mid-1970s with the government and private sector developing integrated approaches to maintenance with the recognition of the link between reliability and maintainability and the emergence of RCM, FMEA and TPM. (Borris 2006, 1; Murthy *et al.* 2002, 289; Moubray 2001, 2); Murthy *et al.* 2002, 289; Moubray 2001, 2).

The concept of the *fourth generation of maintenance* is presented by Dunn, S. [Online] (2007) that considers equipment availability, reliability, safety, environmental considerations, product quality, equipment LC, cost optimisation and risk management continues to experience expected improvement and optimisation. The focus will be on eliminating equipment failure as opposed to preventing or predicting failure, while still attempting to be proactive rather than reactive (Arunraj and Maiti 2007, 654; Waeyenbergh and Pintelon 2002, 229; Parida and Kumar 2006, 239; Dhillon 2002; Dunn, S. [Online] 2007). Vieira and Sanz-Bobi (2014, 6) echoe the same views but also relate maintenance to AM by stating that maintenance methodologies need to be integrated within an AMS in order to assist the decision-making process and in so doing improve the efficiency of maintenance as well as general management actions, thereby reducing costs and risk while improving quality, asset life and reliability.

2.2.1 Maintenance Concepts

The maintenance of physical assets is generally based on tried and tested maintenance approaches, philosophies, theories, and strategies (Mungani and Visser, 2013, 2). However, selecting the best strategy or approach is not an easy task, especially since there are numerous theories, models, and frameworks for maintenance. According to Mungani and Visser (2013, 2) it is often challenging to differentiate between maintenance approaches or strategies due to the common base of maintenance tactics. The lack of common terminology used within the maintenance field; interchangeable use concepts such as approach, strategy or tactics; and the often unclear definition of these concepts leads to confusion and makes the scientific comparison between different approaches challenging (Vosloo and Visser 1999, 27; Velmurugan and Dhingra 2015, 34). The author states that: "The different guiding concepts, such as maintenance philosophies, maintenance policies and maintenance approaches must be defined" (Vosloo and Visser, 1999, 27). The following section will attempt to review the maintenance concepts and terms to understand how they will be used within this study. Vosloo and Visser (1999, 27) describe a hierarchy of maintenance terms and concepts with the highest level being maintenance philosophy followed by maintenance approach, maintenance types (processes), maintenance tasks and then maintenance technologies.

2.2.2 Maintenance Philosophy

According to Vosloo and Visser (1999, 28) the maintenance philosophy consists of various elements of organisational policies, the maintenance approach, will assist in translating the business strategy to a maintenance strategy and can be defined as

> *to form the framework of principles from which the maintenance policies for each technical system can be deduced.*

The author states that when an organisation uses philosophies such as business-centred maintenance (BCM), RCM, and TPM in their entirety it can be referred to as a maintenance philosophy. However, in some scenarios only a selection of elements from RCM or TPM can be used. Smith and Hinchcliffe (2003, 184) states that RCM is a philosophy as well as a journey, Ben-Daya *et al.* (2009, vii) also introduces RCM as a philosophy. Mungani and Visser (2013, 5) mention that TPM is regarded as a maintenance approach or philosophy, Stretton and Catoir (2011, 217) state that TPM is a very effective philosophy for maintenance management while Pintelon and Gelders (1992, 305) also introduce TPM as a philosophy.

However, the maintenance philosophy is described as preventive, corrective or predictive by Alectris [Online] (2014). Amadi-Echendu *et al.* (2010, 56) mention that there is a need to move towards a "condition-based-maintenance" philosophy; Ben-Daya *et al.* (2009, 340) say that maintenance philosophies can be identified as proactive and reactive while Mobley (2004, 4) states that Predictive Maintenance (PdM) should be regarded as a philosophy or attitude.

Vosloo and Visser (1999, 28) go on to mention that maintenance philosophies are essentially maintenance approaches that are created by combining maintenance processes or types that are suited to a specific technical system.

2.2.2.1 Reliability Centred Maintenance

RCM is a structured framework to understand the maintenance requirements of a complex system and was initially developed by Nowlan and Heap (1978). RCM originates from the United States civil airline industry in the 1960s and provides a methodology for selecting the appropriate maintenance approach based on assessing failure mechanisms and the consequences thereof (Woodhouse 2002; Campbell 1999; Dekker and Scarf 1998, 112). Port *et al.* (2010, 44) state that "RCM aims to achieve maximum system reliability using maintenance tactics that can be effectively applied to specific system failures in the operating environment."

The RCM philosophy, which is built on a method to enhance systems, considers cost effectiveness in the process of identifying, selecting and developing maintenance strategies and policies (Siddiqui and Ben-Daya, 2009, 400). Bloom (2005, 31) states that RCM should be regarded as a reliability program and does not imply the reduction of PM and could either reduce or increase work. The philosophy is different from other maintenance strategies as it aims to preserve system functionality in contrast to just maintaining equipment and in so doing isolate it from the system. RCM is regarded as a systematic way of developing a planned maintenance program composed of cost-effective tasks while simultaneously conserving important plant functionality (Siddiqui and Ben-Daya 2009, 400; Besnard *et al.* 2010, 3). The philosophy assists with systematically formulating a maintenance framework by supporting the process of selecting the appropriate mix of corrective, preplanned, predictive or design-out maintenance approaches based on failure consequences in order to support operational reliability (Prajapati *et al.* 2012, 385; Woodhouse 2000, 12; Willmott and McCarthy 2001, 33).

The RCM methodology has seven basic questions. Emerging from these questions is a documented systematic process that is a manner of selecting the appropriate maintenance requirements or tasks, within the operational context of the asset (Siddiqui and Ben-Daya, 2009, 405). Campbell (1999, 23) notes that the issued SAE Standard, JA1011, "Evaluation criteria for RCM processes" provides a guideline for determining whether a process can be classified as RCM based on the seven questions that need to be answered by the process. The seven high-level questions based on the SAE standard for RCM (Document JA1011), and other published works, about the asset or system are (Besnard *et al.* 2010, 3; Siddiqui and Ben-Daya 2009, 405; Moubray 2001, 7; Kister and Hawkins 2006, 99; Bloom 2005, 134; US Military 1980):

1. What are the functions of the asset?
2. What are the functional failures?
3. What are the failure modes?
4. What are the failure effects?
5. What are the failure consequences?
6. What are the PM tasks?
7. What must be done if a PM task cannot be specified?

The RCM process (see high level overview in figure 2.10) firstly defines the primary (main purpose of the asset) and secondary functions that are performed by an asset within its operating context while considering any applicable performance standards.

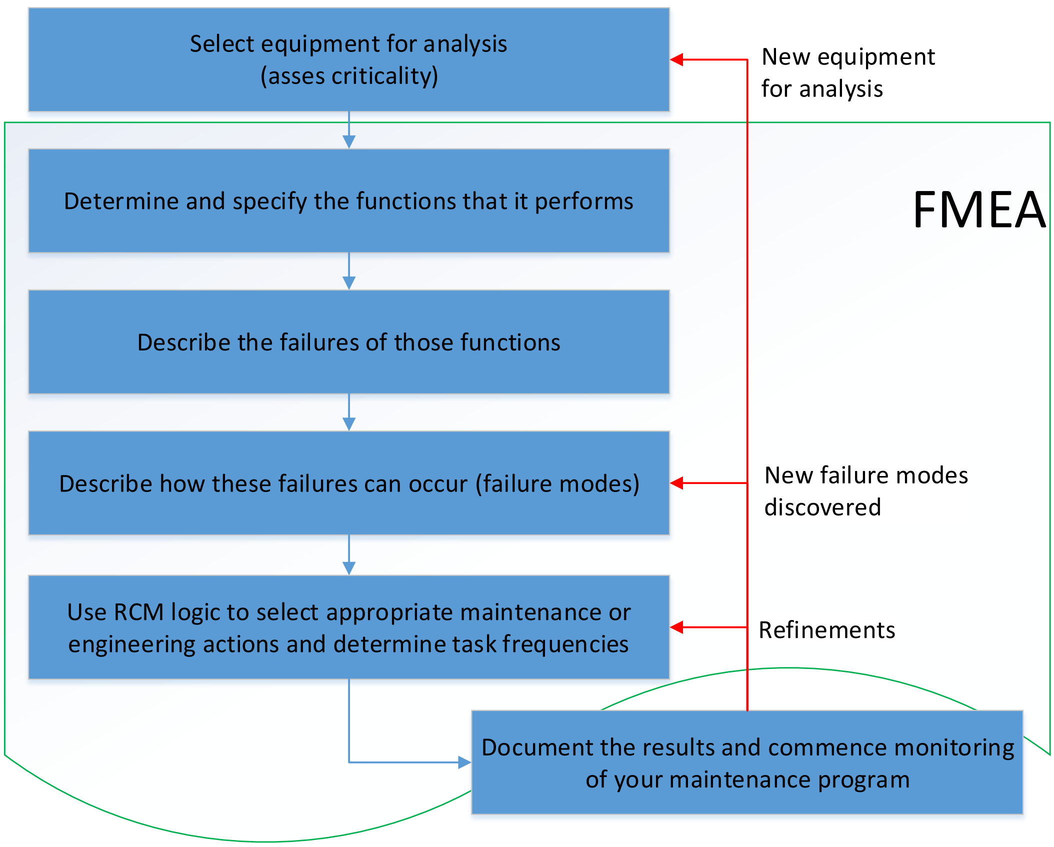


Figure 2.10: Overview of the RCM process (Adapted from Port *et al.* (2010, 44) and Campbell (1999, 23))

According to Borris (2006, 257), the operational context is based on a combination of operating manual, maintenance manual and contract with the purpose of providing the RCM team with information required to perform the

RCM analysis. This is followed by an FMEA where any failures that can occur and prevent the asset or system from performing its function are identified, after which the causes of each failure, also known as failure modes, are identified. The effect or consequences that the failure mode will have on the asset or system are then listed. Generally the listed consequences are categorised as **hidden, safety and environmental, operational or non-operational** and assist in assigning a priority or criticality to each failure mode. The process to this point generates knowledge on system operation, its potential modes of failure and the consequence of these failures. The final step is to select the most appropriate and practical tasks to prevent or predict a failure, allow Run to failure (RTF), or warrant a Design-out maintenance (DOM) based on the RCM decision diagram (Siddiqui and Ben-Daya 2009, 398; Waeyenbergh and Pintelon 2002, 302).

The process is further summarised by Siddiqui and Ben-Daya (2009, 400) as a seven-step methodology with the following steps:

1. system selection and the gathering of information;
2. defining system boundaries;
3. describing systems and outlining functional block diagrams;
4. functions and functional failures of systems;
5. FMEA;
6. logic decision tree analysis (LTA); and
7. selection of tasks.

Owhor *et al.* (2015, 293) summarise seven steps towards implementing RCM.

The first step is to select the critical, high repair-cost equipment that will form part of the RCM analysis process (Owhor *et al.*, 2015, 293). The second step is to define the equipment system boundaries and the functions. Equipment should form part of systems that perform a set of functions. The system inputs and outputs need to be defined (Owhor *et al.*, 2015, 293). The third step is to define the possible ways in which the functions of the system can fail (failure modes) (Owhor *et al.*, 2015, 293). The fourth step is to try to identify and highlight what could potentially cause the failure mode to occur (root cause). Experience from the maintenance and operations staff, RCM and equipment experts could be helpful (Owhor *et al.*, 2015, 293). The fifth step is to understand what the effect of the failure mode would be on the system and furthermore assess these from a safety and operational perspective, and a criticality perspective. A systematic approach to this step can be achieved by using techniques such as FMEA, Hazard and operability studies (HAZOPS), Fault Tree Analysis (FTA) or Risk Based Inspections. The analysis should deliver the critical failure modes that can occur under real operating conditions

(Owhor *et al.* 2015, 293; Ahuja and Khamba 2008, 714). The sixth step is to determine the most appropriate maintenance action to prevent each identified failure mode from occurring. The selected maintenance approach needs to be technically feasible and economically viable. Potential approaches could be CBM or time or usage-based PM depending on the technical and economic feasibility. Alternately DOM can be considered as an option to eliminate the potential failure or RTF should the failure not be critical (Owhor *et al.*, 2015, 293). The last and seventh step is to regularly review the selected maintenance approaches and to ensure that the designed maintenance plans are being executed (Owhor *et al.*, 2015, 293).

According to Campbell (1999, 27) and Hastings (2015, 393) the implementation of RCM requires that it be learnt in order to gain proficiency and reap the benefits. A cross-functional expert team needs to be assembled to obtain the best results from the RCM analysis process and the team should consist of five to eight people and contain members of the functional business area who are experts in these functional areas (Moubray 2001, 17; Plucknette 2009, 34; Bloom 2005, 251). This requires selecting a multi-disciplinary RCM practitioner team (the team should have specialist as well as day-to-day operational knowledge), training in the RCM process, teaching other stakeholders what the benefits of RCM are, selecting an appropriate pilot project to improve team skill with RCM and then expanding to other areas of the plant (Bloom 2005; Plucknette 2009, 40; Siddiqui and Ben-Daya 2009, 413). Plucknette (2009, 27) also notes that RCM facilitators should be part of the team and can speed up the process while one facilitator handles the RCM process as the other can focus on what the team is saying and takes notes. According to Plucknette (2009) all members of the RCM team should also be requested to sign a CM analysis contract, which should be part of their performance contracts, to maintain their commitment to their process (Siddiqui and Ben-Daya, 2009, 413).

It is important to gather critical information and documents that can be used by the RCM team during the analysis process. The quality of the analysis can be dependent on the quality and availability of documentation (Plucknette, 2009, 24). Typical sources of information required by the team will be documentation provided by manufacturers, operations, and engineering procedures, experienced O&M staff, historical maintenance records, training manuals, study guides, design basis documents, external consultants, experienced operators and supervisors, technical staff, operational records, engineering and performance standards, plant equipment drawings and schematics, electrical schematics and so on (Bloom 2005, 93; Hastings 2015, 393; Plucknette 2009, 24).

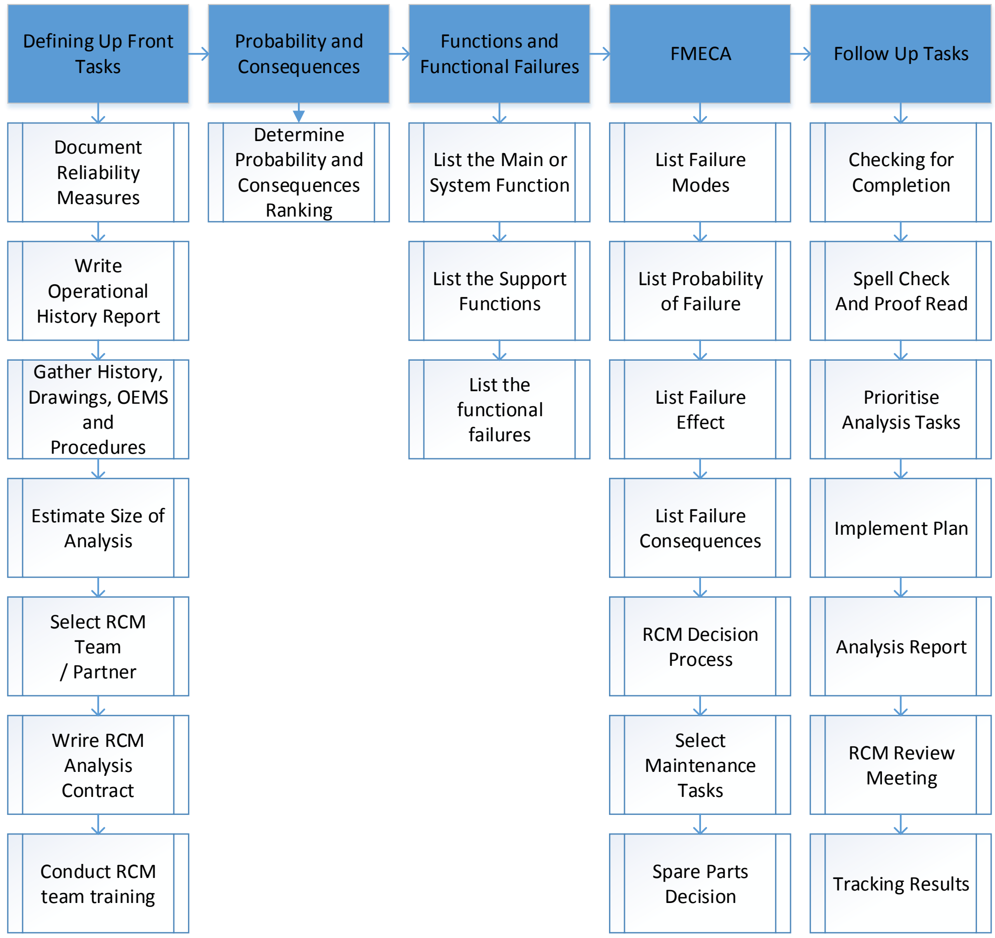


Figure 2.11: RCM Blitz process model flow (Adapted from Plucknette (2009, 9))

Authors have also adapted the original RCM methodology created by Nowlan and Heap (1978). One such adaptation is the concept developed by Smith (1993) and by Mobley (2004) and called RCM II, which is geared for general industry. Plucknette (2009) introduces an RCM concept called RCM Blitz which is summarised in figure 2.11. The process is made of five major steps which are Up-Front Tasks, Probability and Consequences, Functions and Functional Failures, FMECA and Follow-Up Tasks. Plucknette (2009) developed the methodology to be simple and enhancing reliability.

Similarly Bloom (2005) introduces the concept called "Reliability Centered Maintenance Implementation Made Simple" which is based on classical RCM (not streamlined RCM) and further introduces new concepts that have never before been identified. Bloom (2005) introduces concepts and ideas such as not setting up system boundaries, establishing system interfaces, and then identifying functions at the system and subsystem level. The author immediately performs the analysis, and assigns an identifier code at component level, as it reduces the resources required and assumes that the process would end up at component level in any case (Bloom 2005, 256; Bloom 2005, 78). Bloom (2005, 81) introduces the concept of Consequence of Failure Analysis (COFA) that is similar to FMEA or FMECA, but performed at component level as opposed to starting at system level. Furthermore, the COFA RCM logic identifies components as critical, potentially critical, commitment, and economic, and RTF components and considers the consequence of failure based on the asset reliability criteria. The COFA also maintains a clear separation of defining critical, potentially critical, commitment, and economic components from the process of selecting associated applicable and PM tasks. Bloom (2005, 82) states that the COFA "constitutes a simplified and self-contained, all-inclusive RCM logic analysis, that is much more straightforward and comprehensive than the FMEA". Bloom (2005, 134) further states that the COFA logic is in concert with the SAE standard for RCM, and in many ways more advanced. The COFA logic addresses five of the seven questions in the SAE standard while the last two questions are covered by the task frequency considerations. The SAE standard also mentions two key issues, firstly the *PM task interval determination*, and secondly the *continuous RCM review process*. Both these key considerations are addressed by Bloom (2005, 153,193) and within the RCM Blitz process described by (Plucknette, 2009). Plucknette (2009, 111) describes a review process which consists of seven steps, namely checking for completion, spell checking and proofreading, prioritising the tasks, developing an implementation plan (which should consider leadership), an analysis report, RCM review meetings and tracking of results. Bloom (2005, 193) on the other hand calls the review and continuous improvement process – "The RCM Living Program" that considers elements such as feedback, root-cause evaluation, performance trend monitoring, sharing of failure data and an audit process. Therefore it is important to establish the criteria that will be used to measure reliability (Plucknette 2009, 15; Bloom 2005, 82).

RCM cannot always be performed on all equipment and Plucknette (2009, 13), Bloom (2005, 82) and Owhor *et al.* (2015, 293) indicate that a criticality analysis should be performed to identify the most important equipment. (Plucknette, 2009, 29) also states that components often have more than one function and in order to estimate the number of functions that will be used during an analysis the component number can be multiplied by 1.5. The number of failure modes can be estimated by applying a multiplication factor of 3 to the number of components. In a single week session around 70 functions and 120 failure modes can be addressed (Plucknette, 2009, 29). The implementation of these tasks can take up to four to six weeks and requires the appropriate resources (Plucknette, 2009, 117). There thus needs to be a process to rank the importance of each of the identified tasks associated with each of the identified failure modes (Plucknette, 2009, 43) and Plucknette (2009, 47) introduces a means of ranking the importance through the use of a criticality matrix which can be found in appendix F.

One of the major factors regarded as a disadvantage to RCM is its complexity which then also relates to its cost. Justifying the RCM approach is not always easy in a low risk environment, while in industries such as aviation there should be no compromise. RCM is also geared towards reliability but not maintainability, is complex and expensive (Waeyenbergh and Pintelon, 2002, 303). Woodhouse (2002) also states that important system functions that work together could be missed due to failure modes being addressed individually. The complete LCC of maintaining an asset is also not considered in RCM where Evidence Based Maintenance does consider factoring this into maintenance process (maintenanceassistant.com [Online], 2015*a*).

The potential benefits of implementing RCM include safety and environmental protection improvements, extending key and costly equipment lifespans, creating an extensive maintenance database, quality and production improvements, maintenance cost efficiencies, increased plant availability and reliability, reducing spare part requirements, moving from time-based to CBM, greater team coherence and motivation and enhanced technical skill (Brauer and Brauer 1987; Dhillon 2002; Siddiqui and Ben-Daya 2009, 401). RCM assists in determining an optimal maintenance program and efforts, thereby improving operational and cost efficiency. Crucial system functions are preserved while unnecessary maintenance tasks are reduced. These actions increase system reliability while reducing cost without compromising on safety and environmental considerations (Siddiqui and Ben-Daya, 2009, 401). RCM is appropriate for complex assets where a large number of failure modes could occur (Woodhouse, 2002).

FMEA is mentioned on numerous occasions and is an engineering technique that can be used to "define, identify, and eliminate known and/or potential problems, errors, and so on from the system, design, process, and/or service before they reach the customer" (Ben-Daya, 2009, 76). According to Hastings (2010, 282) an FMEA – also known as Failure Mode, Effects and Criticality Analysis (FMECA) – aims to address all the possible ways in which a component can fail, understanding the causes and effects of these failures combined with completing a risk ranking with recommendations on how to prevent failures or mitigate its effects. Van der Lei *et al.* (2012, 158) comment that RCM is a sophisticated AM tool and is based on the FMEA methodology. The FMEA methodology aims to (1) detect potential failures, their causes and effects; (2) appraise and prioritise detected failure modes; and (3) recommend measures that can be applied to eliminate or reduce the likelihood of the failure modes from occurring (Ben-Daya, 2009, 76).

A standard for completing an FMEA, the MIL-SRD-1629A standard – "Procedures for Performing a Failure Mode, Effects and Criticality Analysis" – was developed by the United Stated military (US Military, 1980). Section 3.1 of MIL-SRD-1629A (US Military, 1980, 3) provides definitions for FMEA terms such as failure mode, failure cause, failure effect, local effect, next higher level effect, end effect and indenture levels. Plucknette (2009, 64) also suggests a failure mode formula indicating that the failure mode description should include the location of the asset, what component failed and the specific failure cause. Ben-Daya (2009, 76) and Hastings (2010, 282) note that FMEAs should ideally be performed during the product design or development stages but note that conducting an FMEA on existing products might also provide benefits such as when using RCM to develop a PM program.

The RCM process requires that maintenance task intervals be selected. The section of maintenance task intervals can be complex and methods such as mean time between failures (MTBF) can be used but are often not practical (Bloom, 2005, 163). Krishnasamy *et al.* (2005, 76) also mention that a probabilistic model for failure developed can be used to determine the maintenance interval. Plucknette (2009, 93) also introduces the P-F curve to determine maintenance intervals. Knowledgeable individuals and good historical information are often key to establishing the best maintenance intervals (Bloom, 2005, 163). Other information such as long-term maintenance plans can also be used to align maintenance tasks to improve maintenance overall effectiveness and according to Bloom (2005, 163) selecting the most appropriate PM task frequency is regarded as an art more than a science. Arthur (2005, 252) also states that very little data on P-F curves is published and that often qualitative data is disregarded and the experience and judgement of people are used to select the maintenance interval or frequency.

According to Plucknette (2009, 108) most RCM methodologies do not consider spare parts as part of the process, and that in order to have a complete maintenance strategy, recommendations regarding spare parts need to be considered. Excluding considerations for spare parts can lead to escalated costs and long downtimes, and the author makes suggestions regarding how the provision for spare parts should be approached (Plucknette, 2009, 108).

A key component of the RCM process is to generate maintenance procedures, standards, and routines (Borris 2006, 5; Dhillon 2006). Maintenance procedures and practices need to be reviewed to ensure that they are accessible, realistic and consistent (Hastings, 2015, 315).

2.2.2.2 Total Productive Maintenance

TPM is philosophy of Asset Management and plant equipment that aims to continuously improve industrial type activities by addressing issues related to efficiency and effectiveness in a structured manner (Sachdeva *et al.* 2008, 818; Nakajima 1988; Kumar 2008). The prevention of equipment failure, promotion of autonomous maintenance with the use of the entire workforce (Ahuja and Khamba 2008, 715; Conway and Perry 1999, 281), reduction in maintenance cost and non-value adding activities and redesign of equipment and maintenance practice are all elements that form part of TPM (Rausand and Hoyland 2004, 416; Sachdeva *et al.* 2008, 818). According to Tywoniak *et al.* (2008, 1557), TPM is framework for continuous improvement and particularly important and relevant to engineering AM. TPM aims to derive the maximum equipment effectiveness by improving availability which often requires equipment modification with a focus on investing in human capital as opposed to capital investments (Pintelon and Gelders, 1992, 305). The philosophy is largely associated with the manufacturing industry with Rausand and Hoyland (2004, 416) stating that it was developed to support just-in-time manufacturing and other types of programs that would assist in improving product quality. According to Willmott (1994) and Nakajima (1988) the ultimate goals that TPM sets out to achieve are zero defects, accidents or breakdowns. TPM is a either an operational or a manufacturing strategy based on the context and Levitt (2011, 107) states that TPM is a program for operations in the case of a power plant.

TPM is described by Nakajima (1988), who is also regarded as the founding father of the philosophy as well as other authors as (Kumar 2008; Waeyenbergh and Pintelon 2002, 304):

- having the purpose of extracting the most efficient use of equipment;
- aiming to develop and establish a holistic maintenance program that includes maintenance prevention, preventive maintenance, maintenance improvement over the equipment LC;
- being implemented as a team requiring input from engineers, designers, operators and maintenance staff;
- reaching and involving all from top management to shop floor workers; and
- promoting and implementing of productive maintenance driven by small groups working autonomously.

The TPM philosophy is not complete as a maintenance concept as it fails to offer a framework or guidelines regarding the maintenance approaches such as corrective, design-out, CBM or PdM to be used. TPM can be seen as more of a management strategy (Bloom 2005, 142; Waeyenbergh and Pintelon 2002, 304).

TPM has a range of benefits which include a reduction in overall maintenance cost due to team-based effort to improve maintenance and availability. Combined with improvements in maintainability plants should see an increase in maintenance efficiency, reduced downtime and extended plant life (Rausand and Hoyland 2004, 416; Ahuja and Khamba 2008, 718).

2.2.2.3 Business Centred Maintenance

Business-centred maintenance (BCM) is regarded as a concept which is used to develop a comprehensive maintenance plan while the business remains the focus point (Kobbacy and Murthy, 2008, 39). The BCM philosophy places emphasis on how important it is to identify, map and audit the maintenance function within a business while paying attention to the required administrative support. BCM was developed by Kelly (1987) with a focus on reducing maintenance cost while prioritising safety (Waeyenbergh and Pintelon 2002, 304; Mungani and Visser 2013, 6).

According to Mungani and Visser (2013, 6) BCM can be applied to most industries including power stations, process plants or fleet systems as it is a generic framework. BCM essentially identifies business or corporate objectives and translates them to maintenance objectives, with the purpose of alignment (Kelly 1997; Waeyenbergh and Pintelon 2002, 304; Mungani and Visser 2013, 6).

BCM requires in-depth understanding of system operation which is applied within a top-down bottom-up analysis (Kelly 1987; Kelly 1997). Firstly, the top-down analysis uses the business context to develop maintenance objectives. This is combined with an in-depth analysis of performance data that assists in identifying areas that could immediately targeted for improvement. This also provides a baseline for the development of measurable and achievable improvement goals (Hughes, B. [Online], 2001). Secondly, the bottom-up step then aims to develop a maintenance plan for all equipment. The outcome of the analysis is a life-plan for components or units within a larger system. Part of the life-plan is the decision regarding what combination of maintenance approaches will be effective (Waeyenbergh and Pintelon 2002, 303; Mungani and Visser 2013, 6). The last step is to ensure equipment life-plans are matched with a maintenance strategy. The outcome of BCM is a ready-to-use maintenance schedule. (Kobbacy and Murthy, 2008, 39).

BCM considers maintenance to be a profit centre and to enable this it considers all the thousands of potential different units within a plant and considers their maintenance needs. The process considers the way these units interact and can become very complex as it requires a vast amount of data (Waeyenbergh and Pintelon, 2002, 303).

One of the main advantages of BCM is its focus in increasing profitability which makes it fundamentally different from RCM, which has a focus on improving technical performance (Waeyenbergh and Pintelon, 2002, 304). However, BCM can become very complex as it requires detailed information about production processes and equipment, which is seen as a key issue within BCM (Waeyenbergh and Pintelon, 2002, 304).

2.2.2.4 Risk-Based Maintenance

Risk Based Maintenance (RBM) was initially introduced in the chemical engineering industry and has since expanded to various other industries such as power generation and ship building (Sakai, S. [Online], 2010, 2).

The objective of maintenance is to increase profits and reduce the LC costs while maintaining health and safety standards (Arunraj and Maiti 2007, 655; Khan and Haddara 2003, 562). The probability and consequences of equipment or system failure can be reduced by applying an inspection and maintenance planning methodology that is based on risk analysis. This methodology increases reliability while reducing cost (Arunraj and Maiti 2007, 655; Khan and Haddara 2003, 562; Khan and Haddara 2004, 253; Krishnasamy *et al.* 2005, 69).

A risk-based approach utilises data from failure mode studies and their consequences. Khan and Haddara (2003, 562) states that "risk analysis is a technique for identifying, characterising, quantifying, and evaluating the loss from an event". The integration of probability and consequence analysis is the key building blocks of risk analysis and answers key questions such as: What could go wrong resulting in system failure? How can it happen? What is the likelihood of it happening, and what are the potential consequences of it happening? (Khan and Haddara, 2003, 562). Risk can thus be regarded as an index to gauge priority within risk maintenance technologies. Risk is the product of probability and consequence and often it is observed that 80% of the risk is held by 20% of the devices (Pareto principle) and will require an enhanced maintenance program (Sakai, S. [Online] 2010, 2; Khan and Haddara 2003, 562).

An RBM strategy has the goal of diminishing the overall risk of failure of operating assets while decreasing costs by selecting the best maintenance approach (Vieira and Sanz-Bobi 2014, 18; Sakai, S. [Online] 2010, 2. In the case of high risk, maintenance effort is increased and in the case of low risk, maintenance efforts are justifiably adjusted to consume fewer resources (Khan and Haddara, 2003, 562).

Activities and tasks related to maintenance are prioritised by using the qualitative risk. The number of preventive tasks to be performed are recommended through RBM which will aim to reduce the chance of an unexpected failure (Khan and Haddara, 2003, 562). According to Arunraj and Maiti (2007, 655) RBM consists of two main phases which are **risk assessment** and **maintenance planning**. The RBM methodology proposed by Khan and Haddara (2003) is divided into three modules according to Khan and Haddara (2003, 563) and Vieira and Sanz-Bobi (2014, 18). However, a similar four-module methodology is also proposed by Krishnasamy *et al.* (2005) and applied to nuclear power plants. Khan and Haddara (2003) also divide the system being analysed into smaller manageable units but do not specifically mention it as a module as Krishnasamy *et al.* (2005) do.

These modules within the Khan and Haddara (2003) methodology are:

- Risk identification estimation
- Risk aversion and acceptance analysis (risk evaluation)
- Maintenance planning considering risk

One of the key components of RBM is assessing risk of failure. The higher the accuracy of estimating the risk the more effective the RBM outcome, but there is no single method for assessing risk (maintenanceassistant.com [Online], 2015*b*). Risk can be defined using quantitative, semi-quantitative or qualitative methods. Tixier *et al.* (2002) describes 62 different methods of assessing risk and it is evident that the most appropriate approach will dependent on the data that is available to evaluate a risk.

2.2.2.5 Life Cycle Cost

LCC is the complete cost of ownership associated with equipment, machines or assets and includes costs related to design, acquisition, construction, operation, maintenance and decommissioning (Society of Automotive Engineers 1999; Society of Automotive Engineers 1999; Jardine 2011, 293).

Barringer (2003, 2) states that "life-cycle costs are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced in annual time increments during the project life with consideration for the time value of money". LCC can be seen as an economic model over the lifespan of a project. ISO 156868 defines life-cycle costs as "a technique which enables comparative cost assessment to be made over a specific period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational costs" (International Standards Organisation, 2000, 5).

LCC can also be used to understand the required resources and budget for running the O&M on existing assets (Barringer and Weber 1996, 3-2; Barringer 2003, 2; Hastings 2015, 149).

Barringer and Weber 1996, 3-2 mention cases where LCC can be beneficial in terms of altering provincial perspectives to focus on optimising economic competitiveness by aiming to achieve the best possible long-term LCC. Short-term economic competitiveness, which has costly long-term effects, often stems from a parochial perspective.

LCC can facilitate the process of making the best or mots cost-effective long-term decisions when conflicting elements are at play. Minimising the LCC indicates that the best balance between these elements has been reached (Barringer, 2003, 2).

Net present value and uniform annualised cost are methods used within a LCC analysis (Amadi-Echendu *et al.* 2010, 139; Rahman and Vanier 2004, 2). The net present value method, often used by businesses (Barringer, 2003, 2), seen in equation 2.2.1 calculates the present value for additional expenses while accounting for possible inflation, discounting that amount by an estimated rate over the time period between the expected expense and the present time.

$$PV = FV\left[\frac{1}{(1+i)^n}\right] \tag{2.2.1}$$

The uniform annualised cost method converts future or present costs into uniform annual costs and is expressed by equation 2.2.2:

$$A = PV\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \tag{2.2.2}$$

Notation is as follows:

- PV = present value of expenses
- FV = future value of expenses
- A = end of year expenses
- n = number of years between time of analysis and time of expense
- i = discount rate

In the case of a power plant LCC could typically be investment, maintenance, energy production lost and rest value and can be represented by Equation 2.2.3 (Nilsson and Bertling, 2007, 224):

$$LCC = C_{Inv} + C_{CM} + C_{PM} + C_{PL} + C_{Rem} \tag{2.2.3}$$

Notation as follows:

- C_{Inv} = cost of the investment
- C_{CM} = cost for corrective maintenance
- C_{PM} = cost for preventive maintenance
- C_{PL} = cost for production loss
- C_{Rem} = remainder value

The abovementioned methods are some of the tools used to select appropriate cost-effective alternatives and often used to appraise investments and business units from a economic view (Barringer, 2003, 2). Time is an important factor within these methods as the evaluation is attached to a specific time frame or period. Careful consideration should be given to the analysis of costs related to O&M as these costs can change over time.

The best results are delivered by LCC when engineering and science are synergised with prudent judgement to develop a coherent business case (Barringer, 2003, 2). The judgement would require understanding the appropriate costs for a specific situation as the LCC for each case will differ (Barringer and Weber, 1996, 3-15). The LCC follows a process which can be seen in figure 2.12.

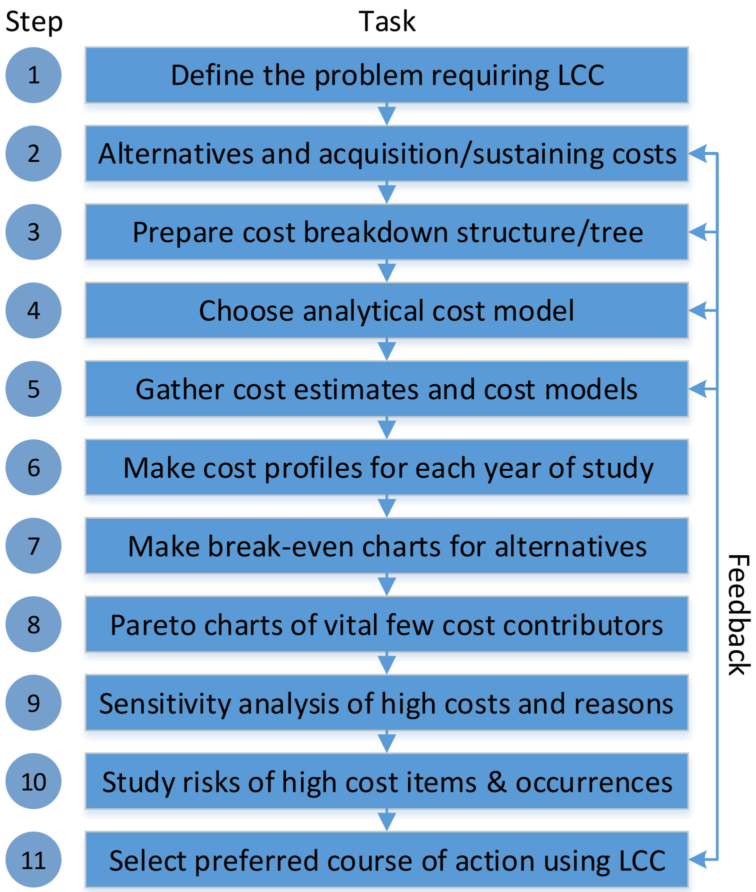


Figure 2.12: LCC process (Adapted from Fabrycky and Blanchard (1991))

Dhillon (2009, 35) mentions that LCC is a very helpful tool to reduce total costs, control programs, compare the cost of competing projects and make choices regarding the replacement of equipment, planning and budgeting. It is also useful when comparing and selecting from competing contractors. The most common disadvantages or limitations of LCC are that it is not an exact science, lacks accuracy, requires data which might not be available, and that complex scenarios need to be considered and it requires extrapolations based on incomplete data, and is not useful for budgeting (Barringer and Weber, 1996, 3-6).

2.2.2.6 Integration and Adaptation of Maintenance Philosophies

The literature regarding maintenance philosophies such as RCM and TPM indicates that these philosophies have their advantages and disadvantages. The literature further reveals that hybrid solutions have been proposed to try and mitigate some of the disadvantages.

Patra (2009) considers the use of reliability, availability, maintainability and safety (RAMS)band LCC within a maintenance planning strategy. Results indicated that the hybrid solution offers an optimised maintenance strategy. Bertling *et al.* (2005) proposes a method called Reliability Centred Asset Maintenance (RCAM) developed to provide a quantitative relationship between PM of assets and the total maintenance cost. RCAM is developed by using RCM principles and attempts to relate the effect of maintenance on the cost and reliability of the system. The method was developed through comprehensive application studies on actual operating power distribution systems (Besnard *et al.*, 2010, 4).

Woodhouse (2002) states that RCM programmes need some aspects of TPM to be more effective with Borris (2006, 3) similarly noting that TPM and RCM should complement each other. Coetzee (2002) also proposes a specific RCM technique by combining concepts from other authors and techniques. Kobbacy and Murthy (2008, 40) note that there is a range of streamlined RCM concepts and warn that although these concepts may sound attractive attention should be paid to whether they are RCM compliant.

Waeyenbergh and Pintelon (2002, 301) notes that organisations struggle to develop maintenance concepts. The author further states that standard concepts found in literature are often not suitable and customised concepts need to be developed by taking aspects from different theoretical concepts. Research related to a partially centralised organisation with a multi-technology portfolio of plants are discussed with the focus on developing a total-company maintenance concept, which could take care of all the different assets within the respective portfolio.

One such customised RCM concept is presented by Bloom (2005) in a book called *Reliability Centered Maintenance Implementation Made Simple*. Bloom (2005, 75) states that the classic RCM requires system boundaries and interfaces to be defined, however his version of "RCM Implementation Made Simple" there is no need to perform this process. He states that RCM decision structure occurs at the component level even after the system boundaries and interfaces have been defined and that plant-level consequences are prevented by considering functional and failure modes at the component level. Defining system boundaries and interfaces can be time consuming, complex and one of the reasons RCM implementations often fail. The "RCM Implementation Made Simple" immediately starts at the component level. Starting the analysis at component/equipment level, regardless of how big or small, has numerous advantages in that all interface points are automatically included, it is straightforward and easy and components are only analysed once.

Bloom (2005, 81) also introduces the concept of COFA which is similar to FMEA or FMECA. He states that FMEA and the FMECA essentially require the analysis at component level but does not accurately convey this. The COFA performs the analysis at component level and includes all the same as well as additional attributes to FMEA and the FMECA. According to Bloom (2005, 82) the COFA method collected information with more conceptual clarity. The COFA framework also included the RCM logic and the identification of critical, potentially critical, commitment and economic components. The conventional RC process classifies consequences into four groups, as follows: hidden failure consequences, safety and environmental consequences, operational consequences and non-operational consequences (Siddiqui and Ben-Daya, 2009, 398). Furthermore, the logic to determine whether a failure is evident, and what the consequence of failure is, is based on the specified asset reliability. In summary the COFA is a simplified, self-contained, all-inclusive RCM logic analysis (Bloom, 2005, 81).

2.2.2.7 Asset Care

The importance of integrating asset care participation into an organisational hierarchy that includes top management as well as the general workforce is highlighted by Sachdeva *et al.* (2008, 818). Asset Care is an integrated part of any organisation and maintaining the health and operation of assets is a core organisational activity (Wenzler, 2005, 76). The sustainable optimised integration of asset care and asset exploitation, which broadly entails maintenance and risk management while using assets to achieve organisational performance objectives, is called integrated AM according to Woodhouse, J. [Online] (2006, 12). The author also notes that this approach is beneficial to any asset type, not just physical assets, and needs to be considered over the entire ALC. However the optimisation of LC costs cannot be realised without considering maintenance/asset care requirements (British Standards Institution, 2008*a*, 19). According to Van der Westhuizen and Gräbe (2013, 20) maintenance can be defined as asset care. However according to Wheelhouse, P. [Online] (2009, 15) asset care does not only speak to maintenance but all stakeholders that have an interest in the reliable and optimal performance of plant and equipment, while trying to find a balance between safety, availability, performance and cost within the bounds of long-term needs and short-term constraints. This is achieved by an asset care programme which is the systematic approach to retaining the mint condition of equipment by completing routine tasks such as cleaning, monitoring, servicing and preventive maintenance (Willmott and McCarthy, 2001, xiv).

The views of Willmott and McCarthy (2001, xiv) are echoed and expanded by Wheelhouse, P. [Online] (2009, 15) who states that ACPs should include maintenance and servicing, inspections, shut-downs, management of spare parts, having an asset strategy ad monitoring performance.

Asset reliability can be improved by even the most basic implementation of an ACP, according to Khan (2001, 127) while Smith and Mobley (2011) state that practising asset care can maintain the inherent equipment capability. Wheelhouse, P. [Online] (2009, 16) further states that an ACP enables an organisation to maintain equipment in order to suit a required need while optimising costs, safety and performance. Value to shareholders can be created by applying the following five principles, namely the reduction in the cost of capital; the reduction of tax; investment with the goal of achieving growth; asset performance improvement; and influencing the judgement of the stock market (Wheelhouse, P. [Online] 2009, 15 Woodhouse, J. [Online] 2006, 12). Asset care can improve the performance of assets and provides a strategic advantage due to the fact that assets deliver enhanced reliability, extended life spans, reduced investment and running costs, thereby improving financial performance as well as raising reputation and stock price (Wheelhouse, P. [Online], 2009, 15). These views are also highlighted by Davis (2007, 30) who notes that an ACP) can optimise the operating cost of assets while verifying that assets are reliably operating close to their design parameters throughout their LC.

Although Wheelhouse, P. [Online] (2009, 15) does state that an ACP does not only include maintenance, general maintenance activities do play a substantial role within AMPs as it is the key activity that ensures the availability of assets to perform their required function. The effectiveness of an ACP to create value is determined by the decisions related to maintenance programmes which need to be taken early within the equipment LC (Wheelhouse, P. [Online] 2009, 15; Davis 2007, 30). Campbell and Reyes-Picknell (2006, 7) states that for an organisation to achieve its goals, maintenance is required to retain the optimal performance of assets, with Weber and Thomas (2005, 11) stating that maintenance effectiveness is improved by performing the correct maintenance at the correct time.

Decision making is a key component of an AMP and Van der Westhuizen and Gräbe (2013, 20) who cite Peterson (2007) view the benefits of asset care, within an asset-optimisation process, as assisting with reducing the occurrence of incidents, improving utilisation, improving quality, decreasing the number of failures, minimising the costs of O&M and optimising the requirement for spare parts.

Davis (2007, 29) states there are six basic components to asset care, which are work identification, job planning, WO scheduling, PdM optimisation, PM optimisation and scheduled outage coordination.

Wheelhouse, P. [Online] (2009, 15) very specifically states that asset care does not only speak to maintenance but all stakeholders that have an interest in the reliable and optimal performance of plant and equipment while trying to find a balance between safety, availability, performance and cost within the bounds of long-term needs and short-term constraints.

An ACP is a term used to describe the combination of tactical and non-tactical maintenance activities that has been structured as part of a maintenance strategy. Tactical maintenance strategies are generally regarded as a grouping of PM activities while non-tactical strategies are a group ofCM activities. RCM and TPM are well known qualitative maintenance management philosophies. In order to schedule and specify maintenance activities, but also to analyse historical failure data on equipment, statistical maintenance interval metrics are defined and used (Dekker and Scarf, 1998).

2.2.3 Maintenance Approach

Maintenance is regarded as a combination of technical and the associated administrative tasks performed in order to keep or return equipment to a state where it can perform the function it was intended to (Besnard *et al.*, 2010, 3). Vosloo and Visser (1999, 28) state that a within a maintenance approach exists a combination of maintenance types or processes. The dominant maintenance approaches identified in the literature are PM and CM (Besnard *et al.* 2010, 3; Amadi-Echendu *et al.* 2010; Rausand and Hoyland 2004; British Standards Institution 2010). Márquez (2007, 69) also makes the analogy of CM being "restoration" and PM being "retention" within the maintenance discipline. However, Prajapati *et al.* (2012, 385) mention that CBM is classified under PM but considered as an approach by many professionals, while Vosloo and Visser (1999, 28) also categorise CBM as a maintenance type along with

CM and PM. Another approach found in literature is DOM (Tsang 2002, 24; Kumar 2008, 782).

2.2.3.1 Corrective maintenance

CM, also known as RTF, is executed after an equipment failure has occurred, is therefore event-driven, and associated with emergency breakdowns, often requiring the replacement or repair of equipment. In certain scenarios CM can be performed as soon as practicably possible or requires a scheduled shut down to action repairs. According to Besnard *et al.* (2010, 3) CBM is performed after the occurrence of a failure and the intention is to restore the equipment to a state where it is able to perform its intended function. CBM is generally only performed in the case where there is no cost-effective measure that could be taken to prevent failure and is regarded as unplanned maintenance tasks by Smith and Hinchcliffe (2003, 20). The BSI defines CM as "maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function" (British Standards Institution, 2010, 12).

The cost of performing CM is often far greater than avoiding equipment failure in the first place, and these costs are significantly escalated in the event that there is loss of life or damage to the environment (Mitchell and Amadi-Echendu, 2007). The lifespan of equipment is often significantly impacted by only following a CM approach as the operating condition of equipment is not taken into account. However, there are scenarios where CM is feasible, will not negatively impact an entire system and is economically viable (Nakagawa, 2006, 2).

2.2.3.2 Preventive maintenance

There are dominant subcategories related to PM within literature. Rausand and Hoyland (2004, 364) state that PM tasks can be classified into categories such as age-based maintenance (tasks performed at a specified age of the equipment), clock-based or Time-based Maintenance (TBM) (tasks are performed at specified calendar times) (Besnard *et al.*, 2010, 3), CBM and opportunity maintenance. Similarly Vosloo and Visser (1999, 28) follow the idea that within a preventive maintenance approach there exist maintenance processes such as planned maintenance, TBM and CBM (Prajapati *et al.* 2012, 385; Vosloo and Visser 1999, 28).

The process of maintaining equipment before failure occurs is regarded as PM. The prevention or the reduction in the probability of equipment failure while it is in an operating state is achieved by performing PM (Besnard *et al.*, 2010, 3). The BSI defines PM as "maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item" (British

Standards Institution, 2010, 12). According to Smith and Hinchcliffe (2003, 20) PM involves performing preplanned inspection or servicing in order to retain equipment capability and functionality at certain points in time. The author also notes that the word "preplanned" is key within the definition and is indicative of a proactive culture. A more comprehensive definition is provided by Dhillon (2002, 3) who defines PM as:

> *All actions carried out on a planned, periodic, and specific schedule to keep an item/equipment in stated working condition through the process of checking and reconditioning. These actions are precautionary steps undertaken to forestall or lower the probability of failures or an unacceptable level of degradation in later service, rather than correcting them after they occur.*

Predetermined maintenance is also defined as "preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation" (British Standards Institution, 2010, 12).

Predetermined maintenance is also described in the literature as planned maintenance, age-based maintenance, TBM, scheduled maintenance or routine maintenance (Blischke and Murthy 2003, 380; Fraser *et al.* 2015, 640; Kostic 2003, 276; Levitt 2011, 329; Hastings 2010, 319). Predetermined maintenance could involve a six-monthly preventive maintenance and module cleaning in the case of a PV plant (EPRI, 2010, 8), while on transformers it might include the cleaning of bushes and visual inspections including oil level checks (Murugan and Ramasamy, 2015, 187). This type of maintenance is often used to prevent voiding of OEM warranties and performance maintenance on less-critical machines where the pattern of failure is well known (Andrawus *et al.*, 2006*b*). According to Prajapati *et al.* (2012, 392). This type of maintenance is determined by the average useful life of the equipment or it could be based on operational failure history. The tasks associated with PM typically involve inspections, calibration, lubrication, modification and adjustment (Rausand and Hoyland 2004, 364; Parida and Kumar 2006, 243).

2.2.3.3 Condition-Based Maintenance

Wiseman, M. [Online] (2006) and Ahuja and Khamba (2008, 713) states that CBM is also known as PdM. CBM is defined by British Standards Institution (2010, 12) as "preventive maintenance which include a combination of Condition Monitoring (CdM) and/or inspection and/or testing, analysis and the ensuing maintenance actions".

CBM includes the inspections at predetermined intervals in order to ascertain the condition that a system is in. Pending the result of the inspections which are performed on a continuous or periodic basis, the decision is made whether to perform a maintenance task and thereby triggers a maintenance intervention that is dependent on the equipment condition. According to Grall *et al.* (2002, 142), a policy that is condition based is more effective in systems that gradually deteriorate, compared to a strictly age-based policy. Mitchell and Amadi-Echendu (2007, 77) states that CdM methods and practices have been proven and if applied correctly work sufficiently for various equipment types capable of detecting anomalies early.

Emmanouilidis *et al.* (2010) summarises the cornerstone of a CBM strategy and the use of CdM is the deployment of appropriate sensors, hardware and software subsystems that are integrated into a system in order to provide diagnostic capability to interpret asset operating state and offer a prognosis of how the condition will evolve with time has also been proven as an effective maintenance strategy, as maintenance can be performed in the event that it is required and not at pre-scheduled intervals.

2.2.3.4 Design-Out Maintenance

DOM entails design improvement maintenance where the equipment or system design is changed to increase reliability and maintainability while reducing resource requirements (Tsang, 2002, 24). According to Kumar (2008, 781), it is becoming standard practice to combine risk analysis with LC costing in order to determine whether it is an appropriate choice as to design-out the maintenance requirement or to design the system for maintainability, if pursuing of DOM is technically viable or financially feasible. Knowledge in the subject area of maintainability and reliability engineering is required to apply DOM and tools such as FTA, FMECA and risk analysis is required to determine the best possible LCC (Kumar, 2008, 782).

2.2.4 Maintenance Management Framework

Maintenance management is defined by the British Standards Institution (2010, 5) as

> *all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics*

Prasad Mishra *et al.* (2006, 145) mention that the term "framework" is not always defined by authors and that in some instances it is regarded as a prescriptive set of things which need to be done while in other cases it is presented via diagrams or graphical representations. The Oxford (2010) Dictionary defines framework as "a basic structure underlying a system, concept, or text". According to Prasad Mishra *et al.* (2006, 145) a framework means that "one should design and develop a framework representing the modus operandi, the systems to be developed, the activities to be carried out and the ultimate vision of the new style of managing maintenance in the organisation". Márquez *et al.* (2009, 167) characterise a maintenance framework as "the supporting structure of the management process".

A maintenance management model or framework is regarded as the supporting structure which is crucial to managing the maintenance function effectively (Márquez, 2007, 21). The literature identifies several proposed variants of maintenance management models and frameworks (Campbell *et al.* 2010; Prasad Mishra *et al.* 2006; Campos and Márquez 2011; Márquez 2007; Waeyenbergh and Pintelon 2002; Hassanain *et al.* 2003). A range of authors introduce views on what should be considered in terms of best practices, steps, sequences of activities or models to manage the maintenance function (Campos and Márquez, 2011, 807). In many cases these maintenance management frameworks are created by synthesising frameworks developed by other field experts (Márquez, 2007, 21).

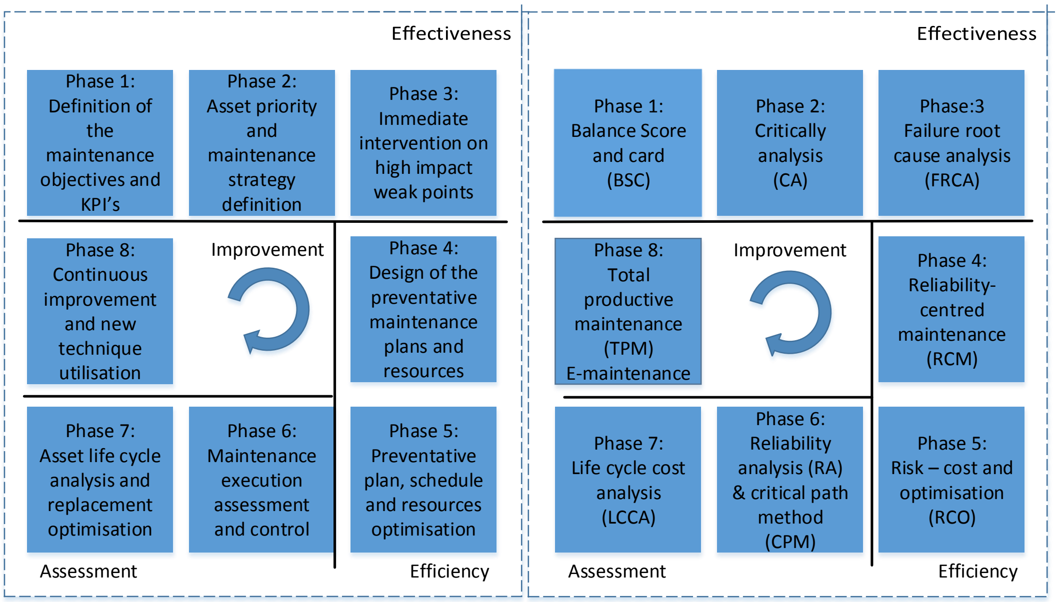


Figure 2.13: Generic maintenance management model (Adapted from Tsang (2002, 10))

A two-part generic framework, developed through the integration of other models, is introduced by Márquez *et al.* (2009) and first considers developing the maintenance strategy and thereafter focusing on the strategy implementation. The framework is presented as eight management building blocks with various maintenance engineering techniques playing an important role within each one of the blocks (Márquez *et al.*, 2009, 167). The eight phases can be seen in figure 2.13.

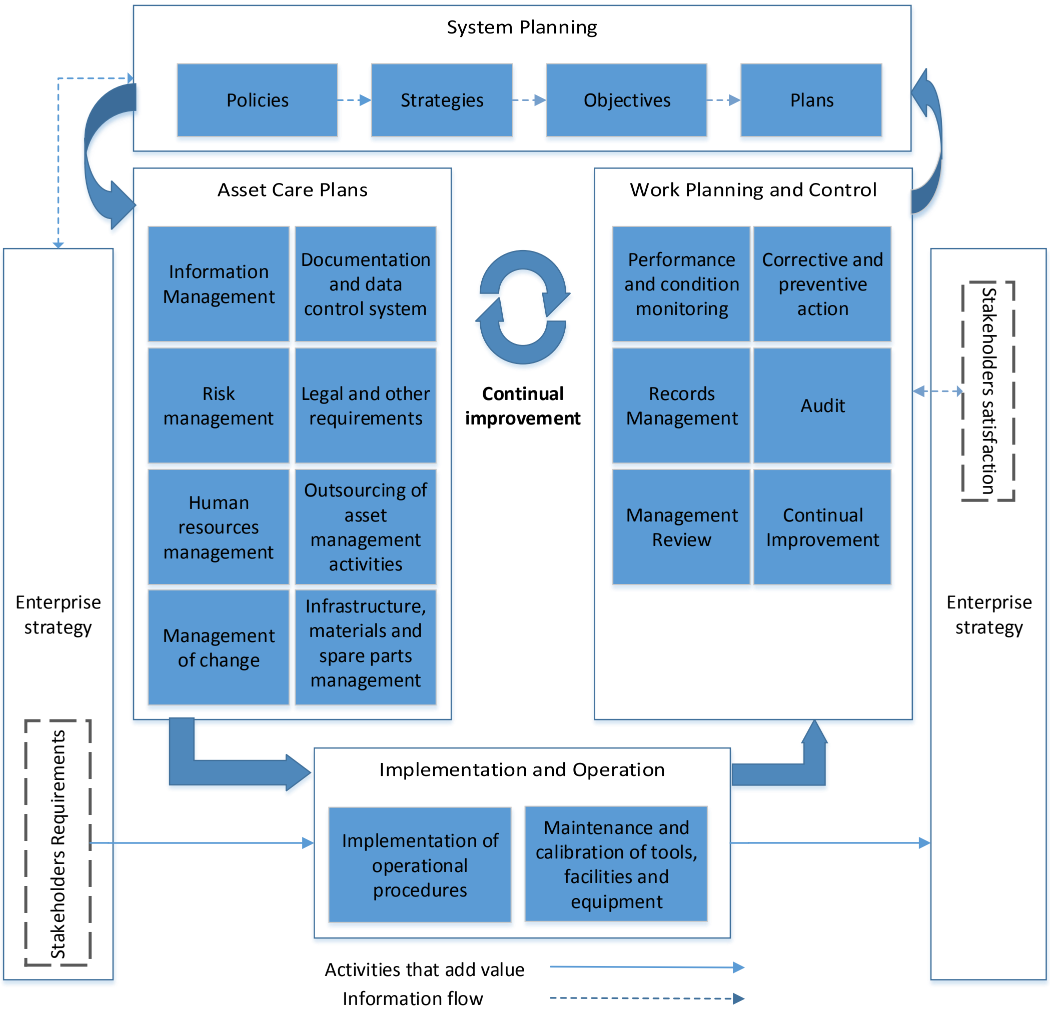


Figure 2.14: Maintenance management framework (Adapted from Campos and Márquez (2011, 807))

Waeyenbergh and Pintelon (2002, 311) also introduce a framework for maintenance concept development and note that there are an increasing number of organisations that are looking for custom developed maintenance concepts. Campos and Márquez (2011), after analysing other maintenance management frameworks, introduces a maintenance management framework with elements that have been arranged with input from industry experts and is representative of the PAS 55 requirements (British Standards Institution, 2008*a*). Campos and Márquez (2011, 807) note that the PAS 55 can be seen as a complete reference to maintenance management and that the proposed framework creates the vital link between other functions in the organisation and the maintenance function.

The model, as seen in figure 2.14, consists of four modules or macro-processes, namely System Planning, Resources Management, Implementation and Operation, and Assessment and Continual Improvement (Campos and Márquez, 2011, 807). The model also takes stakeholder requirements and approval into consideration while being designed in such a fashion as to be efficiently used across all organisational levels. The top direction of maintenance is captured in the System Planning process, Resources Management falls in the medium level and acts as a supporting and control process while execution level also produces data that can be used within the process of continuously improving the maintenance function (Campos and Márquez, 2011, 808).

A universal methodology for developing a maintenance system does not exist, nor does a completely structured approach that leads to a optimal maintenance system (as en example a specific organisational structure, specific maintenance procedures, policies, etc.) (Duffuaa and Haroun, 2009*a*, 4)

BS EN 13306:2010 defines maintenance management as (British Standards Institution, 2010, 5):

> *all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics.*

Waeyenbergh and Pintelon (2002, 302) point out critical success factors of a maintenance concept:

- Good knowledge and understanding of maintenance technology. Production and maintenance staff need to have adequate knowledge and competency to prevent failures.
- Adequate management skills related to planning and control of maintenance tasks and HR management. Studies have indicated that long-term maintenance plans, organisation-wide maintenance knowledge and involvement are important.

- Flexibility to make use of opportunities and trends within the maintenance industry and ITC technologies that open a range of possibilities.

Márquez (2007, 22) also presents a view on the sequence of steps to ensure that the maintenance management framework has all the required functions in place. The steps are:

- A basic PM program should be in place before advancing to the use of a CMMS.
- A WO management system (scheduling, planning, priority) and a maintenance resources management system should first be in place before the implementation of RCM and PdM programs.
- Operators and other staff need to be cognisant of the importance of their role and function within the maintenance framework implementation process.

2.2.5 Maintenance Work Management

According to Gits (1992, 217) a maintenance concept is the decision structure for maintenance actions and policies. RCM, TPM, LCC and BCM are just a few examples. Maintenance decision elements can be derived at operational level, such as maintenance interventions performed by a technician, while others are derived at strategic level, such as policies and concepts. After maintenance objectives and strategies have been developed, maintenance work management, also known as maintenance planning and scheduling, is one of the key elements that determines the success of the maintenance function (Muchiri *et al.*, 2011, 296).

Maintenance work management is a key function in how maintenance resources are utilised and plays an important role in how organisations strive to become more cost-effective (Duffuaa and Al-Sultan, 1997, 163). Improved labour productivity and quality as well as automation are some of the means industry is trying to use to increase profitability. Cost control is a major component of improving profitability, which has led to maintenance management becoming a priority (Duffuaa *et al.* 2001, 207; Paz and Leigh 1994, 1; Duffuaa and Al-Sultan 1997, 163). This once again highlights that the integration of maintenance as an important component in the LC and LCC of assets that needs to be planned and scheduled efficiently to minimise associated costs (Paz and Leigh 1994, 1; Waeyenbergh and Pintelon 2002, 300). The link between O&M (Waeyenbergh and Pintelon, 2002, 300) has resulted in the maintenance function becoming more complex as the operational environment has increased in complexity. The increase in system complexity has resulted in the requirement to have skilled resources and increased the demand for quality maintenance. Maintenance costs and opportunity costs increase as a result of maintenance inadequacy stemming from increased automation. Maintenance activities therefore need to meet organisational objectives by ensuring optimised O&M costs (Paz and Leigh, 1994, 1).

The key resources identified in literature required to perform maintenance are (Paz and Leigh 1994, 1; Duffuaa *et al.* 2001, 210):

- Manpower
- Equipment and tools
- Materials and spare parts
- Standards and procedures

Each of these resources have a different cost and impact and thus each aspect needs to be managed differently. The complexity in controlling manpower due to its vulnerability makes it difficult to manage. The total maintenance costs can be affected by how or when labour is scheduled and can increase overall productivity when effective manpower scheduling is performed (Paz and Leigh, 1994, 1). Maintenance planning and scheduling is thus an important aspect of the maintenance function and in some cases regarded as the most critical aspect (Duffuaa *et al.*, 2001, 207). Al-Turki (2009, 238) states that maintenance planning and scheduling are central to sound and prudent maintenance management. Palmer (2006, 18) attempts to indicate how central the planning process is in coordinating the general maintenance process by his illustration in figure 2.15.

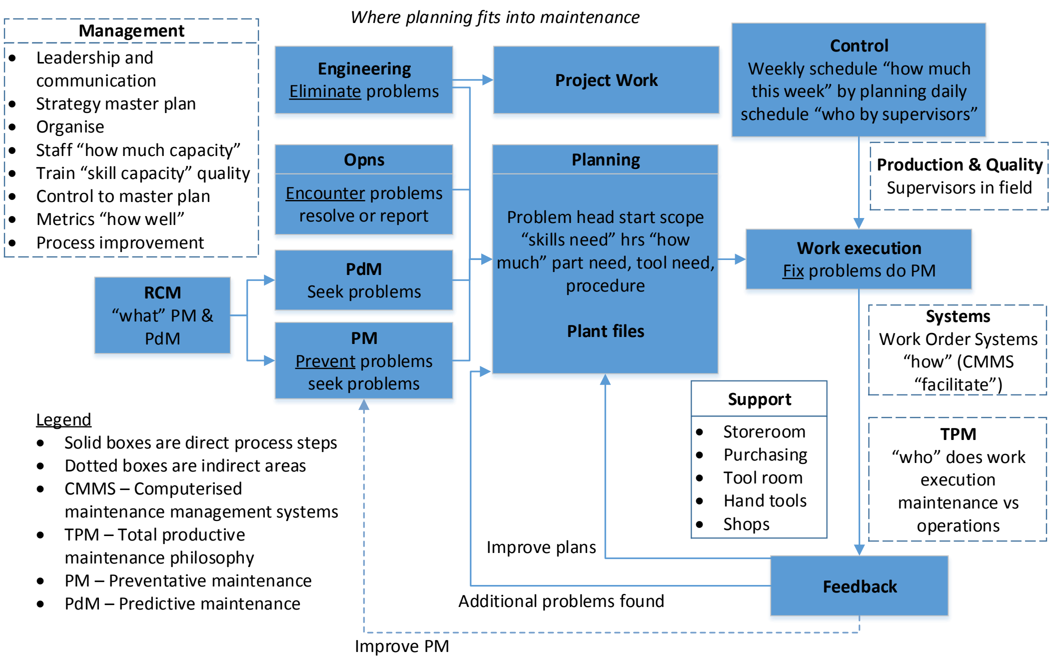


Figure 2.15: The role of planning the in maintenance process (Adapted from Palmer (2006, 18))

Similarly, Duffuaa and Al-Sultan (1997, 163) state that the role maintenance planning and scheduling plays is to plan the resources required for performing maintenance work. The utilisation of resources is controlled by the planning and scheduling function (Duffuaa and Al-Sultan, 1997, 163).

The overall objective of maintenance planning and scheduling is to minimise the amount of resource idle time, scheduling time, job delay time and shut down cost while on the other hand maximising efficiency and the availability of equipment (Duffuaa and Al-Sultan, 1997, 163). Maintenance load is determined by planned and unplanned maintenance activities followed by WOs which are planned, scheduled and then performed by using the required resources in alignment with maintenance policies (Duffuaa *et al.* 2001, 209; Hastings 2010, 289). The typical staff roles as well as the planning and scheduling process are depicted in figure 2.16.

The maintenance work management cycle consists of work identification, work planning, work scheduling, work execution and closing the job (Muchiri *et al.* 2011, 296; Campbell and Reyes-Picknell 2006, 79).

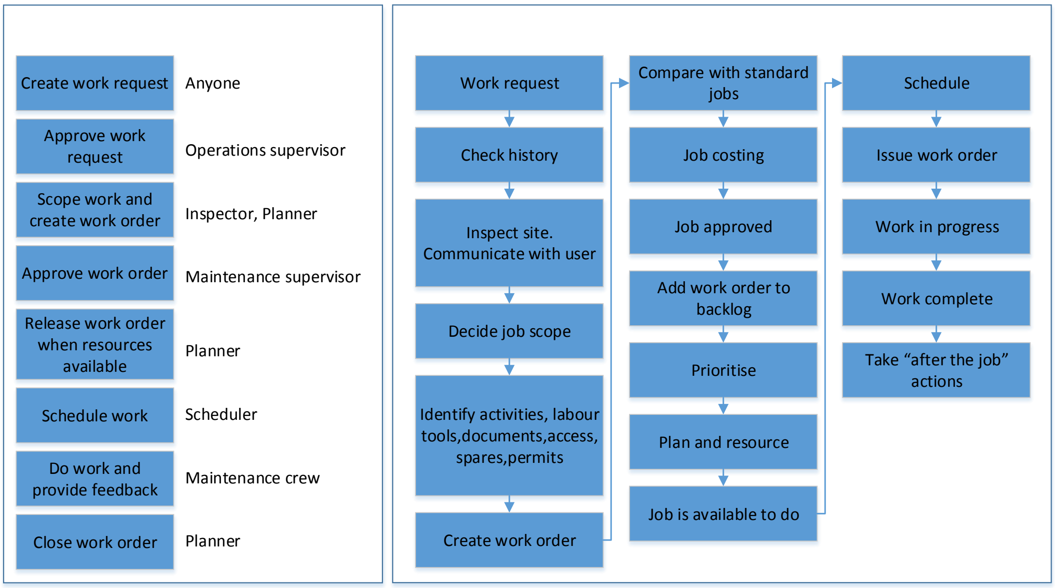


Figure 2.16: Staff roles and sequence of events related to maintenance work management (Adapted from Hastings (2010, 265))

2.2.5.1 Maintenance Planning

Planning is the activity that is used to develop the decisions as well as actions that are required to reach predetermined goals by the most efficient means (Al-Turki, 2009, 237). Besnard *et al.* (2009, 1) note that maintenance planning is of significant importance to wind farm operations and that there is potential to optimise maintenance performance and costs. The planning process can reduce risk, decrease cost, improve overall competitiveness and can be viewed as three planning horizon-dependent levels (Kostic 2003, 278; Al-Turki 2009, 237; Arunraj and Maiti 2007, 656):

- long-range strategic planning (this period covers two or more years);
- medium-range planning (this period could cover from a period of one month up to one year); and
- short-range planning (this covers period which could include daily and weekly plans).

According to Palmer (2006, 27), planning involves making sure that the correct maintenance job is ready to be executed. Expanding on this, within the maintenance management framework, planning is a vital tool that is used to perform preparatory work that can reduce the risk of delaying any work. Planning also provides the framework for the execution of construction works, preventive maintenance plans and shut-downs. The process of how planning should be approached after a work request has been received is summarised by Duffuaa *et al.* (1999, 158) and Márquez (2007, 16):

- Define the work content and provide sufficient detailed information for a skilled worker to understand what is required.
- Plan the WO by correctly specifying the scope and work content.
- Specify the appropriate Craft, number of personnel and affirm skill level for the work to be performed.
- Estimate the time that is needed to complete the work.
- Specify parts, tools and materials that are required to perform the work.
- Order the correct parts and tools.
- Specify any special tools that will be critical on completing the work and ensure they are available when needed.
- Review the safety process or procedures that need to be followed.
- Specify procedures required for management, transit and disposal of any hazardous materials.
- Specify the maintenance procedures that will be required for disassembly, reassembly or completing the work.
- Create a priority worksheet for the work to be performed.
- Estimate the costs involved to complete the work.
- Identify any observations or measurements that need to be made.
- Complete the WO.
- Review and control backlog.
- Use an effective forecasting system to predict maintenance load.

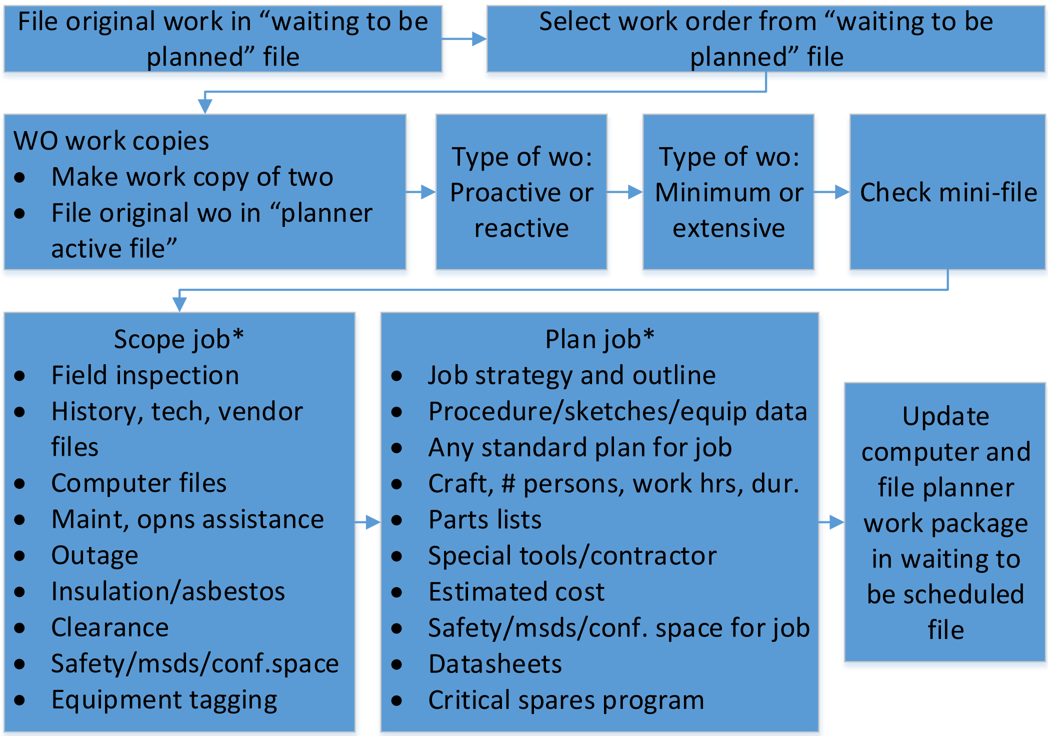


Figure 2.17: Flow chart of the planning process (Adapted from Palmer (2006, 129))

A key position within planning is the planner who prepares maintenance jobs in advance by developing the work plan, which is assembling information, based on a work request in order to facilitate the actual work that will be performed by the technician. Certain organisations call this a work package, which at a minimum consists of the scope of the job, identification of required skills resources and the time estimates required by each identified skill. The planner can ideally add the procedure for completing identified work as well as specifying the required tools and spare parts. The productivity of maintenance staff can be improved due to the initial efforts of the planner (Palmer, 2006, 27). The planning process is depicted by Palmer (2006, 129) in figure 2.17.

(Palmer, 2006, 27) also proposes six planning principles which can be used to guide planners through the subtleties of the planning process:

- **Principle 1**: Planners should be separate from the team that performs the actual work and focus on planning future work.
- **Principle 2**: Planners need to focus on future work and ensure that at least one week of backlogged work has been planned, authorised and ready for execution.
- **Principle 3 – Component Level Files**: The file system should not be at system level but at component level.

- **Principle 4 – Estimates Based on Planner Expertise**: The planner uses his personal experience and files information in order to develop work plans.
- **Principle 5 – Recognise the Skill of the Crafts**: The planner should use inputs from the ROS in order to develop work plans, develop standard procedures as well as refine previous plans.
- **Principle 6 – Measure Performance with Work Sampling**: Wrench time is regarded as the primary metric used to determine workforce efficiency and the effectiveness of the planning and scheduling function.

Information needed for planning and scheduling includes the following (Duffuaa and Haroun, 2009*b*, 98):

- **Materials and Tools Requisition** – as the required materials and tools should be available before work starts. Key information that needs to be part of the requisition is the job specification and code number, spare parts and material required, and special tools required, stock control, stores code and units price as well as the time required for tools use.
- **Maintenance Schedule** – a detailed list of all maintenance interventions and the frequencies at which they occur. This can assist in optimising maintenance plans and analysing trends
- **Plant History** – details of all work performed on the equipment as well as the downtime and reason for failure

2.2.5.2 Maintenance Scheduling

The process of scheduling is aimed at completing more work but specifically more preventive work, and is also aimed an improving future as well as present availability of the plant (Palmer, 2006, 250). Palmer (2006, 73) states that good scheduling is part of good planning. This view is echoed by Al-Turki (2009, 249) who says that a prerequisite for effective scheduling is effective planning. The maintenance scheduling process determines the sequence of maintenance tasks as well as the required resources. Based on the planning horizon of the schedules it can be prepared on three levels Al-Turki (2009, 247):

- (three months to one year) – Medium Range or Master Schedule)
- (one week) – Weekly Schedule
- (one day) – Daily Schedule

Al-Turki (2009, 247) elaborates on these levels and states that medium-range schedules are based WOs that originate from existing WOs, PM, backlogs and potential CM. Medium range schedules also need to find a balance between long-range work and the available manpower. The long-term schedule could be used to understand which spare parts or tools needs to be arranged in advance and can be revised as changes occur. The weekly maintenance schedule is created from the medium range schedule and should also account for operational and financial considerations. The maintenance planner should ideally make the WOs available for two consecutive weeks and sequence the current week's WO according top priority. Techniques such as critical path analysis and integer programming can be used to generate schedules. The daily maintenance schedule needs to be prepared the day before and should be created from the weekly schedule and can be changed or interrupted quite frequently due to CM actions. Work priority is used as a basis to schedule jobs.

In order to perform effective scheduling the following requirements are specified by Al-Turki (2009, 249):

- Work orders which are very well based on a robust planning process and explain the work to be performed in depth. They should also clearly state the required priority, skills and spare parts.
- Time required derived from work measurement techniques.
- Information regarding the skills available for each respective shift.
- Information on spare parts stock and its restocking.
- Information on special equipment and tools required to perform the work and their availability.
- Information on the production schedule and insight regarding the availability for maintenance with the aim of reducing lost production.
- Very clearly defined priority of work which is established in close working relationship between maintenance and operations.
- Information on backlogs, which is work that is behind schedule.

Additional steps in the scheduling process are specified by Al-Turki (2009, 249) which will further enable the maintenance scheduler to develop a maintenance schedule:

- Sort or arrange backlog WOs according to the required skills.
- Use priority to arrange WOs.
- Produce a list outlining WOs that have been completed and those carried over.
- Consider time required to complete jobs, distance and travel and identify WOs which could be grouped based on location.
- In the cases where work requires multi-skilled team, schedule these jobs during the early shift or early in the day.
- Issue the work schedule on a daily basis.
- Ensure that a supervisor is allocated to the work.
- Produce information on backlogs – work that is behind schedule.

(Palmer, 2006, 73) states that advance scheduling (scheduling ahead) needs to provide sufficient planned work for an entire week in advance with the aim of maximising the use of available Craft hours. A meeting can also take place to finalise the One Week Advance Schedule (OWAS) in a collaborative manner (Palmer, 2006, 216). The meeting should have a core set agenda that first covers elements such as schedule compliance, schedule and important work for the week, proposed schedule for the coming week, changes in schedule and priorities (Palmer, 2006, 217). The process of advance scheduling facilitates the completion of proactive work to prevent future breakdown, along with reactive work, and also allows for sufficient time to coordinate the required resources such as spares, materials and tools. He also outlines six principles of planning (Palmer, 2006, 73):

- **Principle 1** – Plan for lowest required skill.
- **Principle 2** – Adhere to weekly and daily schedules.
- **Principle 3** – Schedule from forecast of the highest skills available.
- **Principle 4** – Schedule for every work hour available.
- **Principle 5** – Crew leader handles current day's work.
- **Principle 6** – Measure performance with schedule compliance.

2.2.5.3 Work Order System

According to Palmer (2006, 125) one of the most valuable tools that can be used to improve the effectiveness of maintenance is a Work Order system (WOS). Key features of a WOS are that it can assist the maintenance team to obtain important information related to maintenance work; avoid inconsistency in the use of words, statements, and conversations; and provide a standardised format for information and its flow. The term WO is used as it literally translates into a order to work after the required authorisations have been completed. WOs are part of a process as seen in figures 2.18 and 2.19.

According to Duffuaa and Haroun (2009*b*, 99) the basic documents required for a WOS are a WO, materials and tools requisition, job card, plant inventory, and equipment history files.

He further states that the WO is used for the following (Duffuaa and Haroun, 2009*b*, 99):

- to detail the required resources (time, skills, materials, spares);
- to ensure that the most appropriate maintenance and safety procedures are followed;
- to execute, maintain, monitor and control all maintenance activities; and
- to provide the correct information and data for the work to be completed as well as any analysis that can be used for future improvements.

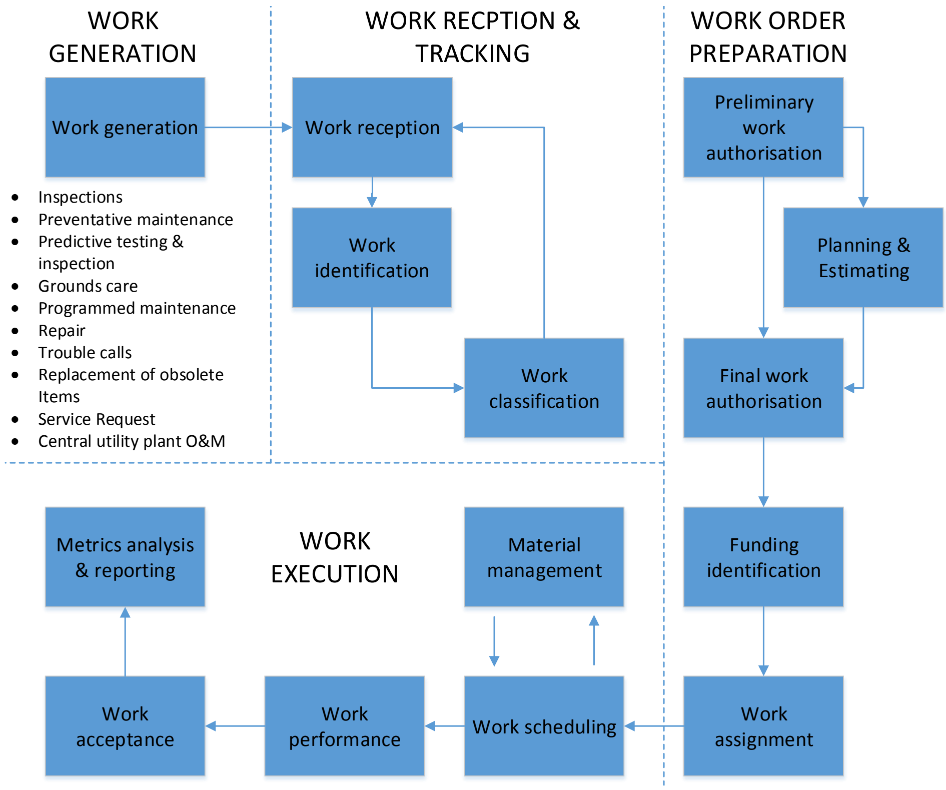


Figure 2.18: Example of WO system (Adapted from NASA [Online] (2001))

Work originates from various sources such as PM tasks, CBM tasks and inspections. The WO has an originator which can be a plant operator, technician or even a CMMS and should provide information than can assist in identifying and classifying the work to be done (Palmer 2006, 125; NASA [Online] 2001; The Commonwealth of Massachusetts [Online] 2005). Additional information that can be provided by the originator is an estimate of the required time, skills, equipment and priority as well as any other helpful information (Palmer, 2006, 125).

WOs then need to go through a planning or preparation phase. The WOs needs to be coded to determine their priority, or type of work (planned maintenance or a breakdown) (Duffuaa and Haroun 2009*b*, 98; Palmer 2006, 125). In the case where a breakdown has occurred maintenance teams are often immediately dispatched and the WO is completed after the repair (Duffuaa and Haroun, 2009*b*, 98).

The planner then needs to plan the work by ensuring details such as spares, tools, equipment and resources are understood and in place for the work to be undertaken. The planning phase is discussed in more detail in section 2.2.5.1. The WO can the be passed on to the scheduling team once the planning phase has been completed (Duffuaa and Haroun 2009*b*, 98; Palmer 2006, 125).

The scheduling team then makes sure that the planned work is scheduled and assigned to specific maintenance staff. Maintenance supervisors or crew leaders will normally receive the WO order via a hard copy or can access the information using a Enterprise Resource Planning (ERP) System or CMMS.

The work is completed by the maintenance team and the WO is updated with all relevant information. The maintenance crew leader needs to check the quality of the completed work as well as the information on the WO. Information can then also be passed on to the finance team to update any relevant details of the equipment to be used for the improvement of maintenance plans. The job is finally verified by the planner who ensures all the required information has been completed, extracts any information that can be used for further analysis, and then proceeds to close the WO (Duffuaa and Haroun 2009*b*, 98; Palmer 2006, 125). The scheduling phase is discussed in more detail in section 2.2.5.2. An example of a WO process flow can be seen in figure 2.19.

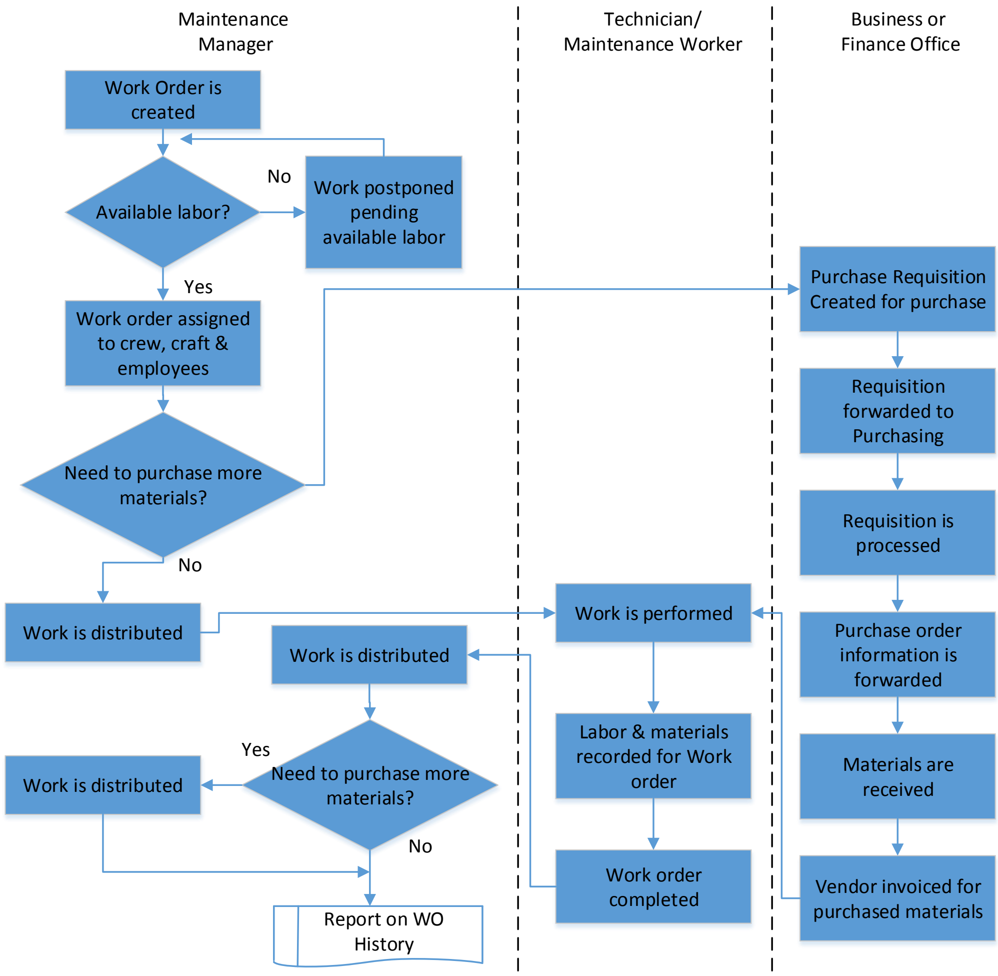


Figure 2.19: Example of WO process flow (Adapted from The Commonwealth of Massachusetts [Online] (2005))

Maintenance work and WOs need to have a priority system. The maintenance work priority system has a significant impact on the scheduling of maintenance and is used to ensure that the most critical work is scheduled first. A priority system should be updated regularly to reflect changes to the operational or maintenance polices and strategies (Al-Turki, 2009, 249)

New WOs are assessed by planners in order to code them according to the plant coding system (an example of coding system can be seen in appendix E). The coding system designates the appropriate priority as well as the type of work (reactive or proactive) or whether the work is minimal or extensive. Codes are later used for analysis of maintenance work and, for example, all the codes that indicate work requiring an outage can be gathered (Palmer, 2006, 602). The WO can also be assigned a status code to indicate where in the WO process it is situated (Palmer, 2006, 604). The entire WO process can be handled via a paper-based system or by using a (ERP) or CMMS. (Duffuaa and Haroun 2009*b*, 98; Palmer 2006, 125).

The team responsible for processing the WOS is the planning and scheduling team. Therefore, the WO includes all the required information to facilitate the efficient planning, scheduling and control (Duffuaa and Haroun, 2009*b*, 98).

Palmer (2006, 797) also notes that technicians should provide feedback once WOs have been completed. Information that should be included in feedback would typically entail the actual duration of work, labour hours, variances from job plans, parts used, updates on drawings, etc. Palmer (2006, 176) is, however, critical of the CMMS electronic WO feedback in the field and states that information is not transferred adequately due to cumbersome input mechanisms.

According to Palmer (2006, 176), On-Site Maintenance Teams (OSMTs) want to provide good feedback if it supports the management and communication around the planning function. Good feedback from the OSMT can be supported by making it mandatory to provide feedback, providing training to the maintenance team and emphasise the importance of the OSMT feedback in improving the maintenance programme, ensuring that planners and schedulers attend all the daily and weekly meetings to emphasise the role that the OSMT plays in scoping and planning work and creating a team environment.

2.2.5.4 Risk Assessments

All maintenance tasks have some level of risk. Organisations need to take responsibility for ensuring that risks to employees are minimised. The process of evaluating risk needs to consider the task that will be performed and assess all the associated detail including the working environment and anticipate what could potentially go wrong. Suitable strategies then need to be developed to mitigate risk of something going wrong. Furthermore, any secondary consequences also need to be considered. One way of preventing potential problems is using a lockout/tag out system (Borris, 2006, 131).

Developing and writing risk assessments for tasks needs to be done by persons who are knowledgeable regarding all the Health Safety Environment (HSE) requirements of the equipment and type of tasks to be performed. Risk assessments can generally all have the same format, but there are three natural levels (Borris, 2006, 131).

A risk assessment should consider all common hazard types that could occur where the work is being carried out, such as electrical, mechanical, battery backups, chemicals, gas temperature, trips and slips, stored energy, working at height, moving vehicles and manual handling (Borris, 2006, 137).

Countermeasures can be applied to reduce or even remove risk with the purpose of achieving an acceptable level of risk. Some of these countermeasures include (Borris, 2006, 141):

- **Eliminating risk** by analysing all tasks and the order in which they occur while considering any changes that could be made to reduce the requirement of a hazardous task;
- **Substituting** materials or equipment can reduce risk;
- **Enclosing** materials or equipment so that operators or technicians cannot come into contact with hazards;
- **Personal Protection Equipment (PPE)** can be worn such as particle masks, gloves, safety glasses, overalls, etc.; and
- **Training** can be provided to reduce risk of injury while having skilled staff and good procedures are very valuable.

Furthermore, deciding on an acceptable risk should be guided by the HSE department or representatives (Borris, 2006, 142).

First drafts of a risk assessment are generally compiled by technical staff due to their comprehensive knowledge and understanding of the associated hazards and safety systems required. Teams who will be involved in the general maintenance process should all be exposed to developing risk assessments and practise it as much as possible. Only once performing risk assessments becomes second nature will teams start thinking about risk assessment when they perform any task (Borris, 2006, 142). Often teams that work on the same equipment and perform the same tasks generate different risk assessments due to working in isolation or in different teams. Different people will see different risks and having a centralised contact point can enable the feedback loop and the sharing of ideas. In the scenario where operators will be performing maintenance it is important to have appropriate risk assessments. Risk assessments also need to be subjected to a continuous evaluation process as there are always changes to equipment, processes, staff or procedures, within an operational environment (Borris, 2006, 146).

2.2.5.5 Standard Jobs

According to Peters (2014, 402) an Standard Job (SJ) is a WO that is stored within the CMMS and contains all the required information that is needed to perform a maintenance job. An SJ is also referred to as a model WO (Peters, 2014, 388). A SJ database can be developed that can assist in defining the job scope, sequence of tasks, materials and spares requirements, estimated time and costs, etc. Once SJ are in place, it also provides a means of measuring the performance of Craft teams (Peters, 2014, 139). Having an extensive library of SJs is important to the planning department. Once completed and reviewed, SJs become a credible template to save time once the job needs to be planned again (Peters, 2014, 211). The SJs can be loaded into the central CMMS and can be accessed by the individual plants and from the Remote Monitoring Center (RMC)-based planning team.

Technicians would conventionally compile the information that forms the basis of SJs after completing large maintenance tasks. Information from planners, technicians, specifications, job history, and engineering is also used to develop robust job plans. Planners are required to describe the work that needs to be done during all maintenance tasks and therefore ensure that a correct description of **what** needs to be done and not **how** it should be done is provided (Palmer, 2006, 59). SJs should thus contain the plans or work instructions on how to perform a particular job.

Standard plans (standard plans are not the same a SJ) are not a dictation of how technician should perform their work but provide guidelines based on previous successfully completed work. Standard plans can be very comprehensive and include other relevant information such as exploded view diagrams and equipment manuals. Standard plans need to be attached to the WO or as part of the SJ details. Technicians can deviate from the standard plans but should provide feedback on why the decision was taken in order to update or improve existing standard plans (Palmer, 2006, 274).

SJs are regarded as a complete description of the work that is required to be completed and include considerations for maintenance planning as outlined in section 2.2.5.1

Mini-files were briefly discussed in section 2.2.5.1 and can contain all information relevant to the component as well as the work history which can be used to improve the planning process. Revisiting information on maintenance can help the planner determine improvement opportunities and having an adequate filing system is crucial to accessing information when needed (Palmer, 2006, 41). Experience within the maintenance field has indicated that the benefit of learnings from feedback and planning is only achieved six months after a conscientious effort has been made in this regard (Palmer, 2006, 43).

Information related to the plant exists in many formats and in many places and the planning process requires access to the information. Mini-files which store information at component level for every single piece of equipment allow the planning department to list or compile (Palmer, 2006, 266):

- all the work that has previously been done on the equipment including the scope of works, job duration, Craft hours and costs;
- maintenance schedules for PM tasks;
- technical data such as data sheets, standard plans, safety information and OEM information;
- parts information summary;
- special notes on abnormal conditions and equipment properties; and
- copies of historical WOs including feedback on related problems and corrective action.

The maintenance procedures are required to perform the maintenance work and having detailed maintenance procedures improves reliability, performance, and overall safety and are required to develop SJs (Palmer, 2006, 146). Planners also extract critical information from large O&M manuals so that it can be attached to SJs. Jobs also often benefit from having the entire O&M manual available and reference can be made to the O&M manual on condition that access is available to the file. All procedures and manuals should always be available to technicians through hard copy or electronic system (Palmer, 2006, 147).

Furthermore, according to Palmer (2006, 147) maintenance procedures should be improved over time as the expertise of the craftsman assist the planner in fine-tuning maintenance procedures. Experienced supervisors, technicians and often retirees are used to develop maintenance procedures under facilitation of someone experienced in writing procedures (Palmer, 2006, 147).

Besides having maintenance procedures, operating procedures are equally important. Studies have found a strong positive correlation between performing operating procedures and the number of years of experience and the ability to handle responsibility (Dhillon, 2002).

During the entire LC of equipment, ranging from the design, commissioning and O&M, humans have a key role to play. Human error can occur as a result of deteriorating interaction with equipment. Human error is regarded as the occurrence of disruption to normal operations or damage to property and equipment. Human error can occur due to inadequate design of equipment, tools, insufficient training and experience, lack of equipment maintenance and standard operating procedures that have been poorly written or are outdated (Dhillon, 2002).

Mobley *et al.* (2008) state that operators are often taught the minimal steps to operate critical systems and that inadequate training of operating personal, poor, outdated, inadequate or non-existent operating procedures, including the failure to manage the adherence to operating procedures, compound issues related to reliability. Standard operating procedures do not only consider operating procedures for equipment but also lockout/tag out, safety, risk assessment and management of change compliance (Peters, 2014, 211).

The use of standards is a key component of any continuous improvement technique and developing standard operating procedures is one method of establishing standards (Borris, 2006, 24). Operating procedures that affect costs need to be effectively managed to improve overall management of assets and the impact of maintenance on the asset LC (Campbell and Reyes-Picknell, 2006, 10). The analysis process followed within RCM highlights existing strategies and identifies required changes to operating procedures (Department of Defence [Online], 2008, 3). Additional component functions can also be determined when reviewing operational procedures, including safety, abnormal operations and emergency instructions (Mobley *et al.*, 2008). Furthermore, changes in the operational environment and operating procedures can result in the discovery of failure modes that have not yet been considered during previous RCM-type analysis (Campbell *et al.*, 2010, 171).

Asset reliability problems are often a function of deficiencies within operating procedures that can lead to operator errors (Mobley *et al.*, 2008). Operating procedures that are complete, relevant and detailed are important as they often bridge the gap between bad training, lack of training or inexperience. Operators or technicians often forget steps or critical actions that can be avoided by promoting the use of standard operating procedures (Borris, 2006, 9). Furthermore, autonomous maintenance or operators performing maintenance can be improved by having detailed and effective standard operating procedures (Kister and Hawkins, 2006, 49).

2.2.6 Maintenance Optimisation

Research related to efficient scheduling of maintenance has become common practice since maintenance has become a core activity within all major industries and can be transformed into a MO problem (Paz and Leigh, 1994, 51). The purpose of optimisation would be to find the balance between factors such as costs, objectives and constraints. Solutions to MO problems can consider multiple criteria and aim to minimise costs while maximising reliability or other performance indicators. Sharma *et al.* (2011, 7) state that the most appropriate MOM considers aspects such as maintenance costs, objectives and reliability measures simultaneously.

Factors such as safety, health, environment, maintenance cost, failure cost, opportunity cost and replacement cost are considered within mathematical models when deriving the optimum balance between the costs of maintenance and most appropriate time to perform maintenance, or other benefits associated with maintenance (Dekker and Scarf, 1998, 111). A number of tools such as reliability maintenance models, simulations, statistical methods, mathematical programming and decision-making tools have been used to realise MO. The use of these tools can combined or they can be used separately. (Dekker and Scarf, 1998, 111) states that four key aspects are involved in MO:

- describing the relevant technical system, what its function is and how important it is;
- modelling system deterioration;
- providing management with the options available regarding the system and all other relevant information; and
- determining the objective function and the technique used for optimisation.

2.2.6.1 Maintenance Optimisation Classification

MOMs are classified as quantitative or qualitative. Qualitative MOMs such as TPM, RCM and PAM are considered to be subjective and based on experience (Arthur 2005, 252; Scarf 1997, 495). Alternatively quantitative MOMs originate from applied mathematics and operational research which are deterministic and stochastic such as Markov decision, Bayesian models and mixed integer linear programming (Garg and Deshmukh, 2006, 206). However, criticism that these techniques are theoretical and not useful in practical real-life scenarios has been presented by Scarf (1997, 494) and Arthur (2005, 251). Arthur (2005, 252) further states that quantitative MOMs often require data which is not available and advocates the use of simpler quantitative approaches that use well-founded assumptions and arrive at an approximately optimal solution.

The objective of MO is often to maximise reliability or to minimise cost within predefined constraints. Common decision factors include optimal maintenance intervals, optimal delay time, spare parts optimisation, HR optimisation, opportunity cost and redundancy Hilber (2008, 8).

2.2.6.2 Maintenance Optimisation – Task Intervals

Andrawus (2008, 143) performs a comparison between two quantitative optimisation techniques within the context of on-shore wind farms. Firstly the Modelling System Failures technique is considered. The Modelling System Failures technique presented by Davidson (1994) considers equipment failure distribution, the delay in repairs, spares management and the availability of resources in the process of investigating equipment failure patterns with aim of optimising maintenance. The process firstly requires a suitable statistical distribution, representative of the equipment failure characteristics, for the asset in question.

A suitable method, such as probability plot, regression analysis or Maximum Likelihood Estimation (MLE), then needs to be selected that can be used to calculate parameters of the previously selected statistical distribution. These parameters that were calculated during the previous step are then used to develop Reliability Block Diagrams (RBD) with the aim of modelling asset failures. Monte Carlo simulations can then be used to simulate the optimisation of key variables such as maintenance costs, spare parts management, equipment reliability and availability, and so on. (Andrawus, 2008, 49).

The second quantitative optimisation method is the DTMM model which considers the consequences of failures, inspection costs and inspection intervals when optimising inspection intervals. The time that an incipient failure progresses from inception to a complete failure is the key consideration when determining the best maintenance intervals.

During the RCM process, a subjective approach which is based on experience is taken when determining P-F intervals, as seen in figure 2.20 (Rausand and Hoyland, 2004, 395).

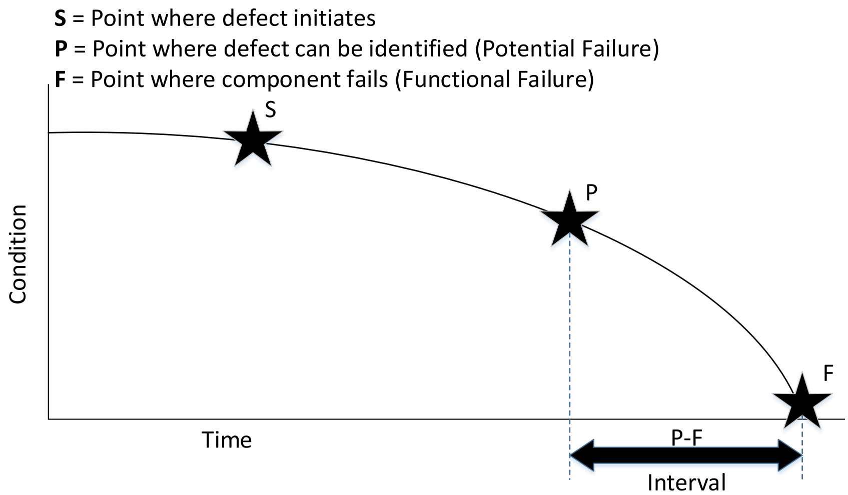


Figure 2.20: Potential-to-Functional failure intervals (Adapted from Andrawus (2008, 55))

The frequency at which PdM activities are conducted is determined by the P-F interval with PdM activities generally conducted at an interval that is less than (P-F interval)/2. Scarf (1997) highlights the quantitative mathematical model called the DTMM to determine the optimal interval between inspections by considering factors such as costs, risks and performance. The delay-time is the amount of time that elapses from the defect being detected to the time that a functional failure actually occurs and is synonymous to the P-F interval.

Andrawus (2008, 143) presents the comparative results, considering data requirements, analysing robustness, practicality and benefits, after applying MSF and DTMM techniques to a case study. Both techniques exhibit different potential benefits and the author concludes that the two techniques are in fact complementary, not conflicting. However Andrawus (2008, 143) concludes his comparative study between the two techniques by stating that the DTMM technique could be incorporated into the RCM process. RCM is regarded as a qualitative technique that can be used for MO, while DTMM is quantitative and combining these methods can provide a balance between often subjective qualitative assumptions and the hard-to-obtain extensive dataset.

2.2.6.3 Concept of the Delay-time Maintenance Mathematical Model

The DTMM assumes a Poisson process of defects rate of arrival (α), delay-times that are exponentially distributed and has a mean of ($\frac{1}{\gamma}$), and perfect inspections where all expected failure modes are detected. The rate at which defect arrives assumes the complete failure of equipment or defects that were detected during inspection.

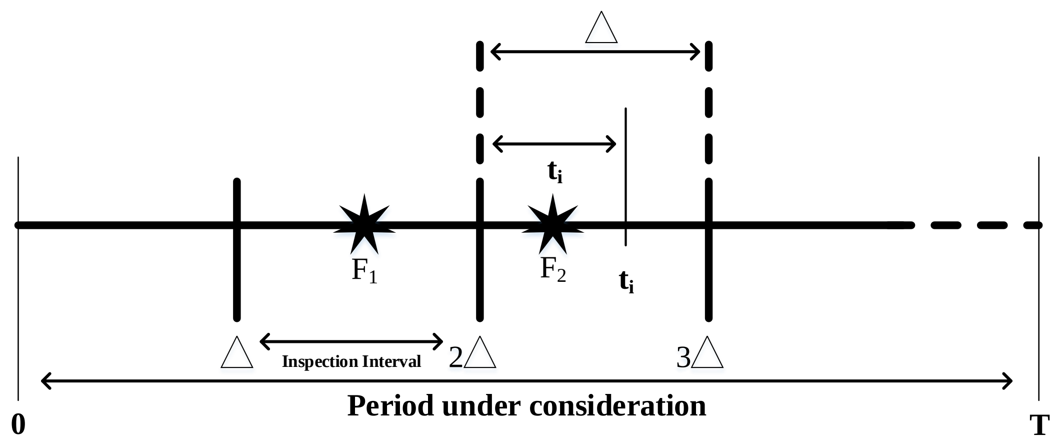


Figure 2.21: Delay-time concept (Adapted from Andrawus (2008, 56))

For example, assume that all the main bearings of wind turbines located within a wind farm are inspected at regular and evenly spaced intervals of Δ within the interval $[0, T]$; where T is a multiple of (Δ) as depicted in figure 2.21. Furthermore, two instances of defects occur (defects arrival) and are noted as F_1 and F_2 and underpin the principles of the DTMM. The inchoate failure F_1 happens between inspection intervals Δ and 2Δ; however it is detected during the next inspection at 2Δ and then repaired, alternatively catastrophic failure F_2 occurs at failure t_i prior to the next inspection at 3Δ.

Additional detail on the concept and derivation of the DTMM can be found in studies conducted by Baker and Christer (1994) and Baker *et al.* (1997). Andrawus *et al.* (2008) presents a case study where the FMECA and DTMM are combined to quantitatively optimise the PdM inspection intervals for key subsystems within 600 Kilowatt (KW) wind turbines.

2.2.6.4 Improvement Processes

Ahuja (2009, 747) and Borris (2006, 154) state that various improvement methodologies exist such as Six Sigma, 5S, Define-Measure-Analyse-Improve-Control (DMAIC), Kanban (which means "signboard" in Japanese and is a scheduling system for lean manufacturing and just-in-time manufacturing), design for manufacture and assembly (DFMA), FMEA, TPM, Just-in-Time (JIT), Total Quality Maintenance (TQM) and Quality Function Deployment (QFD).

Focused improvement is regarded as the systematic identification and elimination of losses (Ahuja, 2009, 722). According to Borris (2006, 11) cross-functional teams are often used to investigate issues and to find permanent solutions during focused improvement projects. The problem under investigation is often evaluated with a cost-benefit analysis to justify the action (Borris, 2006, 11).

Six Sigma is methodology for systematically improving processes or products and relying on statistical and scientific methods. Six Sigma also has an improvement procedure called DMAIC. DMAIC is similar in function to its predecessors in manufacturing problem solving, such as Plan-Do-Check-Act and the Seven Step method (de Mast and Lokkerbol, 2012, 604). Misra (2008, 176) also mentions the DMADV method which is Define, Measure, Analyse, Design and Verify.

Borris (2006, 154) also states that methods such as RCM and Six Sigma DMAIC follow the same improvement methodology which would consider identifying and clarifying the problem, evaluating the cost and risk of the problem, understanding the root cause and finding an appropriate cost-effective solution, justifying the expense, planning and completing the corrective actions, confirming that the applied solution is effective, and finally setting up a system for checking, training, and maintaining the new standard (Borris, 2006, 154).

2.2.7 Reliability and Performance Metrics Measures

A KPI is defined by Bower (2003, 77) as "the measure of performance associated with an activity or process critical to the success of an organisation". Levitt (2011, 218) also states that a measure can be regarded as any means which can be used to understand what is happening within a business unit. Furthermore, the author states that a KPI is a measure of success for a business function and that there are several types of indicators that are important to maintenance management which include quantitative and directional indicators, actionable indicators and financial indicators (Levitt, 2011, 218).

The Asset Performance and Health Monitoring AM subject is outlined in section A.1.6.5 and defined by GFMAM as (GFMAM, 2014, 47) "the processes and measures used by an organisation to assess the performance and health of its assets using performance indicators".

Importantly, KPIs need to be used to monitor the assets and the AMS (IAM 2014*a*, 62; GFMAM 2014, 47).

Each element of a strategic plan can be allocated a specific KPI which can be broken down into various functions or levels of performance indicators. KPIs can be used to understand performance trends related to business processes, departments and functions which need to be improved in order to achieve the organisational objectives (Parida and Kumar, 2006, 20). Furthermore, each organisation needs to monitor the performance to identify improvement areas (Parida and Kumar, 2006, 20).

Lagging performance measures take into account part performance of assets while leading performance measures are intended to predict the future performance. These two indicator types are generally combined to see how the processes are performing and which outcomes are being achieved (IAM 2014*a*, 62; GFMAM 2014, 47). Weber and Thomas (2005, 7) also state that organisations need to have leading KPIs (process based) and lagging KPIs (result based) measures (Weber and Thomas, 2005, 7). The authors present a study that identified leading and lagging KPIs for the organisational maintenance function and performance (Weber and Thomas, 2005, 7).

Performance measures or KPI targets need to align with organisational objectives and stakeholder requirements which are expressed within the OSP and the SAMP. This approach assists in creating the Line-of-Sight and understanding the performance of physical assets and plays an important part in business and risk management (IAM 2014*a*, 62; GFMAM 2014, 47).

KPIs are important strategic indicators of performance and are an aggregation of various performance indicators. The core purpose of a KPI is to understand where there is room for improvement (Kobbacy and Murthy, 2008, 461). Appropriate KPIs need to be developed to evaluate actual performance against the targets. These KPIs set the continuous improvements process in motion by identifying gaps and opportunities which are addressed though selecting and implementing suitable strategies to harness the benefits (Andrawus, 2008, 43).

The discussed principles are depicted in figure 2.22.

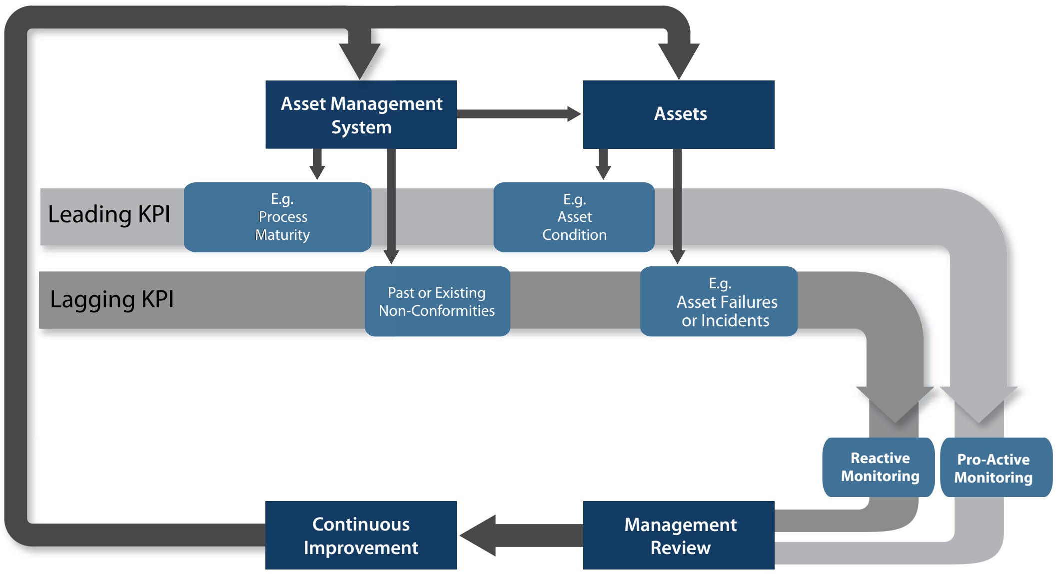


Figure 2.22: System reliability model based on component probability density functions (Adapted from IAM (2014*a*, 63))

According to Palmer (2006, 329) people can relate to overall plant availability and Nilsson (2009, 6) notes that reliability can be measured using key performance indicators (KPIs) such availability, failure rate and repair time. The author also notes that availability is a fundamental measure of reliability. An availability KPI is expressed in equation 2.2.4:

$$Availability = \left[\frac{MTBF}{MTBF + MTTR}\right] \tag{2.2.4}$$

Mean Time Between Failures (MTBF) indicates the mean exposure time between failures. Failure rate (λ) indicates number of failures per time unit

Nilsson (2009, 6). When failures are exponentially distributed (λ) is constant over the time and according to equation 2.2.5 this gives:

$$\lambda = \left[\frac{1}{MTBF}\right] \tag{2.2.5}$$

Repair time (r) is the mean time to replace or repair a failed component, also called Mean Time To Repair (MTTR). Availability can be calculated as 1 - Unavailability (U), which in its turn can be approximated as $U = \lambda \cdot r$ (Nilsson, 2009, 6).

In the case of maintenance KPIs there should be a direct correlation between the maintenance activities and the KPI. During the process of defining a KPI for maintenance a good test will be to understand whether, if the measured function performs as it should, would there be a proportional change, or will the KPI be affected through other external factors? (Weber and Thomas, 2005, 4). Maintenance performance indicators include planned coverage, proactive versus reactive WOs, reactive work hours, work type, availability forecast, schedule compliance, backlog WOs and WOs completed, total cost of maintenance, total production cost, mean time to repair (MTTR), maintenance cost per hour and manpower utilisation (Levitt 2011, 238; Kister and Hawkins 2006, 172; Peters 2014, 68; Parida and Kumar 2009, 22; Palmer 2006, 329).

A KPI related to solar PV power plants is Performance Ratio (PR) that is measured for the degree of utilisation of an entire PV system. Essentially PR, which is a dimensionless indicator, is widely used as a measure of the quality of the PV system. It describes the relationship between the actual and theoretical or reference energy output of the PV plant. The difference between 100% and the PR value aggregates all the possible energy losses including inverter efficiency, wire losses, panel degradation, mismatch, shading, dust, soiling, thermal inefficiencies (temperature effects) and system failures Reich *et al.* (2012).

According to the International Electrotechnical Commission (1998) PR is defined as the ratio of so-called final PV system yield (Y_f) to so-called reference yield (Y_r) and denoted as PR in equation 2.2.6:

$$PR = \left[\frac{Y_f}{Y_r}\right] \tag{2.2.6}$$

2.2.8 Centralisation and Decentralisation of Maintenance

Over the past few years a great deal of discussion has focused on centralised versus decentralised maintenance, both sides of the argument having strong proponents (Dabbs, 2008). The decision whether to centralise or decentralise maintenance functions is always challenging as the decision is multifaceted and dependent on multiple perspectives and criteria (HajShirmohammadi and Wedley, 2004, 16). Duffuaa and Haroun (2009*a*, 6) state that the decision on which configuration to select is dependent on an organisation's maintenance philosophy and load, skills of the craftsmen and the size of the facility to be maintained. HajShirmohammadi and Wedley (2004, 16) mention that the decision to centralise or decentralise maintenance functions requires a trade-off between qualitative and quantitative factors, expertise and additional input from various stakeholders. The author then presents the analytic hierarchy process (AHP), that uses qualitative as well as quantitative analysis, in facilitation of the decision-making process.

In a completely **centralised** system all maintenance functions and services are delivered to the rest of the organisation from a central administration platform. However, in the case of a **decentralised** system the respective production areas, for example, would be managed and supervised by an area production manager (HajShirmohammadi and Wedley, 2004, 17).

One of the key issues noted with decentralising the maintenance function is that lower priority planned preventive work is often neglected to attend to more urgent corrective work. Adopting this approach is detrimental in the long run as it will generate more corrective work due to neglecting low-priority scheduled planned maintenance. A decline in productivity is often observed through this behaviour (Palmer, R. [Online], 2008). Planning and scheduling can assist in increasing productivity by setting maintenance goals (Palmer, R. [Online], 2008).

The structure of maintenance functions can have a significant effect on performance and productivity. The current state of communication technology, especially the internet, enables information to be instantly distributed to multiple remote locations. This communication and data distribution capability has many organisations reassessing the manner in which they manage their resources (HajShirmohammadi and Wedley, 2004, 16).

The maintenance capacity of an organisation is dependent on the level of centralisation or decentralisation adopted within its maintenance framework. Furthermore, the main areas which need to be addressed when forming the structure of the maintenance organisation are capacity planning, centralisation versus decentralisation and in-house versus outsourcing (Duffuaa and Haroun, 2009*a*, 6).

Advantages of centralisation are noted as (Duffuaa and Haroun, 2009*a*, 7):

- improved flexibility and use of resources such as skills and equipment;
- improved efficiency in line supervision;
- improved efficiency in on-the-job training; and
- ability to purchase more modern equipment.

Disadvantages of centralisation are noted as (Duffuaa and Haroun, 2009*a*, 7):

- decreased use of Crafts and more time to get to locations;
- supervision challenges;
- less specialisation on more advances tools; and
- increased transportation costs.

Organisations that operate in a decentralised manner often reduce the flexibility of the maintenance system as functions are allocated to specific units or areas. Depending on the structure of the organisation this decentralisation reduces the skills that are available (Duffuaa and Haroun, 2009*a*, 7). There are numerous factors that play a deciding role in where maintenance should be located within organisations. These factors could include the size and complexity of the organisation and what the organisation delivers. Centralising or decentralising is a key decision. The advantages of centralisation are that it might need less staff and is more efficient. Disadvantages could include challenges around supervision due to the sites often being remote (Dhillon, 2006, 174).

Dabbs (2008) and Mobley *et al.* (2008) identify some advantages of centralisation such as decreased use of Crafts, the ability to purchase and use higher quality equipment, more Craft collaboration and specialised supervision, more suitable training facilities and more effective dispatching of work.

Dabbs (2008) and Mobley *et al.* (2008) also identify some advantages of decentralisation such as less travel time, more in-depth knowledge through repeated work, improved PM due to more interest and improved relationships between production and maintenance.

The size of the maintenance groups will determine if centralised planning offers a significant benefit. More technicians allow the planner to cover a larger scope although the technician-to-planner ratio is low. Palmer (2006, 698) further notes that a theoretical break-even exists where for every three technicians, one could become a planner. The author further notes that a ratio of one planner for every six technicians is a good level at which planning and scheduling could add a significant boost to maintenance productivity. Planners can be geographically spread while being accountable to an overall manager (Palmer, 2006, 698).

The American retailer Sears took a strategic decision in 1991 to convert from a decentralised maintenance system to a highly centralised system, resulting in improved control, efficiency and customer service (Wilson, 1996). Palmer (2006, 698) further notes that centralisation creates an environment where it is easy to implement the planning and scheduling function and control the productivity. The author also notes that organisations that adopt centralised maintenance excel at planning and scheduling (Palmer, R. [Online], 2008).

In practice most organisations will follow a hybrid or semi-centralised approach which is mixture of a centralised and decentralised system (HajShirmohammadi and Wedley, 2004, 17). The configuration of the semi-centralised system would differ between organisations and can exist at any point between the two extremes. The level of semi-centralisation would depend on the allocation of functions to local teams. Paz and Leigh (1994, 50) also states that a semi-centralised or hybrid approach offers the opportunity to retain the advantages of centralised and decentralised maintenance. Similar thoughts are presented by Duffuaa and Haroun (2009*a*, 7) and Mobley *et al.* (2008, 1.45) who state that a hybrid centralised and decentralised system is often a good solution as it can reap the benefits of both practices and provide a more effective solution. (Palmer, R. [Online], 2008) also presents the possibility where a hybrid strategy is adopted where the maintenance function is predominantly centralised but with small decentralised local teams to deal with urgent corrective work (Palmer, R. [Online], 2008).

As part of the study by HajShirmohammadi and Wedley (2004, 16), where 25 organisations were assessed in terms of how they approached the decision whether to centralise or decentralise maintenance, it was revealed that the decision was made intuitively.

Organisations that adopt centralised maintenance excel at planning and scheduling (Palmer, R. [Online], 2008). One of the key issues noted with decentralising the maintenance function is that lower-priority planned preventive work is often neglected to attend to more urgent corrective work. Adopting this approach is detrimental in the long run as it will generate more corrective work due to neglecting low-priority scheduled planned maintenance. A decline in productivity is often observed through this behaviour (Palmer, R. [Online], 2008).

Organisations have also adopted a hybrid strategy where the maintenance function is predominantly centralised but with small decentralised local teams to deal with urgent corrective work (Palmer, R. [Online], 2008).

2.2.9 Summary of Maintenance Literature

The second area of scholarship that is of relevance to this research is maintenance management. This section starts with a historical overview of maintenance. Key concepts within the field of maintenance are reviewed and defined, such as maintenance philosophies, maintenance approaches, maintenance management, work planning and control, and optimisation. The section concludes with a review of maintenance centralisation and decentralisation.

2.3 Key Challenges within Renewable Energy Industry

South Africa is no exception to many other countries which are still dependent on fossil fuels to successfully run the economy. This fossil fuel dependency, in combination with the energy crisis, a significantly high rate of unemployment at 25% (STATS SA [Online], 2013), considerations from an ecological and climate change perspective, as well as the needs of a budding economy, have driven the requirement to use power generation assets of a sustainable nature.

Reaching the goals set out in some of the most influential documents such as the White Paper on the Renewable Energy of the Republic of SA (DME, 2003) and the Integrated Resource Plan (IRP) (DOE, 2011) was propelled into action by an announcement by the Minister of Energy (DOE [Online], 2011) on the 11th of August 2011 that 3725 MW of RE generation capacity was to be constructed and commensurate with the IRP 2010. The determination was further expanded by a 3200 MW determination in December 2011, increasing the capacity to be procured to 6925 MW (DOE [Online], 2011). On 16 April 2015, the SA Government also announced an expedited procurement process to procure an additional 1800 MW of RE assets which should fulfil the first two capacity determinations as well as an additional 6300 MW determination which will aim to sustain the momentum in accordance with the IRP 2010-2030 (DOE [Online] 2015*a*; DOE 2011). This brings the total RE capacity to be procured to 13225 MW which is 5575 MW short of the 18800 MW (excludes hydro) envisaged by the IRP 2010-2030 (DOE, 2011, 14). In addition to the REIPPPP various other programs are also in the pipeline that aim to procure capacity such as the small project program with 200 MW; the gas to power programme with 3126 MW; the coal base load programme with 2500 MW and the co-generation program with 800 MW (DOE [Online], 2015*a*, 4).

RE and the diffusion of RE technologies in SA thus had a lengthy run-up before astounding the world with its REIPPPP. The REIPPPP allows independent power producers (IPPs) to produce electricity and sell it back to Eskom (SA power utility) and successfully allocated 3915 MW of new build renewable generation capacity during the first three bid rounds of the REIPPPP (Papapetrou, P. [Online] 2014, 6; Eberhard *et al.* 2014, 14). The RE capacity of the first three bid rounds of the REIPPPP is to be built by 64 projects of which 32 projects are onshore wind farms and 23 are solar PV (Papapetrou, P. [Online] 2014, 6; Eberhard *et al.* 2014, 14; Eskom [Online] 2015). The announcement of round four projects, on 11 April 2015, of the REIPPPP will see the number of onshore wind projects increase to 37 and solar PV increase to 29. The round four projects will add 1121 MW to the national grid. Across all four bid windows a total of 5243 MW (79 projects) have been allocated and represent an infrastructure investment of ZAR168 billion while contributing to job creation and economic growth (DOE [Online], 2015*a*, 2).

During the first two determinations in 2011 (3725 MW) and 2012 (3200 MW), 1850 MW and 1470 MW respectively, 3320 MW in total, was earmarked for onshore wind generation. This constitutes about 48% of the total determination of 6925 MW. Assuming a similar percentage of the 6300 MW determination in 2015, onshore wind generation will potentially have an additional 3000 MW bringing the total allocation of onshore wind generation to around 6320 MW. The REIPPPP has successfully allocated 2660 MW, a total of 37 projects, of onshore wind generation capacity to preferred bidders across four bid rounds (Eberhard *et al.* 2014; DOE [Online] 2011; Papapetrou, P. [Online] 2014, 6).

In the case of solar the first two determinations in 2011 (3725 MW) and 2012 (3200 MW), 1450 MW and 1075 MW respectively, 2525 MW in total, was earmarked for solar PV generation. This constitutes about 36% of the total determination of 6925 MW. Assuming a similar percentage of the 6300 MW determination in 2015, solar PV generation will potentially have an additional 2200 MW, bringing the total allocation of solar PV to around 4725 MW. The REIPPPP has successfully allocated 1899 MW, a total of 29 projects, of solar PV generation capacity to preferred bidders across four bid rounds (Eberhard *et al.* 2014; DOE [Online] 2011; Papapetrou, P. [Online] 2014, 6).

RE projects have also been built by foreign contractors with long-term O&M agreements awarded to these foreign contractors (GreenCape [Online] 2015; McKenna, J. [Online] 2013). This trend has left the industry in a position where skills transfer has often been limited and Asset Owners are often dependent on foreign O&M contractors in order to operate and maintain these RE assets.

OEMs who currently operate and maintain some of these RE assets under medium-term or long-term O&M agreements often show resistance to the sharing of detailed maintenance tasks and the facilitation of technical skills transfer. Therefore, a significant technical and management skills gap exists in terms of these RE assets being operated and maintained by SA project owners and Asset Managers. In certain cases owners, operators and Asset Managers are kept in the dark by turbine suppliers who do not share detailed maintenance procedures, provide access to data, information and skills on how to maintain these wind power assets. Owners, operators and Asset Managers are forced to remain dependent on third-party O&M contractors. The strained contractor and owner relationships combined with varying management and shareholding structures introduce additional complexity for SA Asset Owners and managers.

2.3.1 Complexity and Alignment of Ownership and Management Structures

The first rounds of the REIPPPP has seen a partnering between global and local SA companies (Donnelly, L. [Online], 2012). Billions of rands of investment have already flowed into SA with 168 billion US dollars, consisting of 79 projects, already committed up to round four of the REIPPPP (DOE [Online] 2015*a*, 2; Eberhard *et al.* 2014, 1). These capital-intensive projects often have complicated ownership structures and are a prominent feature of the first round front runners (Donnelly, L. [Online], 2012). According to energy and power systems research analysts Frost and Sullivan, many large international renewables companies linked to the REIPPPP projects are becoming active in SA even though the ownership structure of the bidding companies is complex due to the structure of the various consortiums. The reason for the complexity in the ownership structures is due to the local-content requirements, resulting in partnerships between local and international players, as well as the intensive private equity requirement to fund expensive renewable projects (Donnelly, L. [Online], 2012).

According to Eberhard *et al.* (2014, 11) the RPF was split into three distinct sections which outline the general requirements, qualification criteria, and evaluation criteria for a bid. Some key non-negotiable contract documents are the Power Purchase Agreement which spans 20 years from Commercial Operation Date (COD) and are signed between the IPP and Eskom as the single buyers of the produced energy (also often referred to as the off-taker), the implementation agreement (IA) signed between the IPP and the Department of Energy (DoE) that acts as a sovereign guarantee of payment in the event that the Single Buyers Office (SBO) would default and also stipulates the socio-economic and economic development targets, and lastly the Direct Agreements (DA) that provides the lenders with the ability to step-in in the event of default (Eberhard *et al.*, 2014, 11).

Renewable power generation assets can have a combination of different shareholders at different times of the projects LC, each of whom may have different goals. The ownership and management structures within the SA assets often combine foreign and local ownership with long-term service or management contracts (Harrison, L. [Online], 2014).

According to Harrison, L. [Online] (2014) the different objectives of these various role players can evolve, align and deviate over the life-time of a project. An IPP or a utility might have a mandate which is aimed at delivering value to its shareholders and has a direct correlation with producing more energy while driving down operational costs. A financial owner, however, will take interest in cash flow and return on investment, an Asset Manager will prioritise ensuring the best return in the event that the asset is traded, but an Independent Service Provider (ISP) or OEM will be focused on reducing their operational costs while maintaining the minimum performance requirements. It is critical that a maintenance strategy can be changed to suit the focus of an owner and have sufficient flexibility to evolve as circumstances dictate (Harrison, L. [Online], 2014).

Market consolidation could, due to reduced margins and increased competition, potentially increase the number of physical assets under management by a single organisation. According to Eberhard *et al.* (2014, 12), global over-supply and mature manufacturing processes of RE technologies have drastically reduced profit margins. Combined with the diversity of energy sources, the modular nature of renewable technologies and large number of developers the SA RE sector is very competitive. This fierce competition drives the industry towards consolidation with increasing vertically integrated supply chains (Eberhard *et al.*, 2014, 12).

Another key aspect to consider is the deal structures of the REIPPPP projects. A presentation on the REIPPPP, as seen in figure 2.23, by the head of SBO, Yousuf Haffejee, highlights the typical key stakeholders within a single project (Haffejee, Y. [Online], 2013). Key stakeholders can include governmental departments, shareholders, contractors, local communities, BEE partners, lenders, land owners and Eskom to mention a few.

According to Eberhard *et al.* (2014, 12) the diversity of sources, modularity of renewable technologies and significant number of project developers contribute to making the RE sector very competitive. Relatively mature technologies and industries are involved in the manufacture of components for RE technologies. However, over the past several years, profits have significantly reduced or disappeared amidst a global over-supply and fierce competition. This has resulted in the industry experiencing some consolidation with continuous vertical integration of supply chains and manufacturers becoming project developers (Eberhard *et al.*, 2014, 12).

The REIPPPP project financing structures have started seeing a major shift, as projects as of round three have seen more balance sheet financing compared to the earlier project financing (Eberhard *et al.*, 2014, 37). The balance sheet financing has played a significant role in driving down bid prices in terms of ZAR/Kilowatt Hours (KWh). This has enabled market players such as Sky Power, BioTherm, Mainstream Renewable Power, Mulilo and Enel Green Power to be more dominant within the market (GreenCape [Online], 2015, 18).

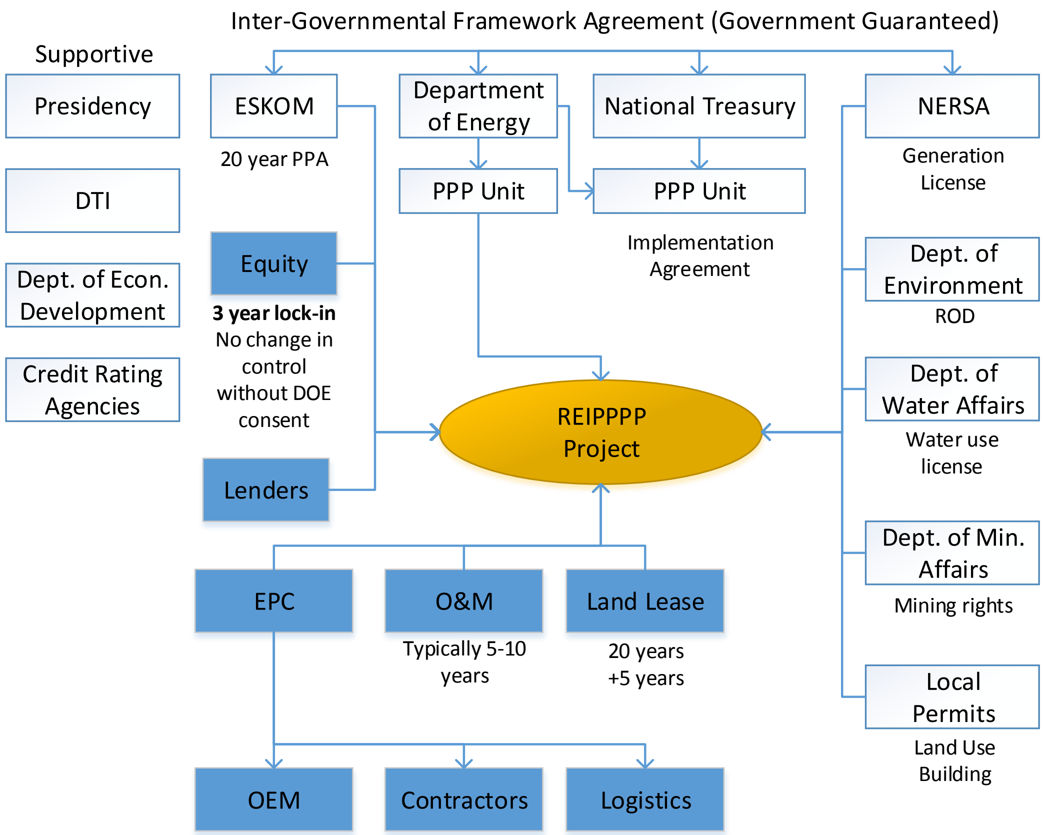


Figure 2.23: Example of REIPPPP project high level stakeholder relationships structure (Adapted from Haffejee, Y. [Online] (2013))

This has enabled market players such as Sky Power, BioTherm, Mainstream Renewable Power, Mulilo and Enel Green Power to be more dominant within the market (GreenCape [Online], 2015, 18). In a number of cases a single entity (IPP, Asset Manager or project agent) is responsible for the management of multi-technology portfolio of RE assets. Scatec Solar own and operate three utility scale solar PV projects in SA, 190 MW in total, and have been awarded preferred bidder status on an additional three solar PV projects totalling an additional 258 MW (ScatecSolar [Online], 2015). BioTherm has two utility-scale solar PV power plants (20 MW), a biogas facility (4.2 MW) and wind farm (27 MW). BioTherm has also been awarded preferred bidder status for three projects in round four of the REIPPPP. The awarded projects consist of a wind farm (120 MW) and two solar PV power plants (131 MW) (BioTherm [Online], 2015). Globeleq, the largest IPP in Sub-Saharan Africa, currently own and operate two utility-scale solar PV power plants (100 MW) and a wind farm (138 MW) in SA (Globeleq [Online], 2015).

2.3.2 Training and Skills

A significant number of RE projects have been built and are being maintained by a combination of local SA consortiums and foreign contractors (GreenCape [Online], 2015). Examples of EPC contractors are Vestas (Danish), Conco (SA), Siemens (German) and Murray and Roberts (SA). Maintenance and service of turbines are covered by agreements with OEMs and typically run for five to 15 years (McKenna, J. [Online], 2013). The O&M agreements are in many cases signed with foreign service companies such as Siemens, Vestas and Sinovel (GreenCape [Online] 2015; McKenna, J. [Online] 2013).

Jobs are an indication of the number of permanent positions that are created in the O&M phase which can last between 15 and 25 years. A key ingredient to their long REPP success is having sufficient O&M skills (GreenCape [Online], 2015). The PPAs in the REIPPPP are typically 20 years (Stands *et al.*, 2014, 18) with a job defined as 12 person months.

In SA the O&M jobs for onshore wind and solar PV are indicated in table 2.1 and table 2.2. The solar and wind industry in SA to date will require 1318 and 1070 jobs respectively.

Constraints regarding skills development have been identified in that universities, sector education and training authorities (SETAs), private training providers and FET colleges cannot respond quickly enough to the market needs (GIZ, 2012). Another major issue is that leaders in the industry have not developed long-term perspectives on skills development, which contributes to the constraint on educational institutions and therefore the industry (GIZ, 2012).

Table 2.1: Onshore wind jobs per MW during O&M stage of REIPPPP projects after 4 bid rounds (Adapted from DOE [Online] (2015*b*))

REIPPPP	MW	O&M Jobs	O&M Jobs assuming 20 year PPA
Round 1	634	2 461	124
Round 2	563	2 238	112
Round 3	787	8 506	425
Round 4	676	8 161	409

Table 2.2: Solar PV jobs per MW during O&M stage of REIPPPP projects after 4 bid rounds (Adapted from DOE [Online] (2015*b*))

REIPPPP	MW	O&M Jobs	O&M Jobs assuming 20 year PPA
Round 1	415	9 273	464
Round 2	435	7 513	358
Round 3	417	3 809	191
Round 4	632	6 117	305

Other countries have also struggled to create holistic, coherent and coordinated skills-development programmes (Strietska-Ilina, O., Hofmann, C., Haro, M.D. and Jeon, S. [Online], 2011). Studies involving 21 countries were conducted in partnership with the European Centre for the Development of Vocational Training (Cedefop) to investigate the skills requirements for the green economy (Strietska-Ilina, O., Hofmann, C., Haro, M.D. and Jeon, S. [Online], 2011). Results showed that even in European countries skills shortages are constricting the growth of the green economy (Strietska-Ilina, O., Hofmann, C., Haro, M.D. and Jeon, S. [Online], 2011), with wind energy companies reporting an acute shortage of skills and high staff turnover in various fields (European Wind Energy Association, 2009). This view is also expressed by Maia *et al.* (2011) who states that skills shortages are likely to constrain certain growth in the wind power segments and that a coherent strategy is needed to address such issues. Strietska-Ilina, O., Hofmann, C., Haro, M.D. and Jeon, S. [Online] (2011) states that "skills development systems need to go beyond matching training to labour market needs; they need to play a catalytic role in future economic growth and resilience by enabling enterprises and entrepreneurs to adapt technologies, compete in new markets, diversify economies and thus accelerate job growth".

A study in Germany, based on surveys and interviews among enterprises and experts, found that the wind industry is one of the RE sub-sectors that suffers from skill shortages. In many countries there is also a shortage of teachers and trainers with the necessary skills and methods to impart industry knowledge (Strietska-Ilina, O., Hofmann, C., Haro, M.D. and Jeon, S. [Online], 2011).

The dominant requirement for skills during the O&M phase is for technicians while the requirement for skilled workers is less. The report by GIZ (2012) mentions that the skills shortage related to the wind industry has been highlighted within the Skills Plan (2011-2016) released by MerSETA (manufacturing and engineering related services) and EwSETA (energy and water services). The MerSETA mandate is also inclusive of addressing the wind turbine service technicians skill shortage as the dominant requirement during the operational phase (GIZ, 2012). Wind service technicians will thus be a vast majority of the required workforce and the demand is estimated to grow at a steady rate every year. GIZ (2012, 6) also mentions that the three main areas of training will be for skilled workers, technicians and professional engineers, while European Wind Energy Association (2009) also mentions shortages in engineers and O&M staff.

Wind turbine technicians can be seen as a specialist area and in the short term OEMs will be likely to fill this skills requirement using expatriate staff. However, it will be to the benefit of all parties if these positions are filled by SA staff. The likelihood of OEM establishing their own training centres is strong in the event that suitable education for wind turbine technicians does not emerge (GIZ, 2012).

In response to some of these challenges the SA Renewable Energy Technology Centre (SARETEC) based at the Cape Peninsula University of Technology in Bellville was established as a national training centre for the RE industry (Engineeringnews [Online], 2014).

Turbine manufacturers are selling fewer turbines and to obtain long-term cash flow are offering O&M service contracts up to 20 years as opposed to the 2–5 year agreements initially seen in the market (Broehl, J. [Online] 2010; Jones, P. [Online] 2010). However, these longer service contracts can result in longer retention of technicians, making them a scarce commodity and placing further pressure on the skills market (Broehl, J. [Online], 2010).

The issues around the shortage of skills are amplified once turbines start coming out of warranty. Europe and the United states experienced this once OEM service contracts started to end in 2008. Like SA, the United States experienced rapid growth of installed wind capacity which started in 2005. The growth, short warranty periods and skills shortage were a concerning factor as the wind farm owner and operator becomes responsible for all gearboxes, generators, blades and other critical parts failures. Inspections related to end-of-warranty also become a critical offering (Broehl, J. [Online], 2010).

RMCs, monitoring an entire fleet remotely from a centralised location twenty-four hours a day, are becoming commonplace within the industry (Windpowermonthly [Online] 2010; Trabish, H. K. [Online] 2009). Wind turbines are equipped with sensors and Turbine Condition Monitoring (TCM) and Supervisory Control and Data Acquisition (SCADA) systems that supply real-time data from the multitude of computer systems and network of sensors via high speed communication networks (Trabish, H. K. [Online], 2009). This data can be analysed to diagnose incipient issues and allows the detection of performance disruptions and enabling the adjusting of parameters or dispatching technicians if required (Windpowermonthly [Online] 2010; Trabish, H. K. [Online] 2009). These systems are also capable of detecting abnormal conditions using automated algorithms, that will then notify the relevant remote operations service specialists who will first try to address the issue remotely (Trabish, H. K. [Online] 2009; Windpowermonthly [Online] 2010). Tim Holt, global CEO for Siemens Renewables Service further stated that Siemens has found that up to 80% of turbine issues could be resolved from their remote diagnostics centres, often just requiring a remote reset (Trabish, H. K. [Online], 2009). This can greatly reduce downtime while the collected data can also be used to identify opportunities to improve performance (Windpowermonthly [Online], 2010). Information from systems such as vibration analysis accelerometers on the main bearing, gearbox and generator to monitor for impending drive train issues, relay analysis back to the RMC. This also enables RMC operators or specialists to perform CBM practices. However, no detail around the requirements for RMC operators or RMC specialist skills or training is discussed in the literature even though people with these skills are becoming an indispensable resource within the industry.

Remote monitoring and analytics are a key element in the reduction of operating costs. However, opportunities for analytics are lost due to the lack of access to data (Harrison, L. [Online], 2014). OEMs are not providing sufficient access to information or facilitating skills transfer as the multi-billion-dollar business market for O&M contracts for wind turbines coming out of warranty is heating up globally (Kessler, R. A. [Online], 2014). This is further addressed in the following sections.

2.3.3 Access to Data, Information and Maintenance Practices

According to Harrison, L. [Online] (2014), key issues raised at the 8th annual SKF Wind Farm Management Conference held in Warsaw, Poland were related to the sharing of knowledge, data access, the emergence of the independent service provider as well as an increasing interest by wind farm owners in controlling and running their own assets (Harrison, L. [Online], 2014).

The restricted access to data for owners by OEMs is common business practice and in certain cases the OEM even has contracts which restrict the sharing of information (Nelson, G. [Online], 2011, 12). This makes it very difficult to develop a O&M budget that can be defended.

The global wind industry grew from about 17.4 Gigawatt (GW) in 2000 to 370 GW in 2014. The O&M space market is significant as about 160 GW of the installed wind capacity will be out of warranty by 2014 and grow by 40 GW per annum up to the year 2020 (Jain and Kapoor, 2015). The O&M market, which has been dominated by OEMs due to their technical expertise and warranty periods, will become a 10–17 billion US Dollar market by 2016 (Jain and Kapoor 2015; Harrison, L. [Online] 2014).

Data is monopolised by OEMs and it creates a scenario where it is difficult for wind farm Asset Managers to develop detailed maintenance strategies (Besnard, F. [Online], 2014). Although studies indicate that a few components such as blade, gearbox and control systems account for 80% of maintenance costs, OEMs are not forthcoming regarding when, how or why these components fail (Attermo, P. [Online], 2014). The priorities of the OEMs and wind farm owners are not aligned as the OEMs control the access to data and information (Knudsen, S. J. [Online] 2014; Huijzer, M. [Online] 2014). There is an outcry from wind farm owners to have access to data such as remote monitoring and analytical information, which are key components to reducing costs and improving performance; but these opportunities are lost due to the lack of access to information (Knudsen, S. J. [Online], 2014). Furthermore, data integrity, accuracy, quality, consistency, validation and documentation are questionable and reduce the amount of actionable information (Knudsen, S. J. [Online], 2014).

Wind turbine failure databases' validity, statistics and reports are being affected by several technical and operational problems. These issues are a result of the lack of event data, contextual data, unknown incident data, manual and ill-documented data sources that challenge classifying into the relevant sub-systems due to incomplete information. Failure information is also mainly related to mechanical components while information regarding electrical component failure analysis is in short supply (El-Thalji and Liyanage, 2012, 249).

Co-operation and sharing of knowledge is required between OEMs, independent service providers (ISPs) and wind farm owners. Wind farm availability can be directly influenced through sharing knowledge and there should be a dedicated effort to share knowledge (Keller, M. B. [Online], 2014). It is often the case that KPIs for the same turbine model operating in similar conditions are significantly different and wind farm owners could learn from one another if they had access to information and knowledge sharing was prioritised (Keller, M. B. [Online] (2014); Aabo (2014)). Spare parts are also more affordable on the open market compared to OEMs but due to the restricted access of knowledge and information it is often very difficult to locate the suppliers (Attermo, P. [Online], 2014). The lack of information on spare part removal rates also creates a challenge as it is difficult to optimise stock levels (Huijzer, M. [Online], 2014). There is a general industry consensus that up to 10%–15% of LCC are related to service during the early stages, maintenance, repair and the replacement of spare parts. This increases to 20%–35% closer to the turbines' end of life (El-Thalji and Liyanage, 2012). The significant O&M costs creates a significant opportunity to increase returns for wind farm owners if the OPEX can be reduced (Harrison, L. [Online], 2014).

Transparent supply-chain for spare parts will reduce delays, costs and help alter the OEM monopoly on original components (Huijzer, M. [Online], 2014). Strong stock positions will become a key element once wind farms exit the warranty periods and owners have to self-manage or opt for the ISP route (Huijzer, M. [Online], 2014). Conflict can arise in the event that an ISP is reliant on OEMs to supply spare parts and successful wind farm management is highly dependent on the co-operation of the OEM (Brinck, C. [Online], 2014).

Another recognised theme within the wind industry is the limited incentive for OEMs to monitor inefficiencies as well as the variance in OEM cooperation (Langfeldt, T. [Online] 2014; Flaig, R. [Online] 2014). The wind farm owner has a focus which is geared towards maximising production at an optimised LCC, but the OEMs are focused on reducing their operating costs during the service and warranty period (Langfeldt, T. [Online], 2014). This is echoed through the dominance of time-based availability warranties opposed to energy-based performance warranties provided by OEMs. Even in the cases where energy-based performance warranties are in play OEMs do not display interest in optimising performance beyond the required level (Langfeldt, T. [Online], 2014).

OEM service and maintenance contracts are seen as very expensive over a 10-year period. Cost estimates for a UK project Enercon E48 800 KW turbines that came on line in 2015 with a 15-year full-service contract were ZAR322 000 per MW per year for the first five years and increasing to ZAR 644 000 per MW per year thereafter (ZAR14 to the Euro) (Knight, S. [Online], 2015). The high costs have encouraged a shift towards using ISPs instead of OEMs, especially in cases where turbines are ageing and has resulted in service costs reducing.

ISPs often provide a more cost-effective alternative to turbine OEMs (Jain and Kapoor, 2015). One of the advantages of ISPs has been their experience over a range of turbine brands because of their flexibility in knowledge and component supply, with some ISPs operating on a full disclosure agreement with wind farm owners (Brinck, C. [Online], 2014).

The expanding O&M business in Europe will require consolidation of the smaller ISP companies to meet the market needs (Brinck, C. [Online], 2014). The wind business is changing with wind Asset Owners becoming reluctant to outsource all the responsibility to an ISP or OEM. More mature operators are already demanding more involvement in the operation of their assets (Brinck, C. [Online], 2014).

Wind farm owners like Dong and E.ON are determined to take control of AM while working in co-operation with OEMs and even looking for opportunities to influence design and development (Aabo, 2014). UK owners have also highlighted the fact that wind farm owners globally should actively take part in the analysis of wind farm performance and turbine behaviour and not be solely dependent on warranties and the service provider. It is critical to detect issues as early as possible and it will reduce downtime, repairs, costs while increasing revenue (Powles, S. [Online], 2014).

2.3.4 Renewable Technologies and Maintenance

Wind power assets are among the most complex and multidisciplinary applications of modern RE systems and the O&M practices within the industry make a significant contribution to that complexity (El-Thalji and Liyanage, 2012).

Due to the growth within the wind industry and specifically the future O&M market there is a requirement to improve the productivity of wind turbines and maximise investor returns (Andrawus *et al.*, 2006*b*). Given that O&M costs can constitute up to 35% of the LCC, the successful future development will require that the most appropriate maintenance strategies be utilised when considering that the net revenue is revenue generated from energy sales less O&M expenditure (El-Thalji and Liyanage 2012; Andrawus *et al.* 2006*b*).

The global and SA market has seen wind turbines purchased with up to 15-year all-in service contracts that include a warranty with CM (failure-based) and PM (time-based) strategies (Andrawus *et al.* 2006*b*; McKenna, J. [Online] 2013). This view is echoed by Sanz-Bobi (2014, 4) who notes that the wind industry has been adopting a CM and TBM approach at fixed intervals. Typically, these maintenance strategies are adopted until the service contract and warranty of the wind turbines expire, but in many cases these strategies are inadequate to meet the needs of a performance-driven Asset Owner (Verbruggen

2003; Conover *et al.* 2000).

CBM involves running a wind turbine until any of its component fail. CBM is thus performed after the occurrence of a failure and the intention is to restore the equipment to a state where it is able to perform its intended function Besnard *et al.* (2010, 3). This maintenance approach is generally used where the consequence of a failure will not lead to major loss in revenue, unhappy customers or jeopardising health and safety. However, in the event of a catastrophic critical component failure the HSE as well as operational consequences can be severe (Andrawus *et al.*, 2006*b*). The viability of CM strategies is thus driven by the consequences of failures of the electricity network, the wind turbine technology and revenue generation (Andrawus, 2008, 6).

PM and CBM are also discussed in section 2.2.3. PM for wind turbines would include biannual servicing where a turbine-specific check-list is used to verify the operational status and update maintenance records. Activities would include checking gearbox and hydraulic system oil levels, inspecting for oil leaks, cable inspections, drive train vibrations, brakes, access and emergency exit equipment, fixings (blades, gearbox, etc.), shaft alignment, yaw system, bearing condition and greasing, pitch calibration, checking oil filters, and so on. However, if PM is performed too often it will increase operating costs, reduce performance and replace components which are still in a good condition. Alternately when PM intervals are too long, unexpected failures occur (Thorpe, C. [Online], 2005). Time and resources can thus be wasted if the condition of equipment is not known (Andrawus, 2008, 4). This highlights the potential barriers to achieving optimised maintenance performance using CM and time-based PM strategies to support modern commercial drivers of wind farms (Andrawus, 2008, 4).

Failure-rate studies have identified the need for CdM, specifically on drive train components (Crabtree *et al.*, 2014, 3). The research area of PdM applied to wind turbines has for many years been ignored. The application of PdM has started receiving more attention as work is being undertaken to develop CdM techniques that are efficient and reliable. Many of the methods used in the wind industry have been adapted from other industries (Crabtree *et al.*, 2014, 3).

Many quantitative studies, based on public domain data, have been performed on reliability of wind turbines. Results of these studies have shown that wind turbine gearboxes are a mature technology but have a time-based deterioration rate (Tavner *et al.* 2007; Spinato *et al.* 2009). Supporting the research on gearboxes, studies also conclude that gearboxes cause the largest amount of downtime per failure event (Faulstich, S and Durstewitz, M and Hahn, B and Knorr, K and Rohrig, K [Online], 2008).

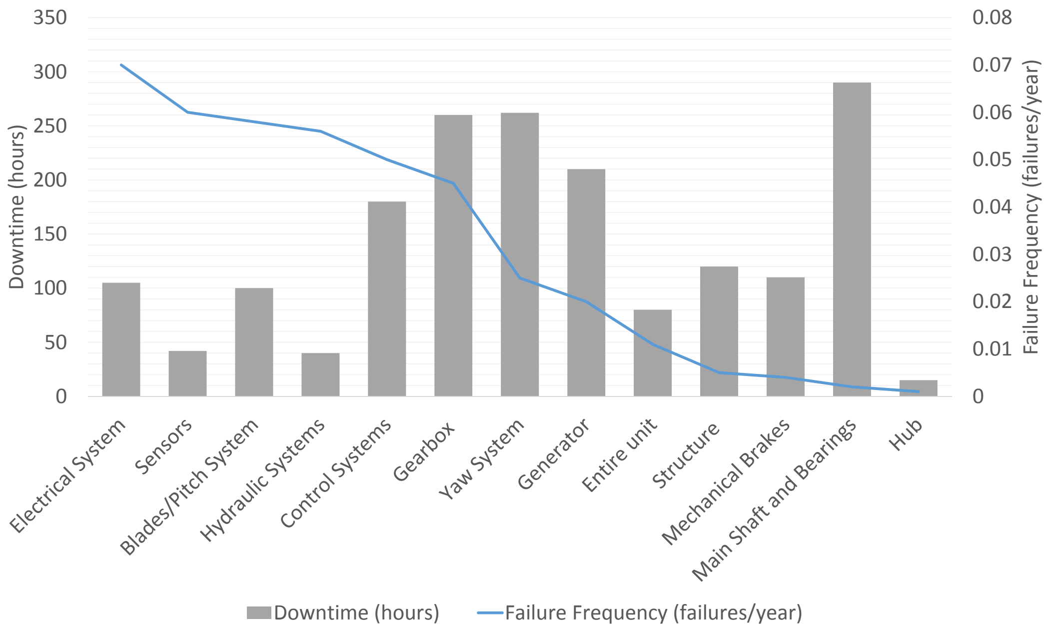


Figure 2.24: Wind turbines in Sweden – average failure frequency and downtime per sub-system and year from 1997 to 2005 (Adapted from Besnard *et al.* (2010, 2))

The results of some of these studies in Europe can be seen in figure 2.24 and indicate sub-assembly failure probability and associated downtime (Crabtree *et al.* 2014, 3; Spinato *et al.* 2009; Tavner *et al.* 2007; Faulstich, S and Durstewitz, M and Hahn, B and Knorr, K and Rohrig, K [Online] 2008).

Long downtime and associated costs, combined with infant mortality on the gearbox and drive train, have steered initial TCM efforts to focus on vibration analysis, and subsequently most TCM systems are vibration-based (Crabtree *et al.* 2014, 3; Yang *et al.* 2014). These TCM systems, using time and frequency domain signal processing techniques, are proficient at detecting drive train faults, but are questionable at analysing wind turbines that work with direct, hybrid or hydraulic-drive technology. According to Yang *et al.* (2014, 675) studies have also shown that the electrical components or control systems of turbines experience significant failure rates but cannot be monitored using vibration monitoring. There is thus a clear requirement that future TCM systems should not just monitor mechanical components but should include electrical and electronic components (Yang *et al.*, 2014, 675).

Various non-destructive testing methods, some already used in practice while others are being laboratory tested, have been developed for wind turbines. Exampled of these are (Yang *et al.*, 2014, 675):

- **gearbox and bearings** – oil particle counters, oil quality analysis, vibration analysis, thermocouples, acoustic emissions, shock pulse method;
- **wind turbine blades** – ultrasonic testing, Fibre-optic strain measurements, acoustic emissions;
- **tower** – ultrasonic testing, acoustic emissions;
- **nacelle** – vibration analysis, thermocouples;
- **lubrication and hydraulic oil** – thermocouples; and
- **power electronic** – thermocouples.

In addition to TCM-based systems, more cost-effective SCADA-based systems using real-time and 10-minute average signals have also been developed (Yang *et al.* 2014, 675; Chen *et al.* 2014, 4). These systems use analysis techniques ranging from statistical methods to artificial intelligence. SCADA systems provide alarms but due to the frequency and the volume of alarms it does not enable rational analysis but work is being undertaken to address the issue (Chen *et al.*, 2014, 12). Integration between commercially available TCM and SCADA data analysis tools is increasing with some recent systems proposing the use of wind turbine modelling including diagnostic and prognostic models to be used for PdM (Chen *et al.*, 2014, 12).

In order to identify and categorise major causes of horizontal axis wind turbines, a detailed assessment on the German fleet including 15 500 turbines was performed. The results in figure 2.25 indicate that component failure and control system failures accounted for 42% and 21% of total failures respectively Windstats Newsletter (2004)(as cited in Andrawus 2008).

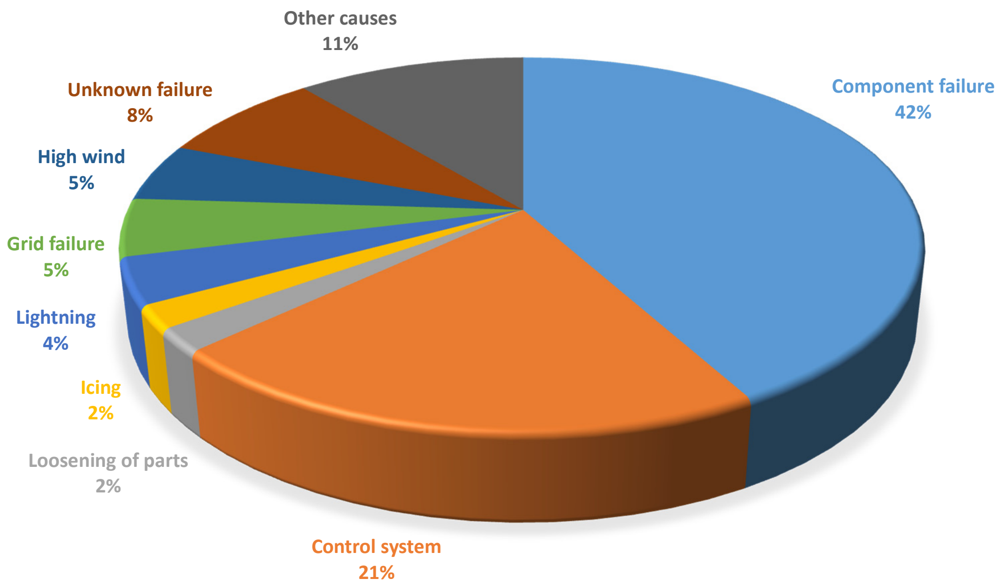


Figure 2.25: German experience of causes of wind turbines failures (Adapted from Andrawus (2008))

Studies undertaken by the Centre for Renewable Energy Systems Technology as well as the Energy Centre Netherlands shows that component breakdown was a major cause of downtime and identify the failure rates of specific components. Onshore turbine failure rates are reported to be 1.5 to 4 times a year (Verbruggen *et al.*, 2002). The implication of these failures is that a significant amount of resources are required to fix turbine and component failures on an annual basis in addition to the HSE and operational consequences. Due to the inefficiency of current maintenance practices a clear need has thus been identified adopt more sophisticated maintenance philosophies and implement more appropriate maintenance approaches. The goal should be to promote O&M and asset management activities that are technically feasible and economically viable while reducing the total LCC and wind farm assets.

The bathtub curve, as seen in figure 2.26, is used to model failure intensity in order to represent the unreliability of repairable systems (Spinato *et al.*, 2009, 389). Many initial studies are based on the assumption that wind turbine assembly failure rates followed a bathtub curve, thus following an invariable failure rate during the useful life. However, recent studies have indicated failure behaviour which did not match that of the bathtub curve (Kaidis, 2014, 45).

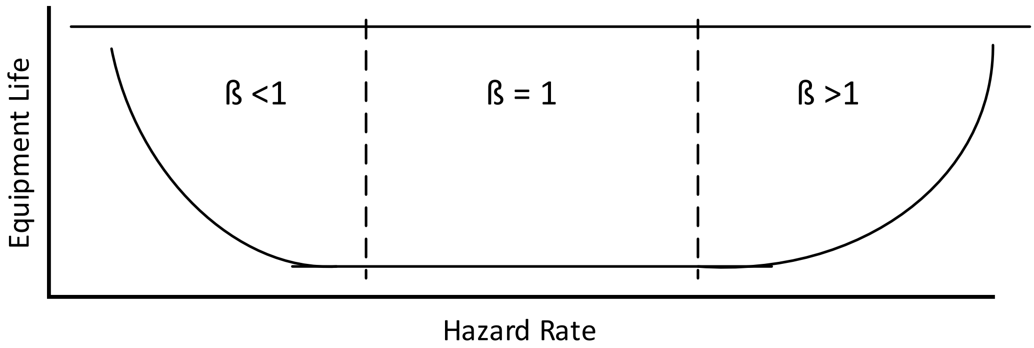


Figure 2.26: Bathtub curve (Adapted from Spinato *et al.* (2009, 389))

The work related to wind turbines PdM has also largely been studied in isolation without consideration for the broader context and the maintenance field and its integration into an asset management strategy (Andrawus *et al.*, 2006*b*).

RCM and FMEA have been extensively reviewed and applied as a maintenance philosophy within the wind industry. RCM is combined with Asset Life-Cycle Analysis (ALCA) to provide a more sustainable method of understanding what the most appropriate, technically feasible and economical maintenance strategies are (Andrawus *et al.* 2006*a*; Andrawus 2008). The approach by Andrawus (2008, xv) is also applied within a case study to determine suitable CBM activities for wind turbines and to identify failure modes and failure consequences of critical components and subsystems of the wind turbine using the RCM approach (Andrawus, 2008, 131).

Besnard *et al.* (2010, 4) propose a RCAM approach, which is a combination of RCM and quantitative MO techniques, The author proposes the method to supplement the qualitative limitations of RCM with a quantitative tool applied to selected components. Das *et al.* (2011, 1582) present the results of an FMEA on a wind turbine system with the purpose of identifying weaknesses in the respective sub-systems. Fischer *et al.* (2012) apply RCM to critical components of a Vestas V44-600 KW and V90-2 MW turbines and include the Asset Owner, operator, a maintenance service provider, a condition-monitoring expert, wind turbine component supplier and researchers in academia as part of the RCM team. The author combines the results from RCM team analysis with failure statistics and assessment of expert judgement to determine the best maintenance action.

2.3.5 Summary of Renewable Energy Landscape Literature

The last scholarship that is of relevance to this research is the RE landscape within SA. The section first reviews the energy sector and specifically the REIPPPP in SA. Key areas such as complexity within the existing REIPPPP ownership structures, skills challenges, restricted access to data and information, and the inadequacy of maintenance practices within the RE industry are discussed. The section concludes with a review of existing maintenance practices within the RE industry which highlighted the perceived inadequacy of maintenance practices to meet the requirements of performance driven Asset Owners.

2.4 Chapter Summary

The purpose of this chapter is to review the present literature that relates to the problem statement and objectives. During this chapter the scholarship of the key foundation areas of the literature is reviewed, sketching the landscape that is framed by the fields of AM, maintenance and RE. The literature analysis adopted an explorative nature evolving through the various scholarly fields, attempting to provide a holistic, comprehensive view of the problem introduced in Chapter 1.

The chapter first focuses on AM and explores the history and current trends of the discipline of AM showing how it has matured and is relevant to modern industry. Key AM concepts are discussed, highlighting attributes of AM for consideration during this study. The section is concluded by a review of the six subject groups forming the 39 subjects developed by GFMAM to describe AMBOK.

The second part of the chapter considers the field of maintenance. The section also reviews the history of maintenance and the paradigm shift from maintenance as a "necessary evil" to a value creating activity. Key AM concepts are discussed highlighting attributes of maintenance such as maintenance philosophies, maintenance types, work planning and control, centralisation and optimisation.

The final section of the chapter explores the RE landscape in SA and considers challenges faced by the global RE industry. Aspects related to reduced profit margins, complexity within ownership structures, training and skills and access to information are reviewed. The section concludes with a review of existing maintenance practices within the RE industry, which highlighted the perceived inadequacy of maintenance practices to meet the requirements of performance-driven Asset Owners and touches on the use of hybrid or adapted RCM methodologies within the scholarship to develop adequate maintenance plans for the RE industry.

This chapter contributes towards the first four research objectives stated in section 1.3:

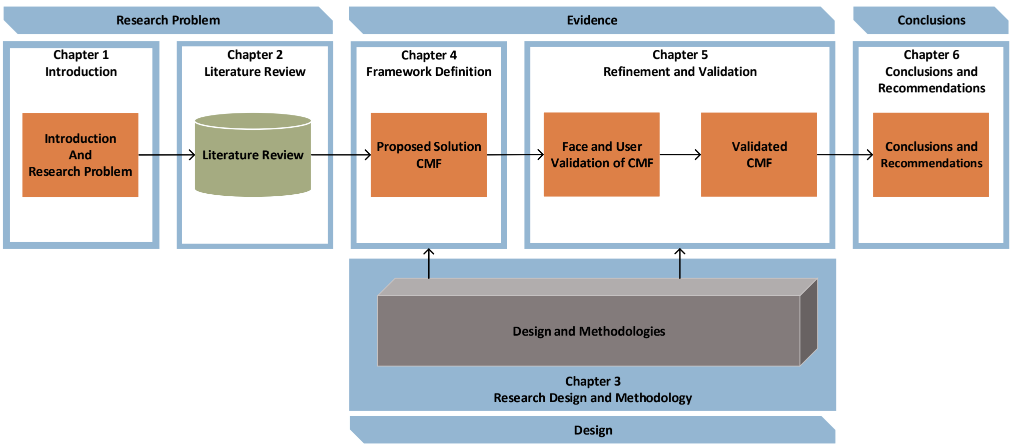
- Review and establish the key or fundamental concepts in the maintenance field and identify philosophies used to develop maintenance plans.
- Review and establish key concepts in existing maintenance management frameworks and within the discipline of AM.
- Review the RE sector in SA.
- Contextualise the synergy between key elements within the realms of maintenance, AM and the SA RE sector.

The research design and methodologies for conducting the research follow in the next chapter.

Chapter 3

Research Design and Methodology

If you fail to plan, you are planning to fail! – Benjamin Franklin



This chapter presents the research design and methodology. Firstly the philosophical world view and the research approach are discussed, followed by a description of the research. The chapter concludes with a discussion of the research and reasoning methods.

3.1 The Nature of Science

Science does not have a fixed meaning, but rather a multitude of meanings that adapt and develop as science does itself. Lewens (2015, 2) poses the following questions regarding what science is by stating:

> *does it describe the world as it really is, or does it merely provide useful models to help us to manipulate it? Does it make progress, or are the theories of any age destined to be shed one by one, like a snake's skin? Is there a clear, rigorous "scientific method" or just an ad-hoc hodgepodge of various techniques?*

It can therefore be said that obtaining a single definition for science is difficult. However, the aim of science could provide a lens through which science can be understood. The purpose of conducting any scientific research is to determine why things happen as they do (Jooste, 2014, 54). Scientific methods include Induction and Deduction, Hypothesis Testing, Naturalism, Kuhn and Paradigms, Lakatos and Research Programs, Feyerabend's Anarchistic Theory of Science, among others.

3.2 Research Approach

The research approach and the chosen plan for conducting the study are described, with science and scientific research as the backdrop.

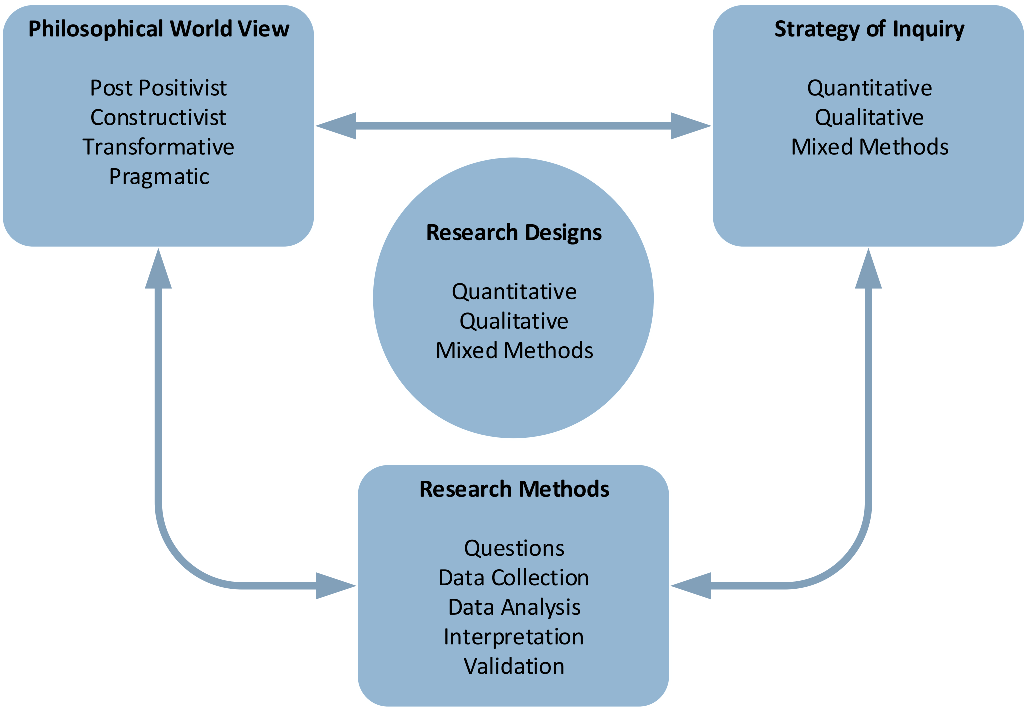


Figure 3.1: Research design framework (Adapted from Creswell (2009, 5))

Creswell (2003, 3) introduces three framework elements (as seen in figure 3.1) that a researcher needs to take into consideration, which are a philosophical world view about what constitutes knowledge, strategies of inquiry (procedures of research) and methods (data collection and anaylsis). The research approach is determined by these three framework elements. However, there are additional elements which contribute to the selection of a research approach such as the researcher's personal experience, who the audience is and the nature of the research problem (Creswell, 2003, 3).

The purpose of selecting a research design is to identify the particular type of study and determine or select an appropriate strategy of inquiry that will be followed for the chosen study type. Bryman *et al.* (2014, 55) and Creswell (2003, 3) focus on three main classifications of research approaches: qualitative, quantitative and mixed methods. These authors note that it is often challenging to locate a study within a single method.

3.2.1 Philosophical World View

Creswell (2003, 3) states that researchers begin a research project with assumptions regarding how and what they will learn during their study. These philosophical assumptions are extended to understanding what knowledge is (ontology) and how we know it (epistemology). This research will adopt a pragmatic worldview, which is derived from the work of Mead and Dewey, and set forth the beliefs guiding the research (Gray, 2004, 20). A pragmatic world view provides the foundation for the following claims regarding knowledge (Creswell 2003, 12; Cherryholmes 1992, 13; Duram 2010, 3):

- Pragmatism can use qualitative and quantitative methods if required by the researcher (mixed methods) and is not committed to a single philosophy.
- Researchers are able to freely select methods, techniques and procedures that can fulfil their requirements and purpose.
- The researcher is enabled to discover the best understanding of the research problem by using mixed methods.
- The intended consequences and research direction drive the *what* and *how* to research as opposed to first rationalising the use of mixed methods.

These characteristics of a pragmatic world view allow the researcher to develop a holistic analysis and include a range of factors into the study that are regarded as relevant (Duram, 2010, 3). Pragmatic studies are inductive in nature and transition from a complex problem to a theory of understanding in order to address a real-world problem (Duram, 2010, 3).

3.2.2 Research Design

According to Creswell (2009, 5) research design is a plan for conducting research and entails the intersection between philosophical world views, strategies of inquiry and selected methods. It provides a structure to guide the research method as well as the subsequent data analysis (Bryman *et al.*, 2014, 100).

Bryman *et al.* (2014, 41) state that qualitative research generally uses an inductive reasoning that is informed by constructionism and interpretivism. However, he further qualifies this by stating that researchers seldom subscribe to all of the mentioned positions. Qualitative research often has contrasting traditions which makes it challenging to define exactly what constitutes qualitative research (Bryman *et al.*, 2014, 41). Bryman *et al.* (2014, 41) also mention that qualitative research focuses on concepts, and treats theory as emergent from the gathering and analysis of data, as well as attempting to identify underlying or inherent patterns. Against this background it is proposed that the research be placed within a qualitative paradigm as there will be a generalisation of qualitative findings based on previous research. This study follows a predominantly qualitative approach in order to answer the research questions.

The research questions are of an exploratory nature. A qualitative literature review is used to explore the synergy between the relevant topics of study. This is followed by the development of a proposed CMF and supporting business processes to address the research questions. A verification of the CMF and supporting business processes is undertaken by a two-pronged validation process. Face validation, which has identified shortcomings, is strengthened with user validation using semi-structured interviews of expert participants that resemble cases of similar and non-related environments in which the proposed framework could be deployed and includes Asset Managers and owners that operate multi-technology portfolios of RE assets. This resembles a qualitative cross-sectional design.

3.2.3 Research Methodology

Supported by the research design, three research phases are used in support of answering the research objectives and questions.

The first phase uses a qualitative literature review, to collect and analyse data in order to establish the fundamentals in the maintenance, AM and RE sector in SA. The literature review addresses the first four research objectives, covering key concepts such as maintenance philosophies, maintenance frameworks, challenges within the SA RE sector, and the AMBOK in order to lay the foundation to synergise these concepts.

Although not a core research phase, this chapter (Research Design and Methodology) covers the fifth research objective.

During the second phase the development of the framework is addressed and related to the sixth and seventh research objectives of the study. Through content analysis of the literature, the CMF is developed by synthesising the findings in the literature review into a structured framework.

The third and final phase of the research forms the two-pronged validation process, which is based on work by Borenstein (1998). The validation of the CMF is addressed by laboratory testing in the form of face and user validation using face-to-face semi-structured interviews with experts. The validation is performed to check whether the framework offers a truthful and practical representation of the results and can be used to support the management of ACPs within an AM organisation that owns, manages and operates a multi-technology portfolio of RE assets in the SA RE sector. The CMF and supporting business processes are introduced and explained to selected individuals involved in organisations that operate within the field of O&M, AM, and the SA RE sector. Some of the participants also own, manage and operate a multi-technology portfolio of RE assets in the SA RE sector. The insights gained from the qualitative analysis of the information collected from the semi-structured interviews aim to conclude the validation and address research objectives eight and nine and research questions three, four and five by gaining a deeper understanding of the competency required to develop and manage ACPs within the RE sector and the level of centralisation.

Finally, the research reaches conclusions and makes recommendations for industry and future research, thereby satisfying the last research objective.

The research framework (see figure 3.1) has as its last element the research methods. Table 3.1 summarises the research design and indicates the respective research methods and the chapters where they are utilised.

Phase	Approach	Process	Method	Chapter
1	Qualitative	Data Collection Data Analysis	Literature Review	2
2	Qualitative	Data Analysis	Content analysis	4
3	Qualitative	Validation Face Validation	Semi-structured Interview Validation	5
	Qualitative	Validation User Validation	Semi-structured Interview Validation	5

Table 3.1: Summary of research design and methodology

3.3 Reasoning Methods

The two scientific reasoning methods discussed in the literature are inductive discovery and deductive proof. Induction begins with fragmented details and moves towards a connected view of a specific situation; in contrast, deduction starts with a view of a situation and then moves back to the particulars (Gray, 2004, 6). According to Bryman *et al.* (2014, 9) deduction is where the researcher formulates a hypothesis regarding what is known within a specific domain (theory and practice) and then has to subject the hypothesis to empirical scrutiny. Induction is when generalisable inferences are drawn from observations and data.

Mutual exclusivity, however, does not exist within the inductive and deductive process (Gray 2004, 6; Bryman *et al.* 2014, 9).

The introduction uses inductive reasoning to derive the research problem and questions. The first two phases of the research also use inductive reasoning to develop an initial proposed framework based on the premises found in the literature review.

A deductive process is followed in the third phase as the framework is presented before conducting semi-structured interviews which are used to make inferences regarding the wider population of practitioners involved with maintenance and AM within the RE sector. The findings are then used to deductively validate the CMF.

3.4 Chapter Summary

This chapter contributes towards the fifth research objective stated in section 1.3:

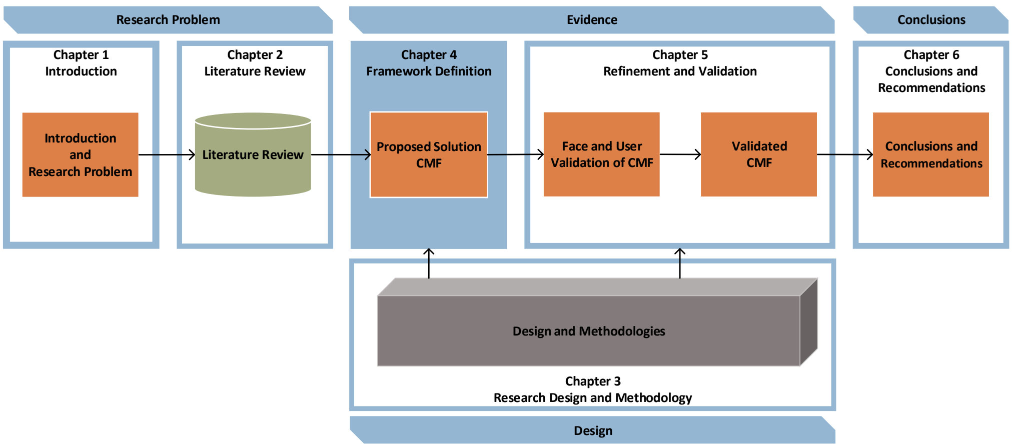
- Devise a well-founded research methodology.

This chapter discusses the research approach, design, methodologies and methods of scientific reasoning during this thesis. The literature study, combined with relevant information obtained from practice, provides sufficient information to propose a framework and supporting business processes and meet the research objectives. The next chapter discusses the CMF and supporting business process development.

Chapter 4

Central Management Framework for Asset Care Plan Development

The whole difference between construction and creation is exactly this: that a thing constructed can only be loved after it is constructed; but a thing created is loved before it exists. – Charles Dickens



The literature analysis consists of Chapter 2, which discusses the AM discipline and maintenance management landscape, and reviews key challenges in the SA RE sector. Together with practical experience a platform is established in this chapter to propose an ISO 55000-compliant CMF that could be used to manage ACPs within a multi-technology portfolio of RE assets in SA. First, an overview of the CMF development is provided. Thereafter, each phase of the CMF is discussed in detail.

4.1 Overview

The literature analysis in Chapter 2 clearly indicates that the field of AM and more specifically maintenance management is large and diverse. The novelty of the ISO 55000 series of standards and formalised AM discipline, combined with the non-prescriptive requirements of the ISO 55000 series of standards, create a daunting challenge in developing operational or maintenance frameworks that are compliant to ISO 55000.

Asset Managers, owners and operators of REPPs in SA require structured guidance on how to apply the ISO 55000 series of standards when developing the strategy and planning requirements, and developing a maintenance management framework. The study provides an ISO 55000 series-aligned CMF with key features that are expressed using supporting business processes that can be used to centrally manage ACPs.

This study provides detailed business processes that cover the AM framework establishment, Asset Care Plan development, work planning and control, and competency management and continuous improvement.

The framework and supporting business processes are based on a thorough and broad literature base presented in Chapters 1 and 2. The *Asset Management Framework* phase is based on the GFMAM *Strategy and Planning* AM subject group and in support of developing an OSP, AM policy, AM objectives, AM strategies, and AMPs while considering the requirements of stakeholders and the context of the organisation. Existing frameworks within the maintenance field are modified for the *Asset Care Plans Development* phase to account for best practices in literature to ensure the ACPs are developed using modern techniques and tools such as RCM and a CMMS while accounting for key issues faced within the RE industry in SA such as the lack of competency and access to information. Furthermore, detailed business processes are presented for the *Work Planning and Control* phase that are critical in planning, scheduling and executing ACPs. The *Competency Management and Continuous Improvement* phase is also presented and takes into account the ongoing feedback required to improve the AMS , ACPs and the ongoing effort to build and retain organisational culture and competency.

The framework and supporting business processes are practical, provide a structured guideline and give a holistic approach to the problem and could be used to support Asset Managers, owners and operators of REPPs to implement the framework and features.

This section provides an overview of the development of the framework and the supporting business processes. First the framework is presented and the framework features are discussed. Thereafter, the detailed supporting business process that relates to each framework feature is discussed in sections 4.4, 4.5, 4.6 and 4.7.

4.2 Proposed Central Management Framework

The proposed solution to the problem is an ISO 55000-aligned guidance framework supported by business processes that can be used to manage ACPs within a multi-technology portfolio of REPPs. The CMF is developed through an iterative process and influenced by literature study fields of AM, maintenance management and the RE industry.

The proposed CMF, shown in figure 4.1, has four key phases that are represented by business processes and their associated steps. The following four phases are integral to the CMF:

- *Asset Management Framework – Phase 1*
- *Asset Care Plan Development – Phase 2*
- *Work Planning and Control – Phase 3*
- *Competency Management and Continuous Improvement – Phase 4*

Each of the four framework phases are supported by a set of key elements of the business processes that are constructed through various steps as seen in figure 4.1. The grey box represents each of the four phases, the light-blue box represents a key business process element and the dark-blue box represents the steps within the business process element.

Each key element and step of the supporting business process is also numbered to act as a logical sequential guideline to users when following the framework. However, it is important to note that the framework is not bound to a specific sequence and therefore the steps are not linked to one another in the framework. The framework also forms a continuous flow between the phases as these phases could be performed concurrently and influence each other.

The *Asset Management Framework* phase consists of steps outlined in a business process that relates to the discipline of AM. This phase is based on the GFMAM Strategy and Planning AM subject group and focuses on AM maturity of the organisation, scope of the AMS, developing the OSP, SAMP (that is the AM objectives and strategies) and AMPs while considering the requirements of stakeholders and the context of the organisation.

The *Asset Care Plan Development* phase considers the development of detailed ACPs for RE assets. Existing methodologies and tools within the maintenance field, such as RCM, are modified and enhanced while a central CMMS is leveraged to account for best practices in literature and address key issues faced within the RE industry in SA such as the shortage of local skill/competency, inadequacy of applied maintenance philosophies and limited access to information.

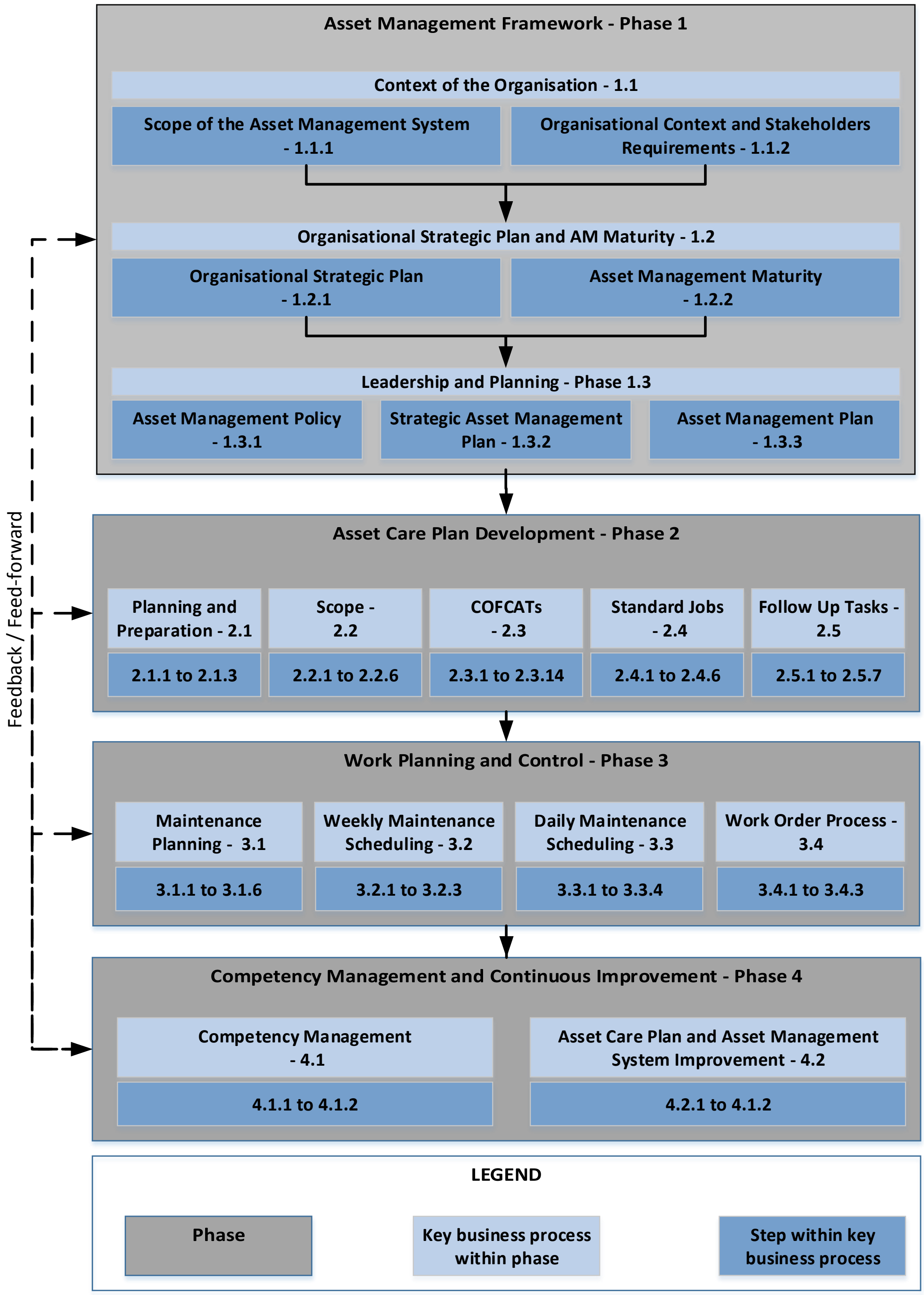


Figure 4.1: Central management framework (CMF)

This phase reinforces the Line-of-Sight between the OSP and AM activities by creating a link to the previous phase by considering the AM objectives and strategies and incorporating them into the ACP development process and between the maintenance activities and the overall organisational objectives.

The *Work Planning and Control* phase forms a key part of the ACP management as it is critical in planning, scheduling and executing ACPs. The previous phase considers developing the detailed ACPs (or maintenance plans). However the Work Planning and Control phase ensures that the plans are executed to ensure that organisational and AM objectives are achieved. This phase also has a key input into the following phase as a feedback loop. Furthermore, the centralisation of the work planning and control function could deliver significant value within a multi-technology portfolio of RE assets.

The *Competency Management and Continuous Improvement* phase considers the ongoing feedback from the various business functions required to improve the AMS and embed organisational culture. This phase considers continuous improvement of employee and organisational competency to ensure that AM is practised effectively. Secondly this phase also considers feedback from the other phases to improve ACPs and also improve the overall AMS and plant performance to ensure that organisational and AM objectives are achieved. This further reinforces the Line-of-Sight between the organisational activities and the overall organisational objectives.

All the phases and business processes within the framework influence each other and work together to develop an ISO 55000-compliant management framework for ACPs. Although the steps are not explicitly linked it is key to understand the interaction that exists between the different steps. The framework could be viewed as an interconnected web of activities which is also indicated by the feedback and feed-forward loops indicated 4.1.

Each phase and step of the supporting business processes are discussed in detail within this chapter. The discussion will follow the logical structure of the presented framework and steps within each of the supporting business processes.

Distinctive features of the framework is the *Asset Management Framework* phase which focuses on getting the core requirements of ISO 55000 series of standards in place. This phase lays the foundation for articulating the OSP, AM objectives and AM strategies, via the SAMP and AMPs that feed into the ACPs and creates the Line-of-Sight between the strategic planning and work planning and control. Furthermore, the framework also considers continuous improvement of the organisational competency and factors that influence the performance of the maintenance system and asset performance. The framework creates a foundation for a holistic maintenance management framework, as discussed in section 2.2.4, and in addition offers a ACP management platform.

Key features of the framework related to the *Asset Management Framework* phase are:

- Converts the ISO 55001 requirements for the core strategy and planning elements into a business process.
- Identifies stakeholder requirements and AM objectives that are relevant to the SA RE sector.
- Adds the AM maturity assessments as part of the core strategy and planning requirements.
- Creates core inputs into the Asset Care Plan Development (ACPD) process.

Key features of the framework related to the *Asset Care Plan Development* phase are:

- Provides an improved RCM compliant process.
- Integrates creating the Line-of-Sight between the SAMP and the maintenance tasks.
- Does not require the definition of system boundaries and input output functions.
- Considers RCM analysis at component level.
- The Consequence of Failure, Cause Analysis and Task Selection (COFCATs) process identifies components as critical, potentially critical, commitment, and economic components and determines whether the occurrence of the failure is evident or not.
- The COFCATs process also includes the decision process for determining the consequence of failure based on the asset reliability criteria or AM objectives.
- The COFCATs process thus constitutes a simplified and self-contained, all-inclusive RCM logic analysis, that is much more straightforward and comprehensive than the FMEA .
- Considers the required competency and skills to complete the analysis.
- Develops the SJs to facilitate the work planning and control process.
- Requires that key maintenance procedures, operating procedures, risk assessments and other technical documentation be reviewed or created as these are often not shared by the OEM.
- Considers practical quantitative method (DTMM) to optimise PM frequency.
- Considers ALCA to determine economically feasible PM options.
- Considers ALCA to mitigate the consequences of obsolescence.
- Can be applied to multiple technologies or asset types.

Key features of the framework related to the *Work Planning and Control* phase:

- Has a centralised view on managing work planning and control.
- Uses pre-developed ACPs.
- Maintains the Line-of-Sight between tasks and SAMP.
- Creates core inputs into the ACPD process.
- Can be applied to multiple RE technologies.

Key features of the framework related to the *Competency Management and Continuous Improvement* phase:

- Creates the process for addressing the competency/skills from a staff and organisation perspective in light of the SA RE skills shortage.
- Creates continuous improvement loop with the ACPs and AMS.
- Uses focused improvement initiatives.
- Facilitates the Line-of-Sight.
- Considers organisational culture.

The framework also has the following overall features:

- Practical – It should be possible to apply the framework in practice.
- Holistic – The framework should provide an integrated, holistic approach to the problem that incorporates multiple disciplines.
- Structured – The steps in the framework should be logical and guide a structured decision-making process.
- Facilitates the Line-of-Sight.
- RCM compliant.

4.3 Reader Orientation

The section aims to guide the reader on the logic of the framework and the business process diagrams.

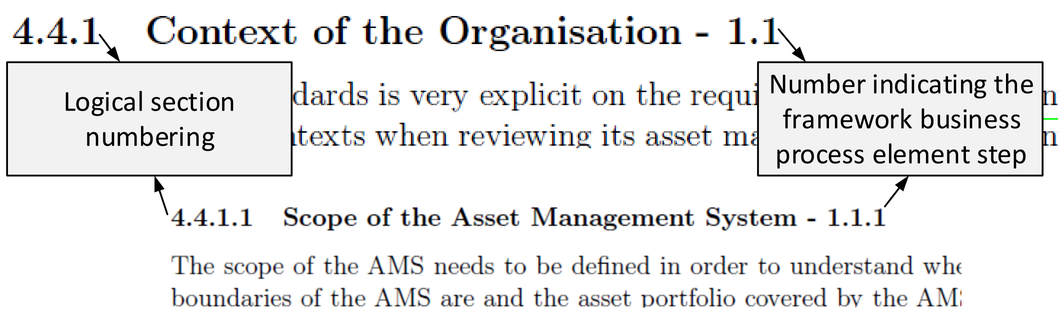


Figure 4.2: CMF numbering logic

In figure 4.2 the number on the far left is the **document section number** while the number on the far right is the **number indicating the framework business process element**, or the **number indicating the framework business process element step**. The numbers on the far right are used within the framework and all business process diagrams as reference and not the section numbering on the far left. In the example the section refers to step 1.1.1 (Scope of the Asset Management System) of the business process element 1.1 (Context of the organisation) of phase 1 (Asset Management Framework). The numbering pattern can also be seen in figure 4.3.

Figure 4.3 orientates that reader regarding the overall framework. The **phase** represents each of the four phases within the framework. Each of phases is represented by business process that contains **key process elements** and each process consists of a number of **steps in the process**. The arrows indicate that the user can **continue to the next phase/process/step**, with **feedback loops** indicating that there are interdependencies between all the phases of the process.

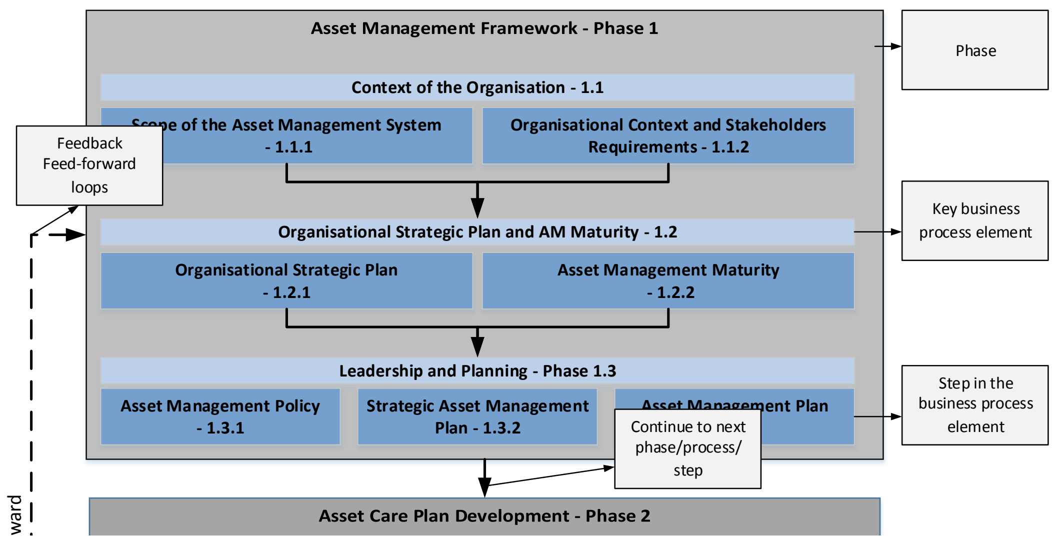


Figure 4.3: CMF guidance

The business processes navigation is also explained in figure 4.4. There is a clear indication of the **start of the phase and business process** as well as the start of the step in the business process. The **start of the next step in the business process** is also indicated. In the example in figure 4.4 phase 4, the *Competency Management and Continuous Improvement* phase is started. Furthermore, the **key process element Competency Management – 4.1** also starts here and immediately moves into step 4.1.1 which is *Organisational*

Culture – 4.1.1 that is then followed by the next step in the process, *Team competency- – 4.1.2*.

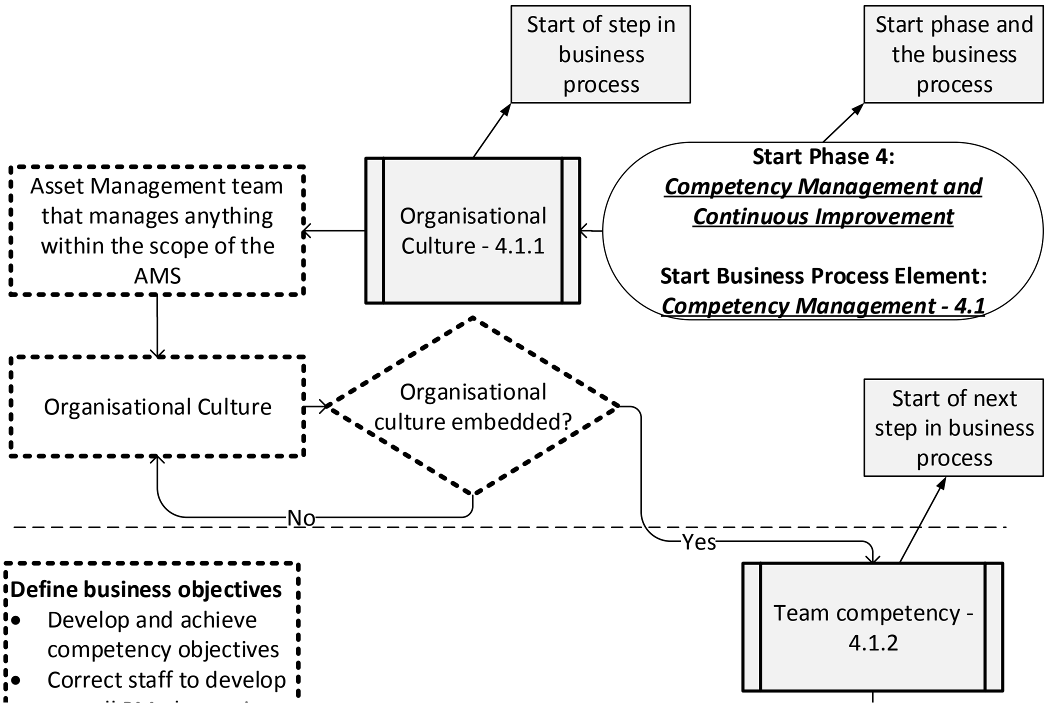


Figure 4.4: CMF process step guidance

The context of the proposed solution is one where a centralised headquarters is responsible for the overall strategic management of a distributed portfolio of multi-technology RE power plants, as seen in figure 4.5. The centralised nature is selected as the assumption is that organisational functions encapsulated in the four phases of the CMF can be optimised by leveraging shared resources, knowledge and systems.

The HQ has core teams which would consist of top and senior management, an engineering team as well as the Remote Monitoring Center (RMC). The RMC is a team which monitors and reports on plant performance and also performs maintenance planning and scheduling using the central CMMS. The HQ team has access to high-speed communication networks with all the modern communication mediums such as telephones, mobile phones, tablet computers, internet and video conferencing facilities. Strategic, policy making and core engineering functions are retained at HQ level.

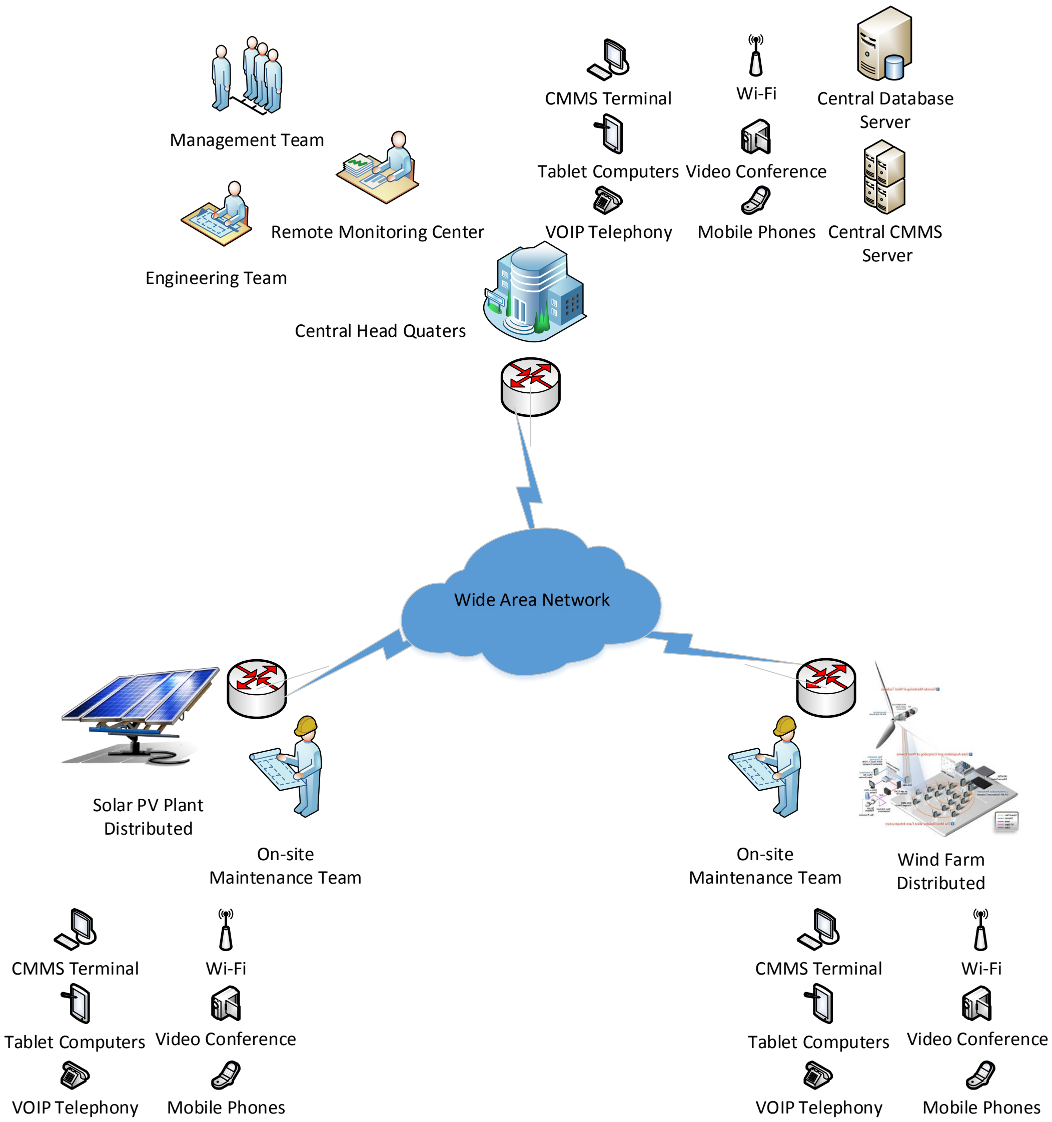


Figure 4.5: Central headquarters with distributed assets under management

The REPPs are distributed and connected to the HQ via high-speed communication links and also staff who have access to modern communication mediums such as telephones, mobile phones, tablet computers, internet, video conferencing facilities and the centralised CMMS. The OSMTs are responsible for performing the maintenance and interacting with HQ teams.

The framework and business processes have been drawn in Microsoft Visio 2013 using the standard flow chart symbols and rule set. The complete framework and business processes are divided into the respective steps for illustrative purposes within the text of this chapter. The complete diagrams can be found in appendix C. However, the text in these diagrams is too small to read and they are purely to illustrate what the process would look like should all the steps be joined in a single process diagram.

4.4 Asset Management Framework – Phase 1

The discussions in sections 2.1.3 and 2.1.4 and practical experience are synergised in phase 1 which notes that the GFMAM strategy and planning group highlights the core AM activities that need to be undertaken to develop, implement and improve AM within an organisation. The activities take into account the stakeholder requirements, organisational objectives and influence of the changing demand on the asset portfolio over time. Key elements to this groups are the SAMP that outlines how the organisational objectives will be converted into AM objectives and strategies, how the development of AMPs will be approached and what the scope and role of the AMS is in terms of supporting the organisation to achieve the AM objectives. AMPs provide clarity on how the organisation intends to achieve its objectives by deriving value from the assets by specifying the required resources, time scales related to LC activities such as acquisition, maintenance, operation and disposal.

This phase is also focused on the long-term strategic requirements of the asset and provides the direction and guidance to enable the creation of investment and maintenance plans. This guidance puts into place the resources that are required to manage the assets coherent with achieving desired outcomes.

Section 2.1.3.3 notes that the AMS needs to be considered in parallel with the assets to ensure that the AMS is capable of delivering the developed plans. Ensuring that the AMS is capable of performing the intended function could involve improving business processes and making decisions to use CBM. The initiatives will inevitably be linked to other strategic considerations related to information, human resources and training. The scope of the AMS needs to consider the entire portfolio of assets that are required to successfully deliver the OSP and should not exclude any business critical assets.

The *Asset Management Framework* phase consists of a few key elements that are:

- Context of the Organisation – 1.1
- Organisational Strategic Plan and Asset Management Maturity – 1.2
- Leadership and Planning – 1.3

These key elements and business process steps will be discussed in detail for the remainder of the phase 1 narrative.

4.4.1 Context of the Organisation – 1.1

The ISO 55000 standards are very explicit on the requirement to consider internal and external contexts when reviewing its AMS, as discussed in section 2.1.4.1. External context could include considerations such as financial, regulatory, economic, social and political while internal context could include considerations such as culture within an organisation, vision and mission, values, and social and political factors.

Stakeholder consideration also plays a significant role in determining organisational objectives and decision making. Stakeholders also have a interest in the reliable and optimal performance of assets while maintaining a balance between other factors such as costs and safety. These considerations are as described in sections 2.1.3 and 2.1.4.

The context of this study is placed within the RE industry in SA that is currently dominated by the utility scale REIPPPP projects. The complex ownership structures and stakeholder interest creates an environment where there might not be a common view on the management system of these RE assets. The context of the organisation, and the internal and external factors that influence decisions within the organisation are important aspects to be considered as part of a AM framework.

4.4.1.1 Scope of the Asset Management System – 1.1.1

The scope of the AMS needs to be defined in order to understand where the boundaries of the AMS are, as well as the asset portfolio covered by the AMS. The process of defining the scope of the AMS can be seen in figure 4.6.

The example in figure 4.6 assumes that a management organisation (owner or contracted) is responsible for managing a fleet of RE plants that consist of different technologies such as wind and solar PV technologies. The scope of the AMS could include the entire REPPs as an asset and all the underlying asset types found within the REPPs such as transformers, control systems, wind turbines and inverters.

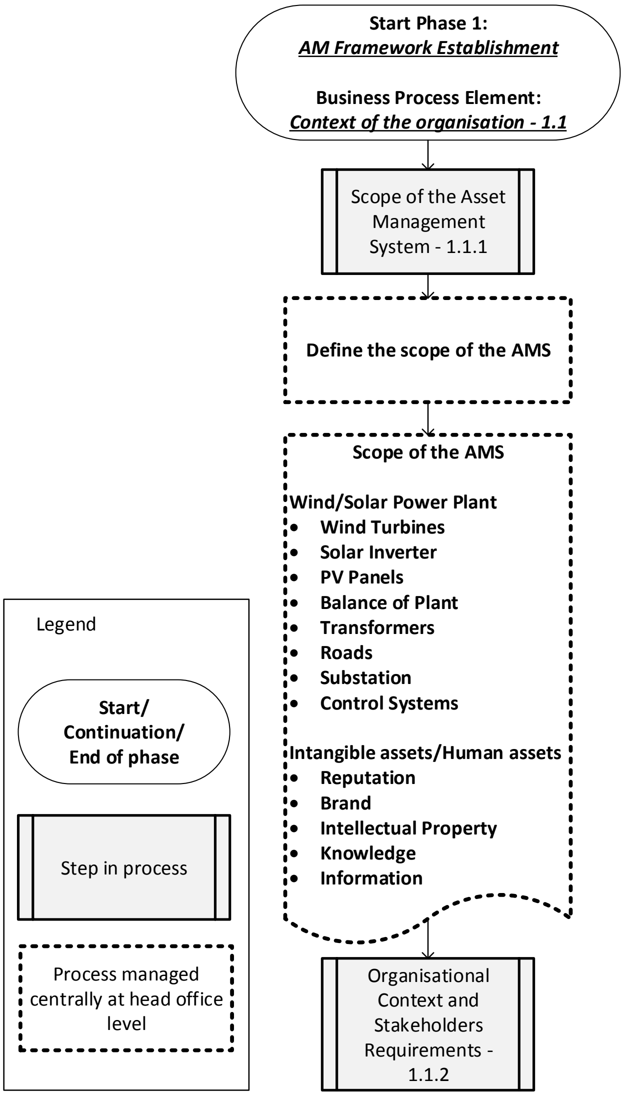


Figure 4.6: Scope of the asset management system – 1.1.1

Defining the scope of the AMS is important to align the AM policy and the SAMP with the internal and external stakeholder requirements (refer to sections 2.1.3 and 2.1.4).

4.4.1.2 Organisational Context and Stakeholders Requirements – 1.1.2

Once the scope of the AMS has been defined the needs, expectations and requirements of external and internal stakeholders with regard to AM have to be identified and documented. For example any expectations that the stakeholders may have regarding the recording and reporting of financial and non-financial information that relates to AM need to be considered. The process of achieving the described requirements can be seen in figure 4.7. Firstly the stakeholders that are relevant to the AMS need to be defined.

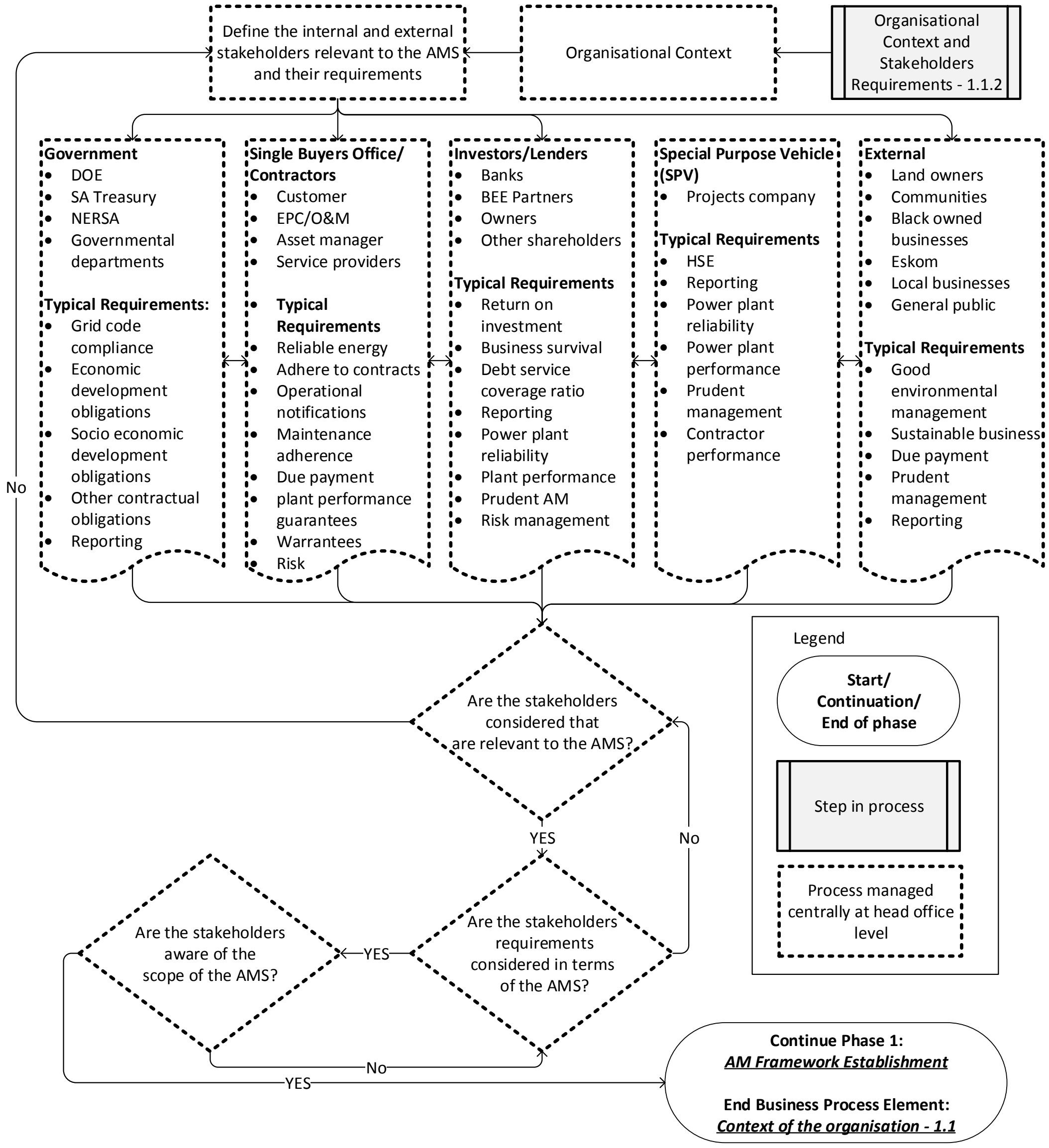


Figure 4.7: Organisational context and stakeholders requirements – 1.1.2

These stakeholders, in the SA context, can be numerous governmental departments, customers, lenders, investors, the public and the project company boards (Special Purpose Vehicle board). All of these stakeholders have numerous requirements of AMS depending the scope of the AMS as seen in figure 4.7.

In the SA context government has created a contractual environment where if an IPP does not adhere to the obligations such as grid code, economic development commitments, the IPP could face penalties or lose its operating licences.

The customer is essentially a single entity, Eskom, and referred to as the SBO and would expect reliable energy delivery and adherence to any other requirements of the Power Purchase Agreement (refer to section 2.3.1).

Investors and lenders expect REPPs to perform at their required level in order to generate profits and pay back debts.

Contractors and Asset Managers expect that the revenue generated can pay their fees while they balance their costs, risk and the REPPs in accordance with contractual obligations.

The REPPs are operated within a Special Purpose Vehicle (SPV) that can have key contractual agreements such as an O&M contract with a single party or multiple parties. Other key agreements can include SPV management that could include the overall management of the REPPs, including all financial and reporting requirements.

Other key external stakeholders can include land owners who have 20-year leases with an SPV, local businesses that are dependent on providing services and the public who are concerned with general environment and their immediate surroundings.

All these various and often conflicting requirements need to be considered and balanced in order to achieve a sustainable project.

The complexity and alignment of ownership and management structures as seen in section 2.3.1 create an environment where it is important to create a common base from which to manage these projects. Fundamental business values that drive the long-term sustainability and performance of REPPs need to be established during the process. The process of establishing all the stakeholder requirements can also create an environment where all the related parties can negotiate and rationalise any trade-offs between priorities.

4.4.2 Organisational Strategic Plan and AM Maturity – 1.2

The strategic level planning activities within a organisation should produce a documented OSP. The OSP should present a long-term plan that encapsulates the vision, mission, values, objectives, policies, stakeholder requirements and risk management of an organisation. Having a well-defined OSP provides the organisation with a clear understanding of their current situation and even more importantly where they are heading. Understanding where the organisation is in terms of AM capability and what the areas of improvement are can be achieved through a maturity assessment. The maturity assessment will help the organisation understand how well the AMS conforms to the requirements of the ISO 55001 standard. The results of the maturity assessments and the improvement roadmap can be an integral part of the OSP.

4.4.2.1 Organisational Strategic Plan – 1.2.1

The strategic level planning of an organisation should produce a documented OSP, that should be informed by the stakeholder requirements as identified in section 4.4.1. The process of establishing the basis of an OSP can be seen in figure 4.8. The process outlined in figure 4.8 is based on concepts covered in sections 2.1.3 and 2.1.4. The organisation needs to develop a OSP which is the long-term plan that encapsulates the vision, mission, values, objectives, strategies, policies, stakeholder requirements and risk management principles of an organisation.

These elements serve to promote internal and external communication and motivation and assert leadership and relate to the *Asset Management Leadership* AM subject as per appendix A section A.1.5.1. These statements are strategic and descriptive of the identity of an organisation, outlining why an organisation is in business and what it seeks to accomplish. Providing clear and understandable vision, mission and values helps members of an organisation to understand who they are, where they are heading, and how they will get there. The vision, mission and values also need to be clearly defined, with the mission directed to achieving the vision with the values playing a key role in how the organisation operates.

The vision, mission and values also provide direction for AM activities of the organisation which are driven by the objectives and context of the business. The organisation needs to clearly define and document its objectives and strategies which need to be SMART and cover all assets within the AMS and be well communicated. In the SA RE context organisational objectives can be to provide reliable power, ensure project profitability or have zero HSE incidents. Strategic initiatives could include developing an HSE system, pursuing ISO 55000 compliance, developing a competency management framework, and can consider KPIs such as power plant availability and performance ratio (solar PV). Departmental and individual responsibilities need to be aligned to the overall organisational objectives, strategies and a Key Performance Measurement (KPM) system in order to reflect stakeholders' requirements.

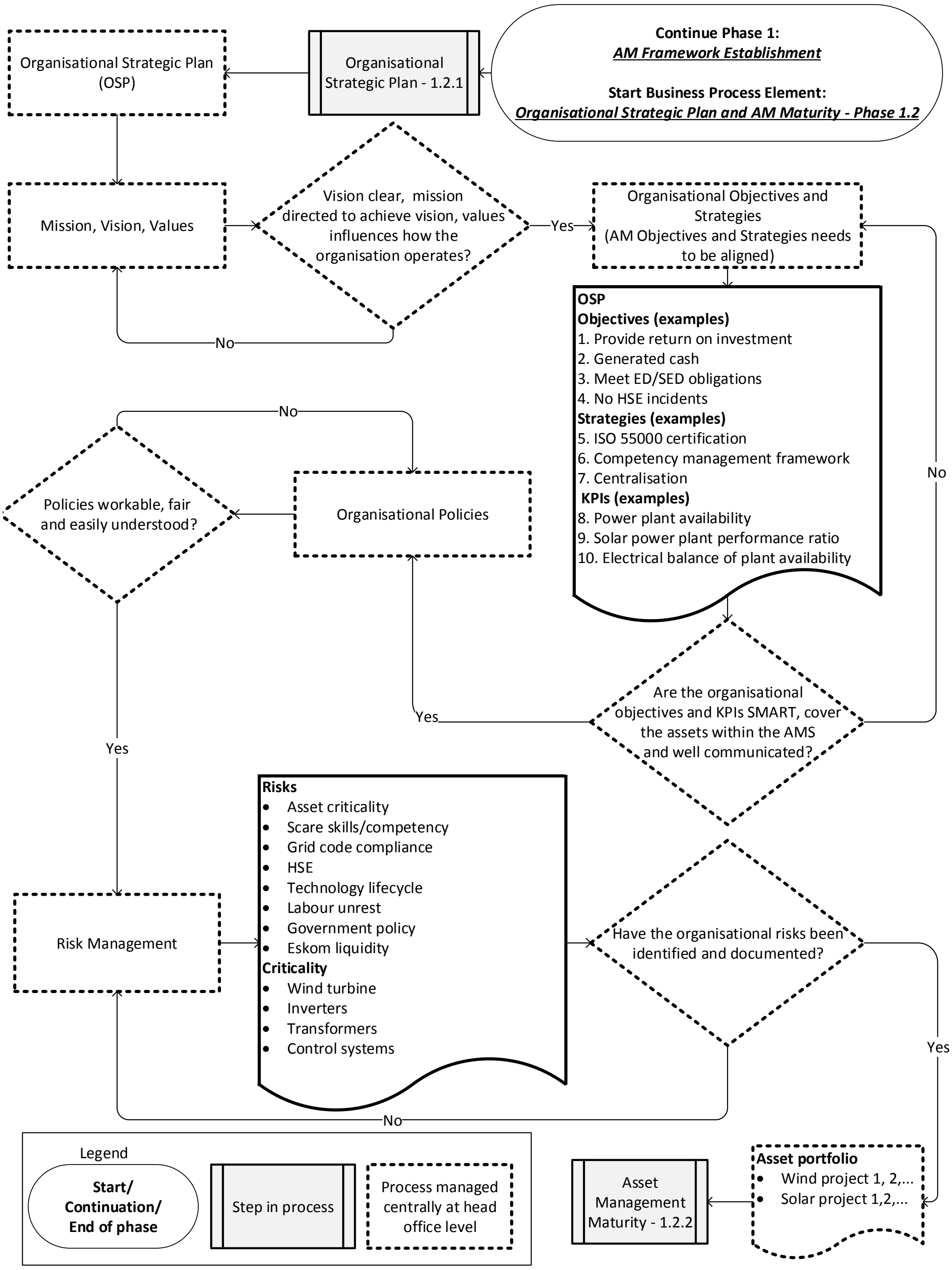


Figure 4.8: Organisational strategic plan – 1.2.1

Once the organisational objectives and strategies and KPIs have been established the organisational policies which support these organisational objectives and strategies and KPIs have to be developed and deployed within the organisation. The deployment of policies in conjunction with nurturing a shared vision and mission can help develop focus within an organisation and support reaching strategic goals. This process also helps to unify divergent stakeholder requirements and overarching business objectives, while the overall business objectives need to be defined in such a manner that they uphold the values and stakeholders' requirements. Furthermore, the process can sometimes result in conflicting objectives and this variability needs to be managed by translating organisational objectives into very concise and effectively communicated functions. The AM policy will form part of the organisational policies and needs to carry the same importance as all other organisational policies (refer to section 2.1.3.5). The organisation should also ensure that policies are workable, fair, communicated and understood by all relevant stakeholders.

The discussion in section 2.1.4.6 highlights that risk management plays a key role within the AMS which it addresses through the Risk Assessment and Management AM subject in appendix A section A.1.6.1. The underlying risks faced by modern businesses are no longer merely financial and regulatory but complex and inclusive of dimensions such as the environment and social aspects. The current operating environment introduces some key challenges within the process of developing and establishing governance frameworks and management principles due to these new risk factors which are important, especially within a complex operating environment like the SA RE sector. Effective control and governance of assets by organisations is essential to realise value through managing risk and opportunity, in order to achieve the desired balance of cost, risk and performance. Organisations also need to document the manner in which they manage risk as part of the requirements of the ISO 55000 series and can consist of risk registers or other mechanisms for the management of risk. Risk assessment and management assist the organisation to deliver on the OSP and extract as much value from the assets as possible. Risk management should provide the organisation with a consistent methodology for assessing and managing uncertainty so as to optimise AM decision making. The organisation needs to understand how risk related to assets and AM can be combined within a corporate governance framework. Establishing a view on asset criticality informs the AM strategy and decision-making processes followed by the organisation. Critically assignment of an asset requires the organisation to assess the potential impact failure would have and is influenced by the vision, mission, values as well as other business policies, key stakeholder requirements, goals and risk management criteria. A criticality ranking of assets can be performed using a probability and consequence ranking as seen in appendix F.

The organisation needs to document risk information in a usable format that will enable easy analysis. Potential risks within the SA RE context could include the ability of Eskom to pay for electricity, grid code compliance, skills shortages, technology and lack of information sharing, with asset criticality ranging from wind turbines and specific wind turbine systems or solar PV systems to transformers. The ISO 31000, Risk Management Principles and Guidance, provides guidance on good practice approaches to Risk Assessment and Management. Furthermore, the portfolio of assets that are relevant to the vision, mission, values as well as other business policies, key stakeholder requirements, goals and risk should be clearly defined.

4.4.2.2 Asset Management Maturity – 1.2.2

AM maturity and the process of understanding the organisational AM maturity is outlined in figure 4.9 and is discussed in detail in section 2.1.3.8.

A capability maturity model can be defined as a way of assessing the various stages of business process development within an organisation and a framework that can be used to improve processes using a pre-defined set of levels.

This step requires that a maturity framework assessment should be used to understand the existing capability, strengths and weaknesses while determining gaps for improvement as discussed in section 2.1.3.8. The maturity framework should be a collection of the best practices that can guide organisations to improve their effectiveness, efficiency and quality. The maturity framework should be a set of structured levels that describe how effectively various processes within an organisation can sustainably achieve desired outcomes (refer to section 2.1.3.8).

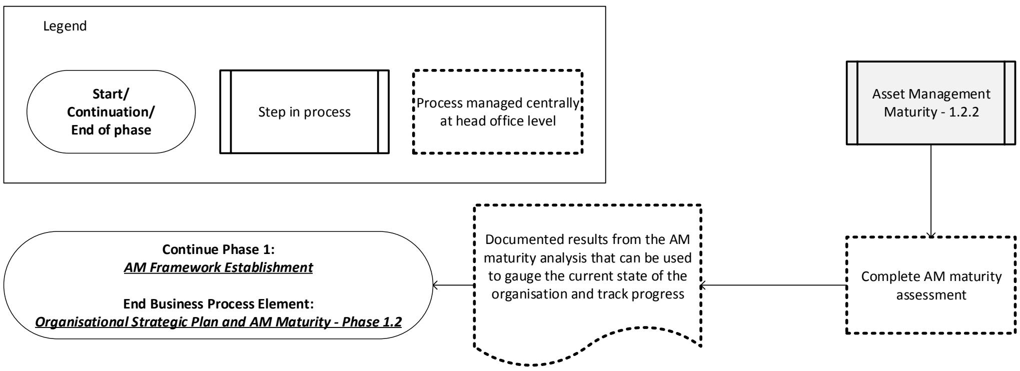


Figure 4.9: Asset management maturity – 1.2.2

AM maturity assessments can support the improvement of AM capabilities that use maturity guidelines as a means of driving improvement within its AM capability. The intelligence gained during the maturity assessment should guide target trajectories, improvement programmes for AM capabilities and monitor the progress over time.

The AM maturity guide developed by the IAM (2015*b*) could be used as a guide to the subject of AM maturity and the manner in which it can be defined, scaled and recognised against the ISO 55001 standard. This could provide a consistent way of measuring capability and maturity by which organisations can identify their areas of strengths and weaknesses.

Using the AM maturity scale can also be useful to diagnose and prioritise the development of new capabilities, benchmarking, demonstrating progress or competency and fostering continuous improvement.

The IAM (2015*b*, 4) maturity 6 level scale and guidance for AM considers both the maturity of the AMS (how it conforms to the requirements of ISO 55001) and the maturity of the AM practices (covering the 39 subjects).

The organisation should also understand that displaying AM maturity transcends simply conforming with the ISO 55001, and in certain cases organisations would choose to develop AM capability beyond that required by the ISO 55001 to achieve their organisational objectives. AM as a discipline is evolving continuously and is influenced by innovation, learning and new technology. The ever-changing trends continuously challenge what is regarded as best practice.

Organisations can choose to asses the conformance of their AMS against the ISO 55001 standard. The conformance or AM maturity assessments should be undertaken by external third-party assessors. Using accredited assessors will deliver the most value to the certification process (IAM, 2015*a*, 35).

Developing capability maturity models for the SA RE industry will be important to understand the existing capability, strengths and weaknesses while determining gaps for improvement within the realm of AM related to managing REPPs.

4.4.3 Leadership and Planning – 1.3

Within the specific step of the CMF, considerations around leadership and planning are addressed, and focus is specifically on the AM policy, SAMP and the AMP as guidance tools that inherently concern leadership within the organisation. The discussion in sections 2.1.3 and 2.1.4.1 support the following key processes within the CMF.

The everyday responsibility of managing and overseeing the AMS can be delegated to anyone in the organisation who is competent and qualified within the field of AM. However, it is critical that ownership and accountability of AM remains with top management.

Top management should continue to show their commitment to AM through continuously communicating AM principles, aligning the AMS with other management systems within the organisation, prioritising and allocating resources to realise AM objectives and strategies.

Top management needs to establish the main goals, key success factors and the strategic document set that lay the foundation for AM. Undertaking these tasks is key to the alignment of the organisational objectives and the day-to-day decision making and priorities.

Team leaders could be required to sign a performance contract that sets out personal goals and focused improvement. Top management should also focus on the more systematic work while constantly striving to find smarter solutions. Leaders should rely on their seniority, but always continue to motive and educate themselves.

Developing and establishing the AM policy is one of the fundamental steps of developing an AMS and practising good AM. The AM policy should clearly define how the organisation will apply the discipline of AM in pursuit of organisational objectives. The AM policy should create the expectations and guidelines for decision making, activities, and behaviours related to AM that should be followed by all employees. Implied within the AM policy should be the AM objectives and strategies that the AMS will be responsible for achieving.

AM objectives and AM strategies within the SAMP link the OSP to the AMPs that describe how objectives will be achieved. There are multiple ways of achieving goals stated within the OSP but there should always be a balance between cost, benefit and risk. AM objectives can be of qualitative and quantitative nature and should be SMART. The strategic planning process and the SAMP further aligns AM objectives, AM strategies and the OSP.

4.4.3.1 Asset Management Policy – 1.3.1

The process outlined in figure 4.10 considers the development of the AM policy which is discussed in detail in section 2.1.3.5 and the AM subject in appendix A section A.1.1.1.

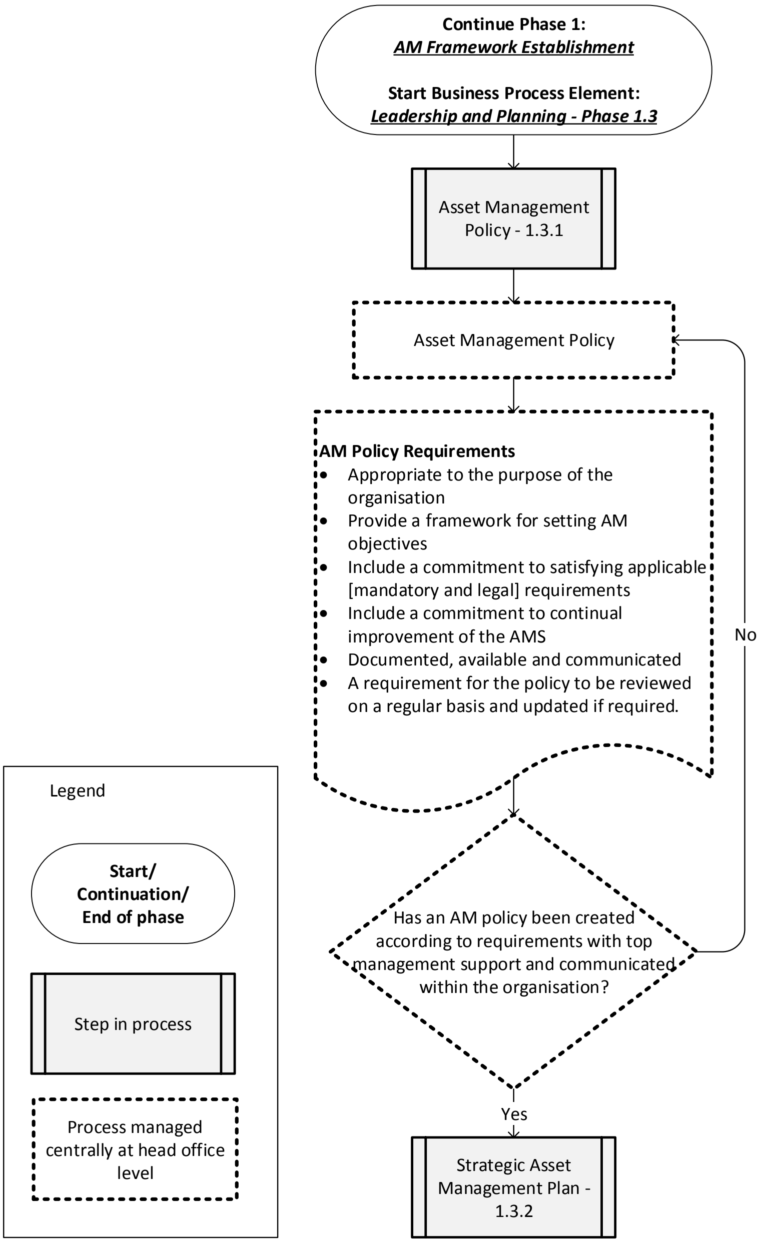


Figure 4.10: Asset management policy – 1.3.1

Having alignment between the OSP and the greater AMS is non-negotiable and links the actions on the ground by employees to the details in the OSP. There is thus an important link between the OSP and the AM policy. The AM policy also needs to be supported by top management and create a clear AM decision-making framework to achieve the required alignment between the OSP and AM activities.

The AM policy needs to have the following requirements:

- be appropriate to the purpose of the organisation;
- provide a framework for setting AM objectives;
- include a commitment to satisfying applicable (mandatory and legal) requirements;
- include a commitment to continual improvement of the AMS;
- be documented, available and communicated;
- commit to providing resources to achieve AM objectives;
- commit to measure and report on the performance of its AM activities and performance; and
- commit to long-term sustainability of AM.

The AM policy also needs to be reviewed on a regular basis and updated if required. The AM policy should be a high-level document with the detail of AM activities contained within the SAMP, AMP and other related policies, procedures and plans. The AM policy needs to be developed with support from top management and effectively communicated to the rest of the organisation with clarity that the AM policy is the core of AM decision making. The AM policy can be communicated during inductions, team briefings or at the start of meetings. All members of the organisation need to be fully aware of the implications the AM policy has for the decisions they make regarding the assets portfolio that they are engaged with (refer to section 2.1.3.5).

4.4.3.2 Strategic Asset Management Plan – 1.3.2

Once the OSP and the AM policy have been documented the SAMP, which is discussed in detail in section 2.1.3.6 and appendix A section A.1.1.2, needs to be developed. The SAMP should be driven by the greater AM planning process and capture the AM objectives and link them to the lower-level plans. Furthermore, the SAMP needs to be part of an iterative planning process that will produce AM objectives, linked to organisational objectives that are informed by demand and stakeholder requirements while remaining consistent with the asset portfolio, the AMS capability, condition and performance. The SAMP should outline the AM objectives and strategies that need to be addressed though the AM activities undertaken by the organisation. Figure 4.11 outlines the key requirements in the process of developing a SAMP.

The purpose of a SAMP is to document and define the objectives and strategies the organisation needs to achieve as a result of its AM activities and outline the time frame within which these objectives should be reached while remaining aligned with OSP and AM policy and how the AMS should support this process.

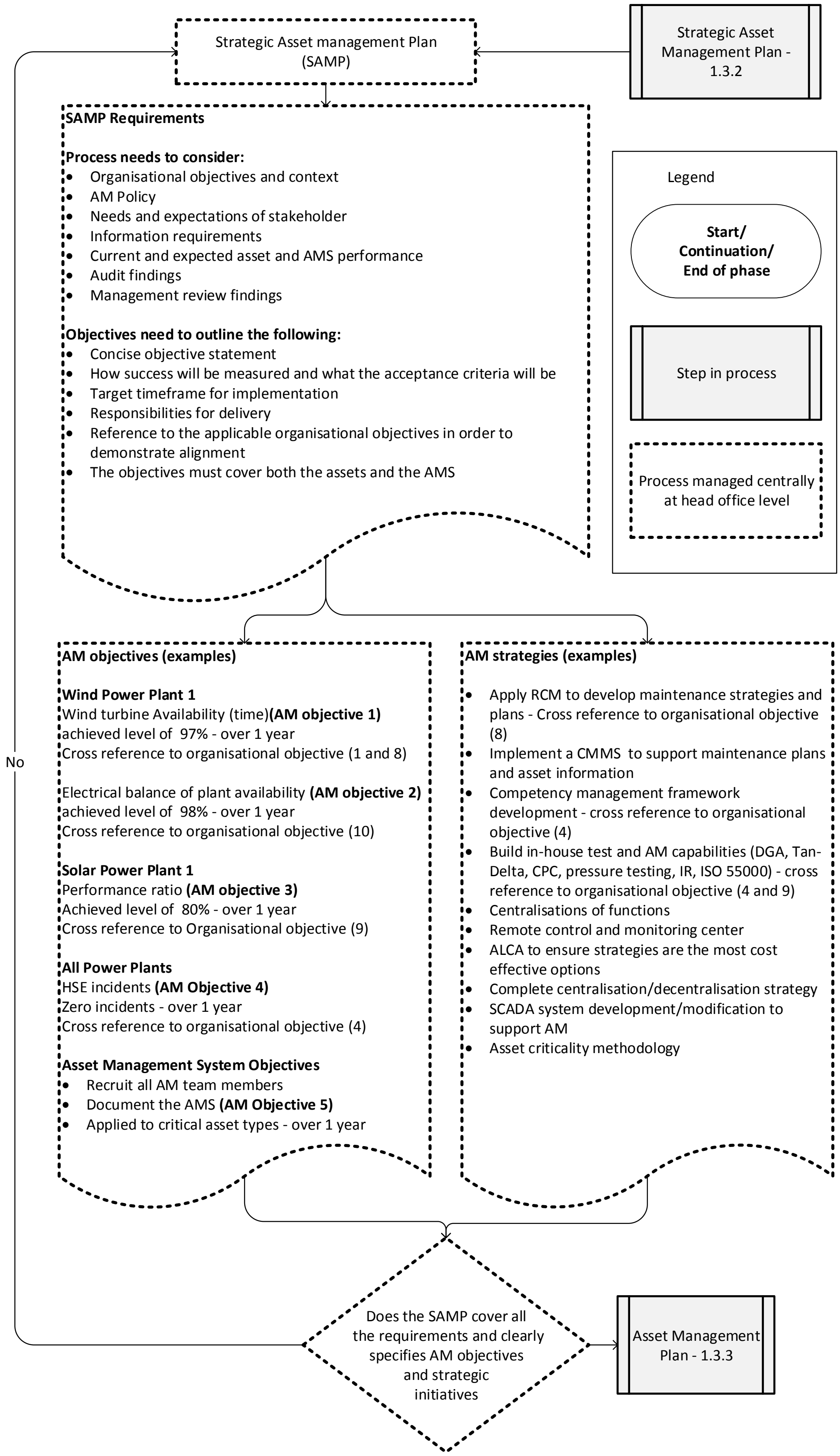


Figure 4.11: Strategic asset management plan – 1.3.2

Further guidance is provided by ISO 55002 on the implementation of ISO 55001 and comments on the contents and structure of the SAMP as per section 2.1.3.6 noting that it should:

- consider organisational objectives, context, needs and expectations of stakeholders;
- be scaled to match the size and complexity of the organisation;
- consider the AM policy and document the manner in which the AM policy principles are applied;
- document the framework for achieving AM objectives and the AM objectives' relationship to the organisational objectives (mapping);
- define the scope of the AMS;
- outline methods, criteria and processes for prioritising, decision making and ALC management;
- consider information requirements;
- consider current and expected asset and AMS performance;
- consider audit findings;
- consider management review findings; and
- define planning and review horizons, schedules and methods.

Furthermore, the AM objectives and strategies need to:

- have concise objective statements;
- be clear on how success will be measured and what the acceptance criteria will be;
- have target time-frames for implementation;
- indicate responsibilities for delivery;
- reference the applicable organisational objectives in order to demonstrate alignment; and
- have objectives which cover both the assets and the AMS.

Very importantly, the last point in the list above states that the SAMP should also consider the objectives and strategies for the AMS and not only the assets.

Asset-intensive organisations often have a challenging time maintaining the alignment between AM strategies and the AM policy. Assistance in maintaining the alignment can be achieved by having AM objectives and strategies that are SMART.

Considering figure 4.11, an example of an AM objective within the SA RE industry could be to obtain wind turbine availability of 97%, measured over a 12-month period. This AM objective could be linked to a single organisational objective or to many. In the example in figure 4.11 the wind turbine availability would become AM objective 1 and could be linked to organisational objectives 1 and 8, such as return on investment targets and overall power plant availability.

The Line-of-Sight is initiated by the AM policy, AM objectives and AM strategies. The AM objectives need to be supported by AM strategies that will deliver the AM objectives. These AM strategies need to be sufficiently resourced and delivered with clear time lines and responsibilities. Using the AM objective example of obtaining 97% wind turbine availability, the associated AM strategies could be to implement a RCM-based maintenance plan supported by a CMMS to manage the maintenance plans and assist with reporting the relevant KPIs. There should also be a clear link (mapping) between the AM strategy and the organisational objectives. In the example in figure 4.11 the AM strategy is related to RCM and is mapped back to organisational objective 8 which is overall power plant availability.

The lower-level planning takes direction from the specified AM objectives and strategies defined in the SAMP. Section 2.1.3.6 discussed the SAMP and states that the SAMP should deliver the right information to the right people at the right time. The SAMP is a high-level plan and should be at the core of developing detailed AMPs that will dictate the activities carried out at asset level and should also be SMART.

Any technical standards and legislation should be considered for decision making as noted in section A.1.3.1. For example, in the SA wind industry turbine lifts might need to be inspected once a year as a legal requirement. Asset information has been identified as a key challenge within the SA RE industry and information is not always shared by the OEMs (refer to section 2.3.3). Establishing a Asset Information Strategy objectives which are SMART will be critical and addresses the *Asset Information Strategy* AM subject in appendix A section A.1.4.1. Furthermore, this process considers core AM activities as per the *Strategic Planning* AM subject in appendix A section A.1.1.4.

4.4.3.3 Asset Management Plan – 1.3.3

The AMP, which is discussed in detail in section 2.1.3.7 and appendix A section A.1.1.5, is the focal point of this step. AM decision making can be assisted by a framework derived from having a consistent and clear AM policy, AM strategies and objectives. The AM policy provides the foundation on which the SAMP and AMPs can be developed and enforced with section 4.4.3.2 clearly stating that the SAMP is a high-level plan and should be at the core of developing detailed AMPs.

AMPs, generally derived from the SAMP, need to be documented and maintained and should clearly define what an organisation intends to do with its

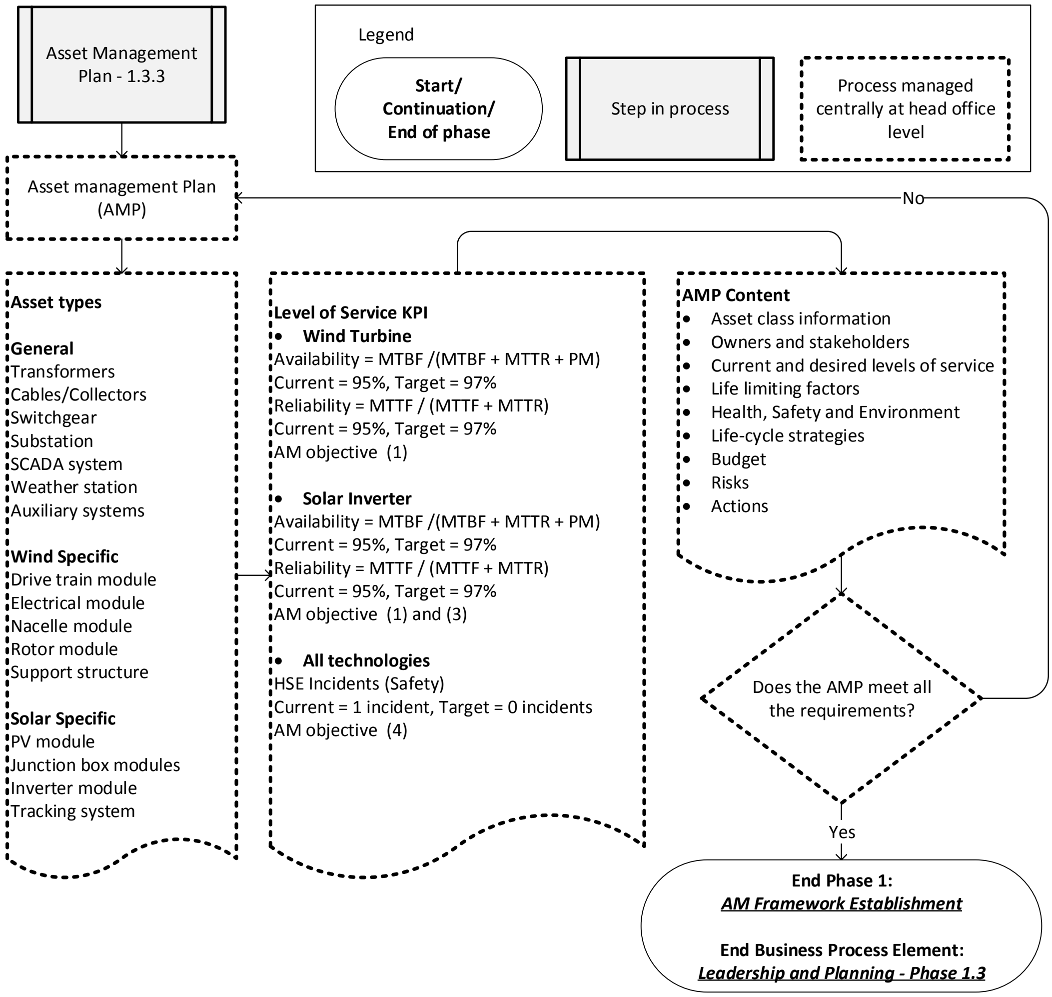


Figure 4.12: Asset management plan – 1.3.3

asset portfolio in order to reach the organisational objectives. Furthermore, AMPs should clearly define the required resources (human, financial, physical, natural and knowledge resources), time-scales (describing when objectives will be delivered and when the benefits will be achieved) and LC activities such as acquisition, maintenance, operation and disposal required to reach organisational objectives. It is important that the AMPs remain aligned with the AM policy and the SAMP (refer to section 2.1.3.7).

In reference to earlier paragraphs, an AMP defines the activities, required resources and time-scales related to an asset or grouping of assets (portfolio). Considering figure 4.12 possible asset types within the RE context could be inverters, wind turbines, PV panels, transformers or control systems.

The assignment of objectives to specific assets types or asset classes is called the required “level of service” of these specified assets or asset groupings. Considering figure 4.12, an example in the RE industry can be that of a wind turbine asset class or type. The "level of service" of a wind turbine can be the time-based turbine availability and reliability that has existing performance figures and corresponding targets. The intent of the AMP is really to write down the AM activities that need to be done to achieve or deliver the AM objectives and maintain or improve the "level of service".

The existing asset class performance or "level of service" can be used as a gap analysis to identify improvement initiatives that need to be acted upon. Improvement projects can span multiple asset classes. During the start of a planning phase of improvement projects resource availability is weighed against the requirements and balanced under each planning iteration. The planning process outputs are tracked and delivered under other frameworks such as budgets, project and risk management.

The planning process illuminates what needs to be completed (requirements) in order to deliver the organisational objectives. The AMP needs to communicate these requirements, developed by the Asset Managers, to internal employees (responsible for completing tasks), management (responsible for providing the resources), fellow Asset Managers (who need to understand the asset class performance expectations) and other specialists (such as human resources and finance who need to understand what their roles are).

Section 2.1.3.7 mentions that AMPs should be short, visual (tables, graphs) and use references to other documents, data sources and plans. A recommended format for an AMP should include the following:

- **Asset class information** – the scope of the AMP should be made clear with an indication of the criticality of the assets and what interdependencies exist with other assets.
- **Owners and stakeholders** – a clear indication of the roles and responsibilities that pertain to the specific asset grouping that is relevant to the AMP.
- **Current and desired levels of service** – a clear mapping of the AM objectives that are addressed by the specific plan and should include level of services statements that are supported by performance measures and targets (historical performance can be used as a benchmark).
- **Life limiting factors** – a detailed account of all factors that could affect the lifespan of the asset such as fatigue, cost or obsolescence.
- **Health, safety and environment** – an outline of any potential HSE concerns that could have an effect on managing the assets.
- **Life-cycle strategies** – an explanation of how each LC phase of an asset will be approached as well as the identification of an known issues. Detailed information such as the maintenance program, statement of operating intent or similar information could be included.

- **Budget** – the detailed budget can be summarised to indicate the resources allocated to the AM activities and could be split into categories such as sustaining capital or discretionary capital.
- **Risks** – a summary of the key AM risks that are relevant to the specific assets or asset grouping.
- **Actions** – a detailed list indicating the resources and priorities that will be used to address identified gaps. This should also include a list of acquisitions and disposal, the use of techniques such as RCM to reduce maintenance costs or to improve reliability and the modification of assets for improvement in performance and maintainability.

An AMP conveys the story of the asset and should not be a lengthy document. The AMP is not intended for the technical experts as they should already understand what the requirements are. It is recommended that the AMP should be around eight pages long (refer to section 2.1.3.7) per asset class. Depending on the organisational structure and nature AMPs can be per asset grouping or cover the asset portfolio. Irrespective of the structure the AMP must be effective within the organisation to achieve the AM objectives.

4.4.4 Related AM Subjects and ISO Clauses

The following clauses of the ISO 55000 series of standards and the GFMAM AM subjects have been identified as being applicable to phase 1 of the CMF through the review and content analysis of the literature in sections 2.1.3 and 2.1.4 with a detailed description of all the relevant AM subjects in appendix A.

Relevant ISO clause/s:

- Clause 4.1 ISO 55001 – Understanding the organisation and its context (International Standards Organisation, 2014*b*, 1)
- Clause 4.2 ISO 55001 – Understanding the needs and expectations of stakeholders (International Standards Organisation, 2014*b*, 1)
- Clause 4.3 ISO 55001 – Determining the scope of the asset management system (International Standards Organisation, 2014*b*, 2)
- Clause 4.4 ISO 55001 – Asset management system (International Standards Organisation, 2014*b*, 2)
- Clause 5.1 ISO 55001 – Leadership and commitment (International Standards Organisation, 2014*b*, 2)
- Clause 5.2 ISO 55001 – Policy (International Standards Organisation, 2014*b*, 3)
- Clause 6.1 ISO 55001 – Actions to address risks and opportunities for the asset management system (International Standards Organisation, 2014*b*, 3)

- Clause 6.2 ISO 55001 – Asset management objectives and planning to achieve them (International Standards Organisation, 2014*b*, 4)
- Clause 6.2.1 ISO 55001 – Asset management objectives (International Standards Organisation, 2014*b*, 4)
- Clause 6.2.2 ISO 55001 – Planning to achieve asset management objectives (International Standards Organisation, 2014*b*, 4)
- Clause 7.5 ISO 55001 – Information Requirements (International Standards Organisation, 2014*b*, 6)

Relevant GFMAM AM subject/s:

- Asset Management Policy (GFMAM, 2014, 13)
- Asset Management Strategy (GFMAM, 2014, 14)
- Strategic Planning (GFMAM, 2014, 16)
- Asset Management Planning (GFMAM, 2014, 17)
- Technical Standards Legislation Decision Making (GFMAM, 2014, 23)
- Asset Information Strategy (GFMAM, 2014, 34)
- Asset Management Leadership citep[38]GFMAM2014
- Risk Assessment and Management (GFMAM, 2014, 43)

4.4.5 Summary – Phase 1

The purpose of this phase is to understand the fundamental elements required by the ISO 55000 series in terms of strategy and planning required to create a leadership platform and create the Line-of-Sight from the stakeholder requirements through to the activities performed by the staff on the ground. The process also establishes the organisational objectives and the AM objectives that can be linked to the maintenance activities developed within ACPs discussed in the following section. Furthermore, the AM framework established also guides the overarching alignment to the ISO 55000 AM framework.

Phase 1 also addresses some key issues identified within the literature review. The SA REIPPPP projects often have complex ownership and management structures. Projects can have different shareholders at different times of the project LC and each may have different goals. Furthermore, the ownership and management structures often range between a combination of foreign and local ownership with long-term service and management contracts. The different objectives of these various role players can evolve, align and deviate over the life-time of a project. Other challenges related to competency or skills and maintenance philosophies, policies and practices also need to be addressed. Developing a clear OSP, AM policy, SAMP and AMPs while considering the relevant stakeholders can provide a coherent understanding of the AM activities required to exercise prudent AM. The alignment between various owners, management, contractors and other stakeholders throughout the project LC can be maintained by having a clear AM framework in place.

4.5 Asset Care Plan Development – Phase 2

The development of ACPs is introduced in phase 2 of the CMF. Asset Care and ACPs are discussed in section 2.2.2.7. The core elements of an ACP such as maintenance plans, maintenance approaches, planning and scheduling, WOs, and optimisation are discussed in detail in section 2.2.

Section 2.2 also states that an ACP is a term used to describe the combination of tactical and non-tactical maintenance activities that has been structured as part of a maintenance strategy. RCM and TPM are well known qualitative maintenance management philosophies. In order to schedule and specify maintenance activities, but also to analyse historical failure data on equipment, statistical maintenance interval metrics are defined and used. The ACPD process is aligned to the *Operations and Maintenance Decision Making* and *Reliability Engineering* AM subject as per appendix A sections A.1.2.2 and A.1.3.6.

Asset Care does not only speak to maintenance but all stakeholders that have an interest in the reliable and optimal performance of plant and equipment while trying to find a balance between safety, availability, performance and cost within the bounds of long term needs and short term constraints. An ACP enables an organisation to maintain equipment and optimise costs, safety and performance.

Value to shareholders can be created by applying principles that enable the reduction in the cost of capital; the reduction of tax; investment with the goal of achieving growth; asset performance improvement; and influencing the judgement of the stock market. Asset Care can improve asset performance and provides a strategic advantage due to assets delivering enhanced reliability, extended life spans, reduced investment and running costs, thereby improving financial performance and raising reputation. An ACP can optimise the operating cost of assets while verifying that assets are reliably operating close to their design parameters throughout their LC (refer to section 2.2.2.7).

Section 2.3.4 also specifically notes that most OEM based long-term (five- to 20-year) all-in-service contracts include component warranty with CM (failure-based) and PM (time-based) strategies. Section 2.3.3 also highlights the monopoly on spare parts by OEMs and the focus on reducing their operating costs instead of optimising performance, which is evident within the dominance of time-based availability warranties as opposed to an energy-based performance warranties. These inadequate maintenance strategies are adopted until the service contract and warranty of the wind turbines expire, but in many cases these strategies are inadequate to meet the needs to a performance-driven Asset Owner. Section 2.3.3 also notes that the interest of OEMs and Asset

Owners are not aligned, with OEMs not always sharing information and data, which also links to the complex ownership and management theme covered in section 2.3.1. These challenges can be addressed though the alignment of the *Asset Management Framework* which is phase 1 of the CMF (4.4) and the proposed *Asset Care Plan Development* process which is phase 2 of the CMF and outlined in this section.

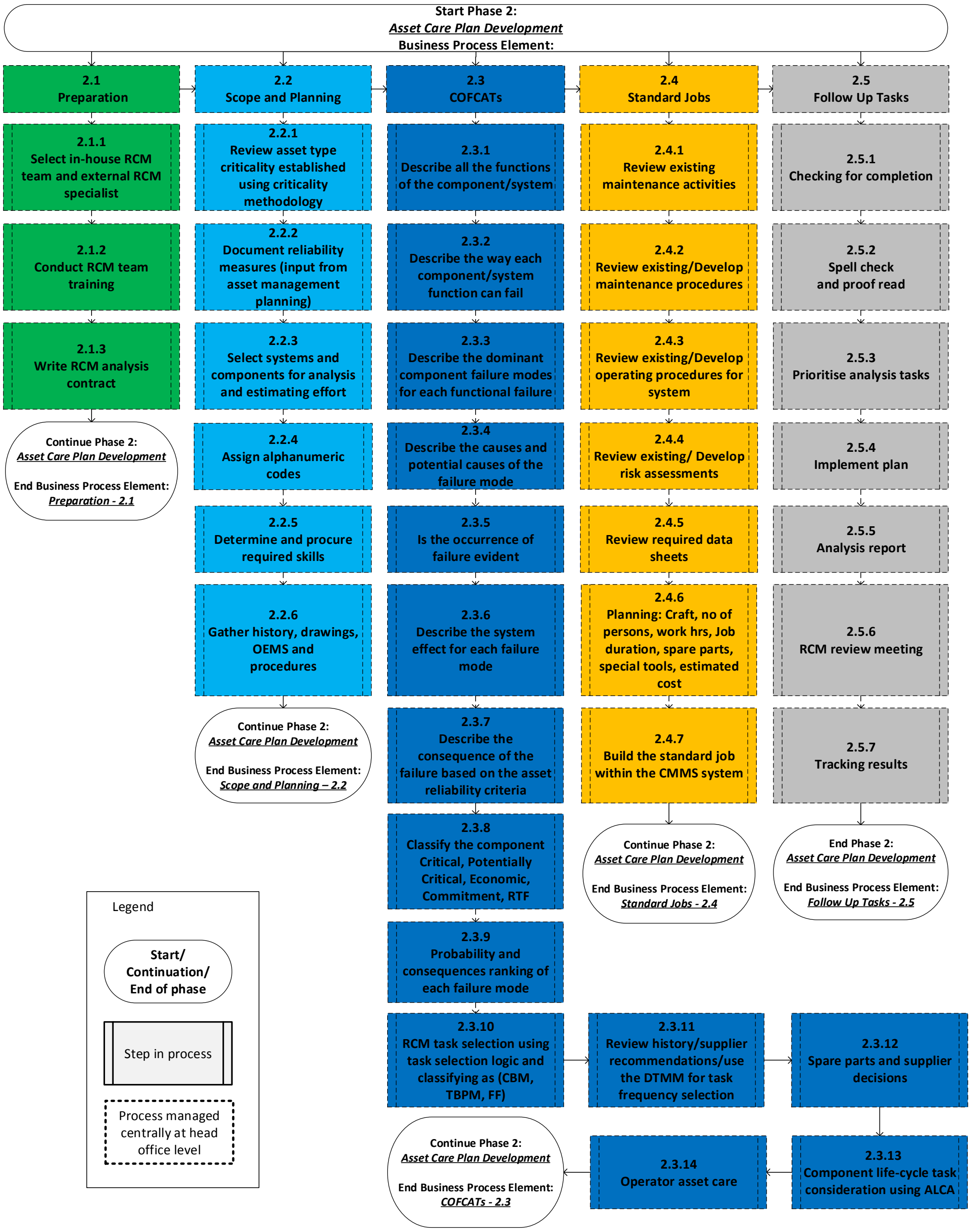


Figure 4.13: Asset care plan development process (including COFCATs) – 2.3

The proposed process, seen in figure 4.13, extends traditional RCM processes discussed in section 2.2.2.1 by addressing considerations for scarce skills and competency, lack of information, SJ development, operator Asset Care, Line-of-Sight between the OSP and maintenance tasks, spare parts, part LC and improved central management. The colours in figure 4.13 are a means of associating the diagram with the COFCATs sheet presented in appendix B. The process is more sophisticated than conventional maintenance philosophies reportedly being used in the RE industry. The ACPD process proposed during this phase is an adaptation and improvement of RCM processes described by Plucknette (2009) and Bloom (2005) and covered in section 2.2.2.1, and will deliver a maintenance plan with a documented and consolidated view on CBM, PM, fault finding tasks, DOM and RTF decisions.

The COFCATs worksheet will be referenced throughout the description of phase 2. The COFCATs worksheet can be found in appendix B figure B.1 to B.6. The COFCATs worksheet example is also populated with an analysis of the insulation oil (the analysis component) of the main transformer on a RE power plant.

The *Asset Care Plan Development* phase consists of a few key elements that are:

- Preparation – 2.1
- Scope and Planning – 2.2
- COFCATs – 2.3
- Standard Jobs – 2.4
- Follow Up Tasks – 2.5

These key elements and business process steps will be discussed in detail for the remainder of the phase 2 narrative. All of the following sections will also refer to figure 4.13.

4.5.1 Preparation – 2.1

Preparing for the RCM analysis is an important part of delivering a robust analysis and results. Part of this preparation is to ensure that the correct team composition, competency and motivation are considered and mobilised to perform and complete the analysis.

4.5.1.1 Select in-house RCM team and external RCM specialist – 2.1.1

A cross-functional expert team needs to be assembled to obtain the best results from the RCM analysis process. The team, consisting of five to eight people, should typically be represented by members of the functional business area who are experts within these functional areas (refer to section 2.2.2.1). Based on some typical roles found in the SA RE industry, as seen in appendix D, contributions could be made by the following roles:

- **Plant Manager** (solar PV and wind) – to provide insight into key technical and commercial issues that affects long term reliability and asset reliability criteria linked to the OSP.
- **Plant engineer, mechanical technicians, electrical technicians** (solar PV and wind) – valuable insight into failure modes experienced, their effects and symptoms over the operational history.
- **Wind turbine engineer, solar technology engineers or performance engineer** – to assist in understanding what tools could be used to detect potential failures, and what failure modes have useful P-F curves and support the analysis process of more complex equipment like solar inverters and wind turbines.
- **Operators and scheduling engineer** – to provide information on typical failures experienced, how they can be detected, their effects and symptoms over the operational history.
- **Process Engineer** – to provide support on the overall function of the asset being Analysed and provide information on what the business impact or consequences is in the event that the asset does not perform.
- **RCM Single Point of Contact** – to ensure that all the relevant role players are present when required and that everyone has the required knowledge of the RCM process.
- **RCM facilitators** (highly trained specialists) – to guide the process and ensure that the RCM process is understood, followed and the analysis is correctly documented. Facilitate the group reaching consensus on contentious items and keep the enthusiasm up. Two facilitators can be used to speed up the process and enable the one facilitator to continue with the RCM process while the other can focus on what the team is saying and take notes. Facilitators can change roles during the process.

4.5.1.2 Conduct RCM team training – 2.1.2

The discussion in section 2.2.2.1 notes that participants of the RCM process should receive some degree of training in order to make them effective participants in the exercise. The entire team does not have to become experts but the RCM single point of contact and the facilitator needs to be RCM experts or well versed within the practice. All participant need to grasp the core concepts and the language within the RCM process being used. Team members need to understand concepts such as single-failures, critical components, hidden failures and RTF components.

4.5.1.3 Write RCM analysis contract – 2.1.3

As mentioned in section 2.2.2.1 an RCM analysis contract needs to compiled to provide clarity on what is required to perform the RCM analysis and what is expected from whom. The contract should include:

- who the attendees need to be;
- who the sponsor is;
- what is required of the meeting location (size, equipment, number of seats, etc.);
- meeting dates, time and location;
- information required for the analysis and who is responsible for gathering and providing the information; and
- signature of all the related parties and participants.

Organisations often have performance review processes. Adding the specific involvement expected from an employee within the performance review contract could assist in encouraging participation from the team members.

4.5.2 Scope and Planning – 2.2

Understanding the scope of the analysis is an important step in the planning. The criticality of components will help define the scope of the analysis process and help focus the team effort. This process will also assist the team understand the importance of the component in relation to the OSP and SAMP and create the Line-of-Sight. Understanding the required skills, competencies, technical information, maintenance information that is required for the analysis is key within the SA context where these elements are in short supply.

4.5.2.1 Criticality analysis of asset type – 2.2.1

The RCM type analysis cannot be performed on all assets and a criticality analysis is often performed to understand what are the most important assets that need to be part of the analysis process. As mentioned in section 2.2.2.1 other RCM methodologies also consider the criticality of assets, but where the criticality analysis occurs during their respective RCM processes differs. This process regards the criticality analysis methodology and ranking of asset criticality as part of the strategic planning process. The specific framework requires the criticality assessment of all assets and asset types to be addressed during phase 1, *Organisational Strategic Plan – 1.2.1* (section 4.4.2.1).

In column A of the COFCATs worksheet (see appendix B figure B.1), the asset type and the respective criticality is listed. In the case of the example COFCATs sheet the main transformer is listed with a criticality of 5.

4.5.2.2 Document reliability measures – 2.2.2

It is important to establish the criteria that will be used to measure the reliability of an asset. The reliability measures should also be developed as part of phase 1 discussed in section 4.4.3.3. The reliability criteria related to the "level of service" should be clear and concise in their definition and communication. The selected reliability criteria also drive the RCM logic and PM tasks that will aim to reduce unwanted events.

This step specifically requires that organisational objectives, organisational strategies, AM objectives, AM strategies and level of service be mapped against the specific asset type to create the Line-of-Sight.

In the case of a wind farm, the organisational KPI could be to have wind turbine time-based availability at 95%. The AM objective can be to maintain 97% availability over an annual period and the level of service expected from a turbine as an asset type would be 97% with a specific reliability measure. These objectives should be mapped against the asset type when starting the ACP development process.

In column B of the COFCATs worksheet (see appendix B figure B.1) are listed any relevant organisational objectives, AM objectives or level of service that is expected from the asset type. In the case of the main transformer the entire plant availability is affected by the device. The plant availability has a designated availability KPI.

4.5.2.3 Select systems and components for analysis and estimating effort – 2.2.3

Step 2.2.1 considers the criticality of an asset and mentions that the RCM analysis cannot be performed for all assets. Furthermore, an asset can have multiple components and this process requires that the RCM analysis occurs at component level. The process of analysing all components removes the requirement to define system boundaries and interfaces that can be a tedious and resource-intensive process (refer to section 2.2.2.1). It is not always possible to perform the RCM analysis for all components due to the cost and effort involved. The criticality methodology used within phase 1, *Organisational Strategic Plan – 1.2.1* (section 4.4.2.1) should be used to rank the importance of the asset, but the specific components of the asset need to be selected for analysis. For example, the main barnstormer is an asset that consists of multiple components such as bushings, oil, tank and windings.

Conducting a type of FMEA process is part of the classical RCM process. The CMF process performs the FMEA type analysis on component level; thus each component will have a function and an associated failure mode. Components also often have more than one function and in order to estimate the number of functions that will be used during an analysis the component number can be multiplied by 1.5. The number of failure modes can be estimated by applying a multiplication factor of 3 to the number of components. In a single week session around 70 functions and 120 failure modes can be addressed (refer to section 2.2.2.1)

In column C of the COFCATs worksheet (see appendix B figure B.1) the component or system related to the asst type should be described. In the example the transformer oil is selected for analysis and described in detail. Similarly for a wind turbine the asset can be a gearbox and the component can be the gearbox oil.

4.5.2.4 Assign alphanumeric code – 2.2.4

A database should be developed that can identify each component. The database needs to contain all the components that will be analysed as part of the COFCATs process discussed in section 4.5.3. Bearings, springs, shafts, for example, are considered to be piece parts and therefore do not have a unique identifier but are important when defining the specific causes of failure at the equipment level. Components are generally contained within a larger system and a component identification can be sorted by system tag number that will assist to review performance on a system basis. A labelling system is useful but not a requirement and using an intelligent labelling system or plant-wide coding system allows better file arrangement and also could be used to group components that are part of a larger system or asset. The planning department should also use these codes as part of the WO system as it can assist with the identification of components and analysis at a later stage.

In column D the COFCATs worksheet (see appendix B figure B.1) lists the alphanumeric code that can be used to uniquely identify the component within the COFCATs worksheet and could also be a reference within the CMMS system. The example indicates that the assigned code is “HV TRAN-OIL” which indicates that the component is oil and forms part of the HV transformer system/asset.

4.5.2.5 Understand the required skill set and expertise – 2.2.5

The scarcity of skills in the SA RE industry, discussed in section 2.3, could pose a challenge when developing ACPs for RE technologies. This step aims to ensure that the correct competency is available to assist with the development of the ACP. The skill may need to be procured and could add a cost and lead time to the analysis. Performing the analysis on a wind turbine or solar inverter component might require external or foreign expertise that needs to be sourced and procured. Considering this requirement will ensure that the analysis performed will deliver the best results.

In column E the COFCATs worksheet (see appendix B figure B.1) specifies the type of expertise that would be required for the analysis. In the case of the main transformer, a transformer specialist or even more specifically a transformer oil specialist should be consulted during the ACP development process. The example could have been for a wind turbine blade which would require a blade specialist.

4.5.2.6 Gather history, drawings, OEM information and procedures – 2.2.6

It is important to gather critical information and documents that can be used by the RCM team during the analysis process. The quality of the analysis can be dependent on the quality and availability of documentation. Typical information, as mentioned in section 2.2.2.1), that should be at hand at the start of the analysis process is:

- plant equipment/electrical drawings and schematics;
- existing maintenance programme details for the relevant asset or component;
- OEM manuals for assets or equipment that is part of the analysis;
- operations, and engineering procedures;
- operational records;
- Applicable engineering and performance standards;
- training manuals or study guides related to equipment;
- maintenance history related to O&M that can be used to assess previous failures. Ideally data should be available on an existing CMMS;
- control logic diagrams to determine the accuracy of alarms for a in depth troubleshooting guide; and
- a list of all the components that will form part of the RCM analysis.

Bad quality information or the lack of documentation and information will significantly complicate and slow the process. This situation also makes the selection of the RCM team very important as each member will have to make a significant contribution to the analysis.

Column F the COFCATs worksheet (see appendix B figure B.1) specifies all technical documents, maintenance history and procedures that could be found.

4.5.3 COFCATs – 2.3

The COFA that is similar to FMEA or FMECA, but performed at component level as opposed to starting at system level, is discussed in section 2.2.2.1.

The COFCATs process is primarily an adaptation of the COFA method introduced in section 2.2.2.1. The COFCATs process is in concert with the SAE standard for RCM and in many ways more advanced as it contains additional enhancements that are relevant to the RE industry in South Africa. The COFCATs method follows all the steps and logic trees within the COFA process but considers additional information when performing the FMEA process by including confirmation that would be found in a FTA. After specifying the failure modes within the COFCATs process the "failure cause" and "potential cause" are also considered. The COFCATs process is embedded with a logic process to identify components as critical, potentially critical, commitment, and economic components and considers the consequence of failure based on the asset reliability criteria specified in step 2.2.2 and links back to the "level of service" identified on a strategic level in phase 1 section 4.4.3.3 of the CMF. Referencing the reliability criteria facilitates reinforcing the Line-of-Sight between the OSP, AM objectives and maintenance tasks. The selected reliability criteria also drive the RCM logic and PM tasks that will aim to reduce unwanted events and provide additional clarity when considering the selection of maintenance tasks and redesign considerations, and facilitates the Root-cause analysis (RCA) during improvement cycles. The COFCATs also has an embedded process to select the appropriate maintenance tasks and maintains a clear separation of defining critical, potentially critical, commitment, and economic components from the process of selecting associated applicable and PM tasks. Other enhancements include consideration for part LC, obsolescence and operator Asset Care.

The COFCATs process also addresses five of the seven questions in the SAE standard while the last two questions are covered by the task frequency considerations. The SAE standard also mentions two key issues, firstly the *PM task interval determination*, and secondly the *continuous RCM review process*. Both these key considerations are addressed by the ACPD process proposed by phase 2 of the CMF. The COFCATs process, which is a step within the ACPD process, constitutes a simplified and self-contained, all-inclusive SAE standard compliant RCM logic analysis that is much more straightforward and comprehensive than the FMEA and considers key factors which are related to the RE industry in SA.

4.5.3.1 Describe all the functions of the component or system – 2.3.1

The first step in the COFCATs analysis process proposed by the CMF is to identify all the functions of a component. Step 2.2.3 touched on why the analysis is immediately performed at component level and that the classical RCM process undertakes an FMEA process which identifies the function of each component.

In column G of the COFCATs worksheet (see appendix B figure B.2) a description of all the functions of a component is specified. Components can have multiple functions that cover normal operational and emergency functions. In the case of the example COFCATs sheet the first function of the transformer oil is to “insulate active parts of transformer” and the second function is to “cool active parts of transformer”.

4.5.3.2 Describe the way each component/system function can fail – 2.3.2

The description of the way that a component can fail, highlights ways each function may be lost, and is identified in column H of the COFCATs worksheet (see appendix B figure B.2). The description of the way the component fails is typically the opposite of the function and in the case of the COFCATs worksheet example the ways that the transformer oil can fail are that it “fails to insulate active parts of transformer” and the secondly “fails to cool active parts of transformer”. This specific step might not add that much additional value to the analysis but offers slight clarification and is part of the SAE standard.

4.5.3.3 Describe the dominant component failure modes for each functional failure – 2.3.3

Column I of the COFCATs worksheet (see appendix B figure B.2) requires the identification and description of all the dominant component failure modes for each functional failure. Failure modes refer to the various types of failure or the various ways in such a component can fail that prevent the component from providing the specified functions. Only realistic or plausible failure modes should be considered. Failure modes can also be coded with the failure mode formula indicating the location of the asset and what component failed.

In the case of the example COFCATs sheet the main transformer insulation oil could fail due to change in its physical chemistry.

4.5.3.4 Describe the causes and potential causes of the failure mode – 2.3.4

The failure cause as outlined in section 3.1 of MIL-SRD-1629A (refer to section 2.2.2.1) specifies the potential physical or chemical processes, quality and design issues, incorrect application of parts or any other plausible reason that could initiate the physical process whereby deterioration proceeds to failure. Specifying the primary and secondary failure causes is done in columns J, K and L of the COFCATs worksheet (see appendix B figure B.2). Considering the COFCATs worksheet example and the function where the transformer oil cools the active parts of transformer, the component fails when it cannot cool active parts of transformer. The dominant component failure mode for this functional failure would be that the "the transformer cooling oil fails due to change in its physical chemistry".

The FTA is described in columns J, K and L as the failure of the transformer oil to cool the active parts of the transformer could be caused by [1] too hot air/water that could be caused [1a] air/water circulation not being adequate, that in turn could have been caused by [1a] fan/pump failure.

Following this type of analysis could enable the ACPD team to determine all the related components that can cause the failure providing a means of understanding what could also be considered as a means of preventing or detecting the failure mode occurring. Preventive maintenance should be considered on the fan/pump, or the fan/pump could be monitored remotely as a means to detect whether the oil is not performing the required cooling function.

4.5.3.5 Is the occurrence of failure evident – 2.3.5

Column M of the COFCATs worksheet (see appendix B figure B.3), requires the indication of whether the failure mode is evident. This question is also the first step in the logic tree (seen in figure 4.14) that is used to determine if a component is critical, potentially critical, commitment, economic or an RTF component. The failure mode needs to be evident to operating personnel (based in monitoring room or on rounds) during their daily duties when it occurs. Understanding whether the failure mode is evident is important to understand as it may affect the maintenance task decision. Components can fail without having an immediate visible effect on the system.

4.5.3.6 Describe the system effect for each failure mode – 2.3.6

The undesirable consequences are specified at plant level and should be defined for each identified failure mode that will result in multiple consequences. Ideally asset reliability consequences could be sorted to list all the steps resulting in a plant shut down; it is therefore prudent to list all plant consequences.

Column N of the COFCATs worksheet (see appendix B figure B.3) identifies the system effects and as an example main transformer insulation oil could experience a short circuit in transfer due to reduction in the electrical strength and breakdown voltage, increasing the dielectric loss of oil.

Highlighting system effects assists in identifying plant effects. Failures do not always result in major system effects but from a compliance perspective the system function failure may result in a critical effect at the plant level. Hidden failures have no effect on the system and the immediate workings of the system remains unaffected during normal operation. The primary reason for considering the effects at a system level is to provide some additional insight into the consequence of failure at the plant level.

4.5.3.7 Describe the consequence of the failure based on the asset reliability criteria – 2.3.7

Column O of the COFCATs worksheet (see appendix B figure B.3) identifies the consequence(s) of failure that can result in an undesirable effect on one or more of the measured asset reliability criteria. This relates to the reliability criteria identified in step 2.2.2 and links back to the "level of service" identified on a strategic level in phase 1 section 4.4.3.3 of the CMF. Specifying how the failure will impact the reliability criteria facilitates reinforcing the Line-of-Sight between the OSP, AM objectives and maintenance tasks. Understanding the link between the failure and the reliability criteria also drives the RCM logic and PM tasks that will aim to reduce unwanted events and provides additional clarity when considering the selection of maintenance tasks, redesign consideration and facilitates the RCA during improvement cycles as mentioned in step 2.2.2.

In the case of the example COFCATs sheet the main transformer failure will result in the inability to export power to the grid and complete revenue loss for 14 business days until interruption insurance activates. This will impact on the total plant availability target of 98%.

4.5.3.8 Classify the component critical, potentially critical, economic, commitment, RTF – 2.3.8

Based on the discussion in section 2.2.2.1 this specific step aims to classify components as critical, potentially critical, commitment, economic or RTF components. This step maintains separation between classifying the component and selecting associated applicable and PM tasks. Separating these steps provides clarity and simplicity and removes some of the confusion created when trying to assign a PM task and classifying (assigning criticality) to the component and allows completing the criticality classification apart from the PM task selection. Furthermore, equipment cannot be grouped when identifying functions and failure modes as their function might differ; however, similar PM tasks can be conducted on similar equipment types, which is another useful reason to separate the classification and the task selection.

Considering the logic tree in figure 4.14, the first and second filters identify the critical and potentially critical component respectively. In the event a component passes the first two filters, it has to contend with the third and fourth filters, that are the commitment component and economically significant filters respectively, that are part of the potentially critical guideline. In the case where a component can be classified by the first four filters a PM programme is required; however, if a component is not captured by any of the filters it is classified as an RTF component. All RTF components still need to have an SJ developed to pro-actively manage a failure.

The component classifications are:

- **Critical Component**: The failure of a critical component is immediately evident and the unwanted consequences of the failure also realised immediately.
- **Potentially Critical Component**: The failure of a potentially critical component is not immediately evident and is regarded as a hidden failure. However, the failure can become critical due to multiple failures, as time progresses or if initiated by other events.
- **Commitment Component**: These are components that can be linked to a commitment which can be statutory, regulatory or contractual commitments. These components can also be classified as critical or potentially critical components.
- **Economic Component**: These are components that do not have any safety, operational or production consequences as a result of failure occurring. The failure of such components would incur costs related to labour, material and other services to restore or replace. LC costing, which was discussed in section 2.2.2.5, can be applied to determine whether a PM task, and which PM task would make economic sense compared to allowing the component to RTF.
- **Run-to-failure (RTF) components**: Components that are classified as RTF components do not have any safety, operational, commitment, or economic consequence as the result of the failure occurring. Importantly, the failure needs to be evident to operations staff. The RTF component thus has no defined PM or proactive maintenance task but has a proactive CM maintenance strategy should the failure occur.

Column P of the COFCATs worksheet (see appendix B figure B.3) indicates whether the component is a critical, potentially critical, commitment, economic or RTF component by using the logic tree in figure 4.14. All the classifications except RTF need to have a PM strategy in order to prevent failures and their consequences while the RTF component needs to have a proactive CM maintenance strategy.

4.5.3.9 Probability and consequences ranking of each failure mode – 2.3.9

Column Q of the COFCATs worksheet (see appendix B figure B.3) indicates the criticality ranking of the failure mode. The result of an RCM analysis can be hundreds of tasks that need to be implemented. The multitude of tasks can raise questions around what tasks should be handled first as there is

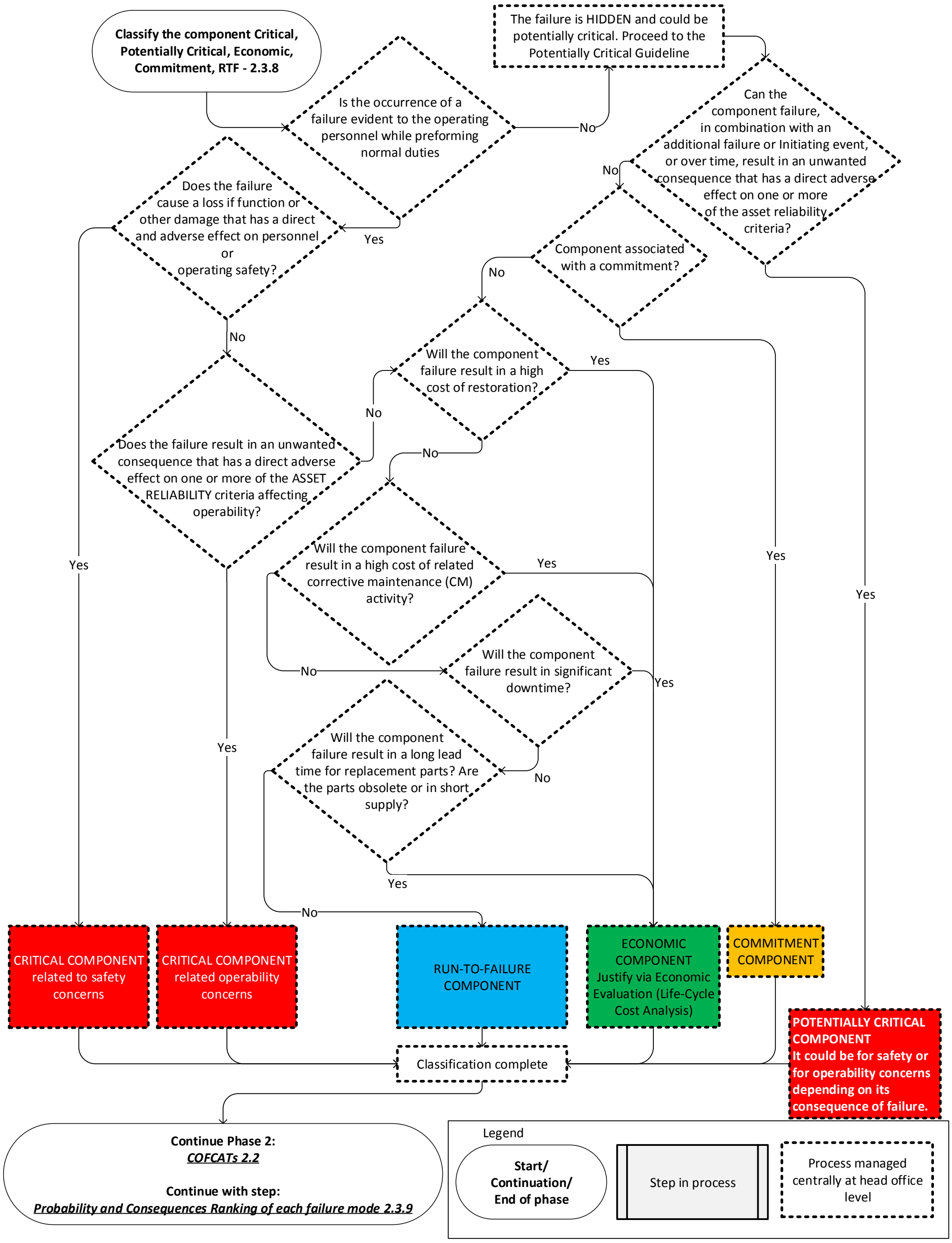


Figure 4.14: Identification of component as critical, potentially critical, commitment, economic or RTF – 2.3.8

always a resource limitation. A single RCM analysis could result in a significant number of PM and CBM tasks, maintenance procedures, operating procedures, management of change documentation and redesign recommendations to be written and followed up on. There thus needs to be a process to rank the importance of each of the identified tasks.

The RCM process identifies tasks that are designed to mitigate consequences and probability of each failure mode. A critically ranking for each task can be identified by combining the consequence and probability of each failure. The probability of each failure mode ranks the likelihood of the failure occurring based on historical data or RCM team experience. A clear boundary needs to be set during each RCM analysis process to understand what constitutes a high, medium or low probability. Once the failure mode probability criteria have been set the consequence criteria need to be established. The consequence of each failure mode needs to ranked against the potential impact on business while covering a range of aspects including HSE and revenue loss. After the criticality ranking methodology has been established it is a simple process of ranking each failure mode that will enable the prioritisation of tasks. An example of a proposed criticality matrix can be found in appendix F.

4.5.3.10 RCM task selection using task selection logic and classifying as PM, CM, DOM) – 2.3.10

The second phase of the analysis process starts at this point. Maintenance tasks are introduced in order to address the cause of equipment failure. The maintenance task selection is applicable to components that are recognised within the COFCATs process (step 2.3.8) and classified as critical, potentially critical, commitment, or economic components.

At the start of this process it is important to have the ACPD team work from a common understanding of the maintenance terminology in order to prevent confusion due to the many different terms used within industry as mentioned in section 2.2.1. Maintenance approaches are discussed in section 2.2.3 and typical terminology used for PM tasks include time-directed, condition-directed, condition-based, proactive, reactive, predictive, failure-finding, in situ, on-condition, and surveillance. Although these different terms could have a different meaning to different people the terminology used in this thesis is summarised in figure 4.15.

Referring to figure 4.15, PM tasks will be split in three categories, namely CBM and TBPM, and Failure-Finding Maintenance (FFM). CBM refers to maintenance activities such as thermography, on line/offline vibration analysis and oil testing. CBM activities can be performed at set time intervals or in response to feedback from equipment that is on line or can send information

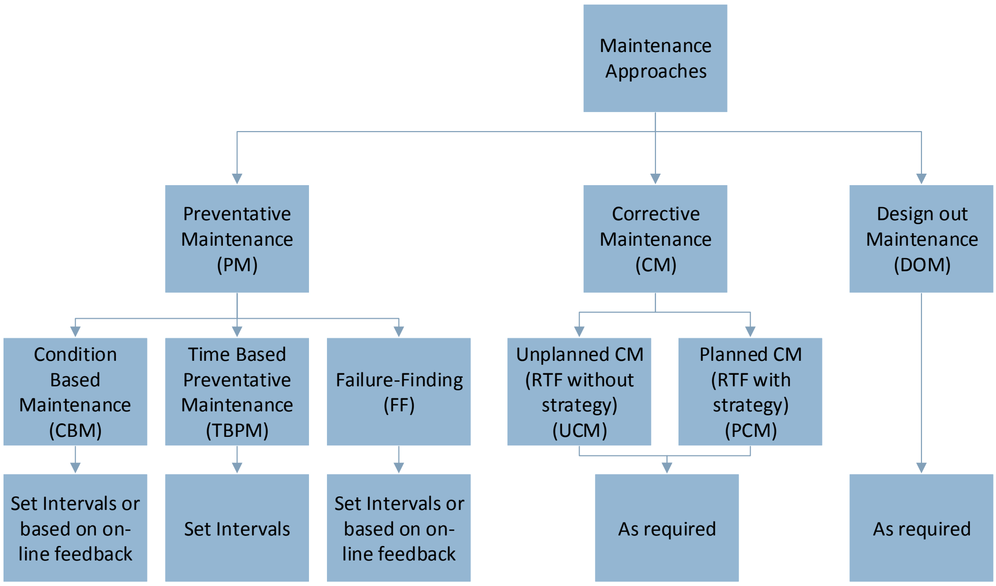


Figure 4.15: Maintenance approaches – 2.3.10

regarding its health status using modern communications technology. TBPM refers to activities such as performing overhauls or part replacements at set time intervals and operating hours. Failure-finding tasks can be regarded as a PM strategy to stop failure consequences at the plant level and is applicable to hidden failures, safety systems and components that only operate on demand. An example of a FFM task could be to check whether the controller that is responsible for controlling the power plant on commands from the system operator is functioning. The plant can operate normally with the controller not functioning but should the system operator send a command and the plant does not respond the system operator can open the main circuit breaker, disconnecting the plant from the grid, as the plant is not compliant to the system operator requirements. Activities that are related to CBM and TBPM designed to prevent failures at the component level by addressing failure causes with the aim of preventing them from occurring FFM tasks on the other hand are designed to periodically detect whether components had already failed to prevent further consequences to the plant. Components that are classified as RTF components in step 2.3.8 will receive Planned Corrective Maintenance (PCM) which means that there is a strategy in place to repair or replace the component should it fail. All other unplanned maintenance is referred to as Unplanned Corrective Maintenance (UCM). Lastly DOM, discussed in section 2.2.3.4 is the decision to effect a design change or improvement to remove the failure mode to increase reliability and maintainability.

All critical, potentially critical, commitment, or economic components need to have an assigned PM task to prevent the cause of failure. Each failure mode needs to be addressed with its own PM task as the failure mode will differ. It is important to involve personnel such as the maintenance and engineering staff who are usually more intimately familiar with internal failure mechanisms of the equipment than the operators.

The maintenance task selection logic tree as seen in figure 4.16 is used to populate Column R of the COFCATs worksheet.

The first task selection is a CBM task that is non-intrusive (always preferable) and typically will involve using a PdM technology, external inspection or a performance test. The second selection is a time-directed (TBPM) task and would typically involve a more intrusive process such as a replacement, overhaul or internal inspection. In the case where an applicable and effective condition-directed or a time-directed task cannot be found, DOM may be required. The proposed PM task needs to be applicable and effective, meaning that it needs to be appropriately applied and able to address the failure cause, and provide some means of addressing the cause of failure that could minimise or prevent the probability of future failure.

PM tasks selected by knowledgeable individuals should have an acceptable degree of probability that they would prevent the failure occurring. The question should be asked if the selected task really makes sense and whether a task is just being selected for the sake of selecting a task. In certain cases applicable and effective PM cannot be specified and a redesign (DOM) or FFM task is the only alternative. Should the DOM not be initiated the risk should be analysed and a decision should be taken whether the risk is acceptable. The application of an FFM task is only applicable to potentially critical components due to the unwanted consequence of failure for critical, commitment, or economic components already occurring when the component failed. Considering the case of a hidden failure where a PM task cannot be identified to detect or prevent a failure from occurring a FFM task needs be specified. FFM tasks can only determine whether a hidden failure has already occurred and enable action to be taken to prevent a undesirable plant consequence before the occurrence of an additional failure or initiating event.

Column R of the COFCATs worksheet (see appendix B figure B.4) indicates the identified maintenance tasks to reduce or prevent the specific failure mode from occurring. In the case of the main transformer example a few PM options are available for the critical component such as hotspot temperature monitoring using thermography (infra-red scan), dissolved gas analysis (DGA), oil quality test, furan analysis, partial discharge measurement, winding tan delta and capacitance tests.

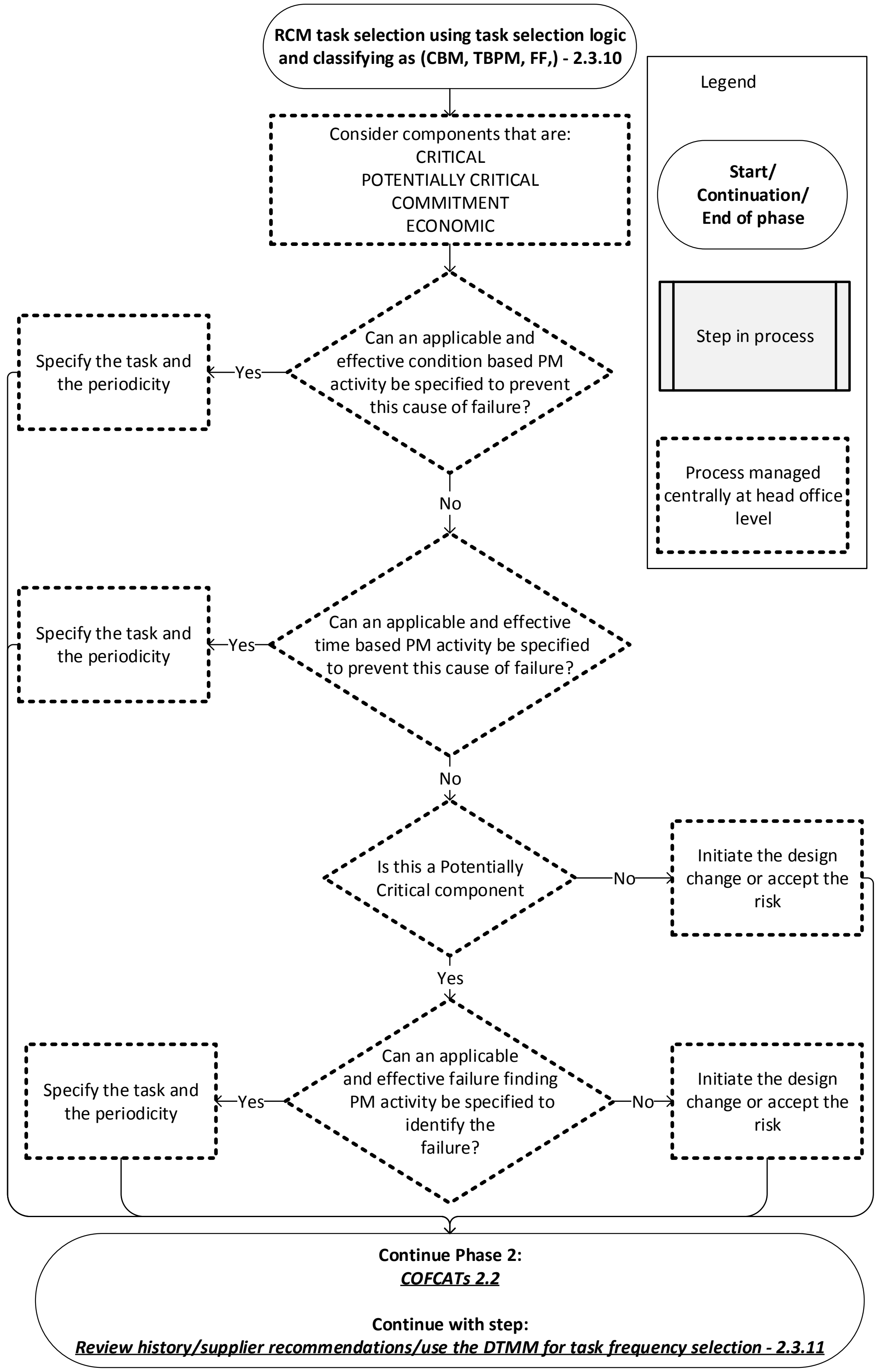


Figure 4.16: PM task selection logic tree – 2.3.10

All the potential options should be listed with a clear selection of a specific task. The COFCATs example selects the DGA analysis as the preferred method of PM which is regarded as a CBM task.

The specific step also relates to the *Maintenance Delivery* AM subject as outlined in appendix A section A.1.3.5 by selecting the appropriate maintenance strategies that include CM, PM and CBM.

4.5.3.11 Review history/supplier recommendations/use the DTMM for task frequency selection – 2.3.11

MO methods are discussed in section 2.2.6. Determining the ideal task frequency is a key element in the COFCATs process. The information gathered in step 2.2.6 such as OEM maintenance recommendations, technical documentation, historical maintenance information or methods such as DTMM, discussed in section 2.2.6, can be used as considerations when selecting the task frequency.

The task frequency should be expressed numerically as hours, days, quarters, months, annually, or over a period of years. As an example three months would be M3, a periodicity of every two years would be A2 or Y2, depending on whether you choose to use an annual or a yearly expression.

Selecting the most appropriate task frequency can be complex or it could be very simple. Using a simple approach is often advisable, but more complex methods exist. Methods such as calculating the probability of failure, or the mean time between failures (MTBF) can be used to estimate the operating life of a component. The DTMM described in section 2.2.6.3 could also be used to determine an appropriate task frequency should the required data and information be available.

Work should be scheduled as efficiently as possible and requires prudent and skilled engineering judgement. Therefore, it is key to have knowledgeable individuals related to the specific component to draw on their knowledge when establishing task periodicities. Having good information and historical data can also greatly assist during these decisions. The reliability program should aim to deliver a reliable plant that can deliver the intended OSP and AM objectives. Therefore, the RCM program must conform to certain constraints such as when the equipment is available to be worked on. The plant should have a long-range maintenance schedule (one to three years) that could be used to facilitate the short term scheduling. Overall prudent judgement by individuals knowledgeable about the equipment and the plant should be used to decide when to perform maintenance should large outages and PM tasks not coincide. Selecting the most appropriate PM task frequency is regarded as an art more than a science.

Column S of the COFCATs worksheet (see appendix B figure B.4) is used to make any notes related to supplier recommendations, technical documentation, historical maintenance information or DTMM calculations. Column T of the COFCATs worksheet (see appendix B figure B.4) is used to note the maintenance task frequency or interval with the example selecting to perform the DGA analysis every three months (3M).

4.5.3.12 Spare parts considerations – 2.3.12

Section 2.3 and specifically section 2.3.3 indicated that spare parts can also be a challenge in the RE sector as OEMs do not share technical information or even supplier information. Spare part considerations thus become even more important in the RE industry as technologies are supplied from abroad and spare parts can only be purchased from suppliers in foreign countries. These parts can often be specialised and require long lead times. Therefore, consideration of spare parts is critical as not making allowance for spare parts can lead to escalated costs and long downtimes. Section 2.2.2.1 also indicated that most RCM methodologies do not consider spare parts as part of the process and having complete maintenance strategy recommendations regarding spare parts needs to be considered. The RCM process can have a direct impact on the amount of spares that are tied up within the inventory, but a simple way to reduce stock holding is by partnering with key suppliers. Section 2.2.2.7 also notes that Asset Care should consider spare parts requirements.

Spare part considerations should include:

- whether the part has a known age or useful life;
- whether part failure is detectable via PdM;
- what the cost of the spare part is compared to the cost of the resulting downtime;
- what probability there is of the part failing;
- what the consequences are of the part failing; and
- whether the part is still available from vendors or obsolete.

Once these aspects have been considered the following recommendations need to be made regarding spare parts:

- whether to stock the spares item(s) or not;
- whether to stock the part at the preferred vendor with a service level agreement on delivery time; and
- whether to purchase the spare part when needed.

Column U of the COFCATs worksheet (see appendix B figure B.4) is used to note the spare part considerations. The example notes that there should be a spare main transformer held on site. This drastic requirement could be due to the plant only having a single main transformer (single point of failure) which is a non-standard transformer size and has a long lead time.

4.5.3.13 Component life-cycle task consideration using ALCA – 2.3.13

Column V of the COFCATs worksheet (see appendix B figure B.4) is used to note considerations or comments related to the LC of the component.

Parts or components within plants can become obsolete within a few years of operation. Projects could be developed, designed and only built a few years after the initial design. The useful life of components should be considered and in the event that the component has reached end of life and needs to be replaced, this needs to be noted and addressed should the component be identified as obsolete or in process of becoming obsolete.

Section 2.2.2.5 discusses LCC and section 2.3.4 also introduces LCC consideration for maintenance tasks. ALCA can be performed to understand the commercial viability of CBM activities over the LC of the component. The ALCA will consider the combined evaluation of capital costs with future performance, O&M implications, life expectancies and eventual disposal or replacement of an asset. Combining RCM with ALCA can provide a more sustainable method of understanding what the most appropriate, technically feasible and economical maintenance strategies are.

This step is also linked to the *Capital Investment Decision Making* and *Life-Cycle Value Realisation* AM subjects as per appendix A sections A.1.2.1 and A.1.2.3.

4.5.3.14 Operator asset care – 2.3.14

Operator care uses operators to perform routine and basic equipment care. In the RE industry in SA operators could be people working out in the solar PV field cleaning PV modules, or it could be an RMC operator remotely monitoring the plants. Fostering reliability excellence requires that operators can take ownership of the equipment performance and can act as the first line of defence against failure.

In the event that an on-site operator could detect a fault during routine work, this should be noted and included as a task during routine tasks. An example would be that facilities staff would clean the area around the main transformer. The transformer has an externally mounted temperature gauge that indicates the oil temperature. Other basic checks could be to see if there are any oil leaks. This could also be provided as part of a basic check sheet for the cleaning of the transformer area. In the case of a PV field when operators wash the PV panels, they could note the condition of the PV panel mounting system and inspect for any loose cables or broken PV modules. Similarly, RMC operators could have real-time trends that indicate the condition of transformer oil, should an on line DGA system be available.

Section 2.2.5.5 also notes that autonomous maintenance or operators performing maintenance (operator Asset Care) can be improved by having detailed and effective standard operating procedures. Therefore, section 4.5.4 step 2.4.3 focuses an developing adequate operating procedures.

Column W of the COFCATs worksheet (see appendix B figure B.4) is used to note actions that can be performed by operators or other on-site crews as basic PM. In the example cleaning staff could check the temperature gauge and for any leaks during routine cleaning of the area and complete a check sheet that they are supplied with. The RMC could also monitor on line temperature. None of the RCM methodologies reviewed in section 2.2.2.1 considered operator Asset Care.

4.5.4 Standard Job – 2.4

All the steps in section 4.5.4 are geared towards using the availability of the ACPD team to develop the SJ in as much detail as possible. An SJ database can be developed that can assist in defining the job scope, sequence of tasks, materials and spares requirements, estimated time and costs of a specific maintenance task. Once SJs are in place, they also provide a means of measuring the performance of Craft teams. An SJ is a WO that is stored in the CMMS and contains all the required information that is needed to perform a maintenance job (refer to section 2.2.5.5)

SJs are part of and assist the maintenance planning process as described in to section 2.2.5. Planning involves making sure that the correct maintenance job is ready to be executed and is a vital tool that is used to perform preparatory work that can reduce the risk of delaying any work. Planners can be given a head start by having very experienced personal establish detailed SJs.

Technicians would conventionally compile the information that forms the basis of SJs after completing large maintenance tasks. Information from planners, technicians, specifications, job history, and engineering are also used to develop robust job plans. Planners are required to describe the work that needs to be done during all maintenance tasks and therefore ensure that a correct description of **what** needs to be done and not **how** it should be done is provided. SJs should thus contain the plans or work instructions for a particular job.

As mentioned in section 2.2.5.5 standard plans (which are not the same as an SJ) provide guidelines based on previous successfully completed work. Standard plans need to be attached to the WO or as part of the SJ details. Technicians can deviate from the standard plans but should provide feedback on why the decision was taken in order to update or improve existing standard plans.

The classic RCM process does not require the development of SJs during the ACPD cycle. The proposed process requires that the SJs be created at the same time as the maintenance tasks are being created. The purpose of including the SJ development at this stage of the process is to use the ACPD team and their skills assembled for the COFCATs stage in the previous section to assist with the development of the SJs. SJs are regarded as a complete description of the work that is required to be completed and based on section 2.2.5.1 should include maintenance planning considerations for:

- defining work content and sufficiently detailed information on the job to be performed;
- correctly specifying the job scope;
- specifying the appropriate Craft and number of personnel required;
- estimating the time that is needed to complete the work;
- specifying parts, tools and materials that will be required to perform the work;
- specifying any special tools that will be critical in completing the work;
- reviewing and creating the maintenance, operating and safety procedures that need to be followed;
- specifying procedures required for management, transit and disposal of any hazardous materials; and
- estimating the costs involved to complete the work.

Developing SJs during the COFCATs process will enable all the skilled and experienced personal to contribute to the process. The planning function will be centrally located and run, bringing with it challenges where planners cannot visit site locations to scope jobs and write detailed plans. The general skills shortages in the SA RE sector will also mean that skilled planners will most likely not be available. The challenges can be mitigated by developing SJs within the COFCATs environment where a skills pool is available to assist the centrally located planners.

4.5.4.1 Assemble mini-file – 2.4.1

Based on discussions in section 2.2.5.1, the third planning principle defined by Palmer (2006) states that mini-files need to be kept at component level based on equipment tag numbers. A mini-file is regarded as a file that is created specifically for single piece of equipment the first time it receives maintenance. A mini-file within this context will refer to a folder within a filing system in a data warehouse or file storage platform like Microsoft SharePoint where planners keep information related to equipment, job feedback and costs. Information needs to be stored at component level and not at system level. This is in line with the COFCATs requirement to analyse failures at component level and not at system level. Revisiting information on maintenance can help the planner determine improvement opportunities and having an adequate filing system is crucial to accessing information when needed and also important in developing SJs.

Information related to the plant exist in many formats and in many places and the planning process requires access to the information. Mini-files store information at component level for every single piece of equipment, allowing the planning department and ACPD team to (refer to section 2.2.5.5):

- List all the work that has previously been done on the equipment including the scope of works, job duration, Craft hours and costs.
- Create maintenance schedules for PM tasks.
- Record technical data such as data sheets, standard plans, safety information, OEM information.
- Keep a parts information summary.
- Make special notes on abnormal conditions and equipment properties.
- Keep copies of historical WOs including feedback-related problem corrective action.

Assembling and reviewing the information mentioned can significantly improve planning efficiency. Having the ACPD team assembled when developing the SJ can also greatly assist in the process of assembling the mini-files as the team can provide key information regarding parts, data sheets, abnormal conditions, special tools, cost estimates, Craft requirements and job duration. Column X of the COFCATs worksheet (see appendix B figure B.5) identifies the location of the component mini-file.

4.5.4.2 Review existing or develop maintenance procedures – 2.4.2

Maintenance procedures are key in planning and executing maintenance. As mentioned in section 2.2.5.5 maintenance procedures are needed to perform the maintenance work and having detailed maintenance procedures improves reliability, performance and overall safety. Maintenance procedures should be improved over time as the expertise of the craftsman assists the planner in fine-tuning maintenance procedures.

SJs should include important information from large O&M manuals or include the entire O&M manual if available. References can be made to the O&M manual on condition that the there is access available to the file. All procedures and manuals should always be available to technicians through hard copy or an electronic system. Maintenance procedures are often provided by the OEMs, but as indicated in section 2.3.3, in the RE environment OEMs are not always open to sharing such detailed information. Maintenance procedures for RE systems might thus not always be readily available and relevant external expertise might be required to assist in developing maintenance procedures for specific RE systems.

Section 2.2.2.1 highlights that the RCM process can be used to generate maintenance procedures, standards and routines, Furthermore, maintenance procedures and practices need to be reviewed to ensure that they are accessible, realistic and consistent.

Having the ACPD team assembled, with the appropriately identified scarce skills in the room, will enable the immediate review of existing maintenance procedures to assess whether they are correct, relevant and applicable. Maintenance procedures might often not have been created as the failure mode had previously not been identified or maintenance for the component had not yet been considered. In this case the ACPD team should draft a procedure if possible, and scope the content or procure the services of consultants who are able to provide an adequate procedure.

Column Y of the COFCATs worksheet (see appendix B figure B.5) identifies the existing maintenance procedures relating to the component. Should the maintenance procedure not exist or not reach the required standard or requirements, a special note should be made regarding the action required.

4.5.4.3 Review existing or develop operating procedures for system – 2.4.3

Operating procedures are just as important as maintenance procedures. Section 2.2.5.5 notes that there is a positive correlation between performing operating procedures and the number of years of experience and the ability to handle responsibility. Therefore, the constitution of the ACPD team should offer the experience that would deliver robust operating procedures.

Humans play a key role during the entire LC of equipment and human error can cause disruption to normal operations or damage to property and equipment. Human error can occur due to inadequate design of equipment, tools, insufficient training and experience, lack of equipment maintenance and standard operating procedures that have been poorly written or are outdated, as discussed in section 2.2.5.5.

Asset reliability (or unreliability) can be linked to operators being taught the minimal steps to operate critical systems, inadequate training of operating personal, or poor, outdated, inadequate or non-existent operating procedures.

Standard operating procedures do not only consider operating procedures for equipment but also include lockout/tag out, safety, risk assessments, and management of change compliance among others. Therefore it is key that adequate operational procedures are developed and linked to the *Asset Operations* AM subject in appendix A section A.1.3.7.

Standard operating procedures can also be a means of developing standards, which is a key component of any continuous improvement techniques. Furthermore, operating procedures that affect costs need to be effectively managed to improve overall management of assets and the impact of maintenance on the asset LC.

There can be a mutual beneficial relationship between the RCM-based analysis and the review and development of standard operating procedures. As discussed in section 2.2.5.5 RCM highlights existing strategies and identifies required changes to operating procedures, while during the development or review of operational procedures, including safety, abnormal operations, and emergency instructions additional component functions and failures can be determined that have not yet been considered during previous RCM type analysis, and this information can be fed back to the ACPD team.

Operating procedures that are complete, relevant and detailed are important as they often bridge the gap between bad training, lack of training or inexperience. The lack of information sharing as detailed in section 2.3.3 can also be bridged through the process of developing operating procedures with a skilled ACPD team.

The function of this specific step in the process is to ensure that standard operating procedures that are required to operate equipment either as part of the maintenance process or general day-to-day operations are reviewed and any deficiencies are identified and addressed while having the experience of the ACPD team at hand.

Column Z of the COFCATs worksheet (see appendix B figure B.5) identifies the existing operating procedures relating to the component. Should the procedure not exist or not meet the required standard or requirements, a special note should be made regarding the action required to rectify the situation.

4.5.4.4 Review existing or develop risk assessments – 2.4.4

Risk assessments are discussed in section 2.2.5.4. All maintenance tasks have some level of risk. The process of evaluating risk needs to consider the task that will be performed and assess all the associated detail including the working environment and anticipate what could potentially go wrong. Suitable strategies then need to be developed to mitigate risk of something going wrong.

As mentioned in section 2.2.5.4 risk assessment should consider all common hazard types that could occur where the work is being carried out such as electrical, mechanical, chemical, gas, high or low temperatures, manual handling, stored energy, slips and trips, working at heights and moving vehicles. Risks can be addressed through eliminating, substituting or enclosing materials or equipment, personal protection equipment (PPE) or training.

Performing a risk assessment for every task would take a considerable amount of time and would be an inefficient use of human resources. Eliminating the repetition of risk assessments can be done by building them in a modular fashion. Furthermore, risk assessment can be split according to complexity.

First drafts of a risk assessment are generally compiled by technical staff due to their comprehensive knowledge and understanding of the associated hazards and safety systems required. Teams who will be involved in the general maintenance process should all be exposed to developing risk assessments and practise it as much as possible. Often teams that work on the same equipment and perform the same tasks generate different risk assessments due to working in isolation or in different teams. Different people will see different risks and having a centralised contact point can enable the feedback loop and the sharing of ideas. In the scenario where operators will be performing maintenance it is important to have appropriate risk assessments. Risk assessments also need to be subjected to a continuous evaluation process as there are always changes to equipment, processes, staff or procedures, within an operational environment.

Risk assessments need to be developed by persons who are knowledgeable regarding all the HSE requirements of the equipment and type of tasks to be performed. The ACPD team should have the relevant technical and HSE people available to develop a first draft of the risk assessment required for each maintenance task. The centrally based planners will also be part of the team and thus have an understanding of the task and the associated risk assessment.

Column AA of the COFCATs worksheet (see appendix B figure B.5) identifies the existing risk assessments relating to the component. Should the risk assessment not exist or not meet the required standard or requirements, a special note should be made regarding the action required.

4.5.4.5 Planning: craft, number of persons, work hours, job duration, spare parts, special tools, estimated cost – 2.4.5

The SJ should indicate all the relevant maintenance planning information, as outlined in section 2.2.5.1, related to the Craft required, number of people, the duration of the job, spare parts, special tools required and the estimated costs. The ACPD team, which consists of technicians, engineers, planners, schedulers, operators and other technical experts, are all assembled for the COFCATs process and should be able to assist in specifying these key requirements of the SJ.

Craft Skill level and Number of People

The Craft skills that are required for the job plans need to be identified. This will assist the scheduling team and supervisors to match the correct crew skills and people for the specified job. The lowest skill level for the job needs to be identified to provide flexibility when the supervisors or the schedulers need to assign work. For example, if the job could be performed by a solar technician or an electrician, the SJ plan needs to note this in order not to limit the choice of who can be assigned the work. A common language around the terms used for designations of Crafts and skills needs to be established within the organisation to reduce misunderstanding. See appendix D for typical designations used within the wind and solar PV industry.

Estimated Work Hours

The estimated work or Craft hours required to complete the job need to be identified. The duration of a job should be specified according to calendar time; this is required to plan and schedule work effectively. The job duration is also required for operators to understand how long equipment will be unavailable or in service. The planner needs to be able to clearly understand the number of persons and work hours for each person to estimate the total labour hours and the total job hours required. Planners would generally estimate work and job duration based on judgement and in reviewing work history. Completing the estimated required hours can now be performed while the entire ACPD team who will be involved in planning and executing the work is present. Work should also be planned according to time estimated for good technicians and not average technicians.

Jobs should be planned for good technicians to set a time standard for all technicians, by which they can judge their skills. The collective team experience should be used to consider aspects that could cause delays based on experience from previous work to improve the accuracy of job duration estimates.

Spare Parts Considerations

The correct identification and coordination of spare parts or materials is an area where the planning function can significantly improve Craft productivity. The planning department often starts by assisting with parts planning and is a key reason the planning department is accepted by technicians.

The core purpose of planning with regard to spare parts is to assist with the parts identification and to ensure that the parts are available before the job is executed. The SJ needs to assist the planners and the technicians to reduce time delays due to technicians having to travel and procure parts after a job has started. The parts requirement needs to be specified for PM maintenance as well as planned RTF components that can have a pre-planned corrective job plan. The SJ needs to identify the anticipated or additional spare parts that may have a fair chance of being used. Attaching the required parts list to the planned job assists the technician in understanding the equipment required and procuring any other unanticipated parts.

Special Tools

One of the areas in which planning can play a significant role is in increasing productivity through the identification of special tools required to perform a job. Special tools are any tools that are not carried within a Craft toolbox. The planner should ensure that all the required tools are identified and available in order to avoid delays or extra trips. In the case of wind farms, having to make extra trips could mean significant delays if a technician has to travel back to the store room due to the large area covered by a wind farm. The planner needs to ensure that the special tool is available for the job. Generally planners rely on personal experience or information derived from previous jobs or from mini-files. Additional sources of information regarding special tools can be found in O&M manuals or recommendations from OEMs and vendors.

Estimating Job Cost

Management needs to have reliable costing associated with maintenance activities. The SJ thus needs to estimate as accurately as possible the cost of the labour and parts. Understanding costs associated with specific jobs can be of great value when assisting redesign or replacement parts. Cost estimation can be completed even without accurate accounting using a CMMS. Having a reasonable cost estimate is more valuable than having none at all. Understanding cost estimate trends can greatly assist when considering components that are at end of life and need to be replaced by a new part. Planners need to be able to understand the cost of jobs without much effort as they need to plan numerous jobs on a daily basis.

An additional benefit of showing component cost information on a job is to convey the relative cost of components to technicians. Technicians will handle more expensive equipment with care and will understand the need to return high value items back to the store.

Labour costs are first calculated using a standard labour rate. This can defuse any tension between Crafts regarding the difference in wages received. The true cost difference between Crafts, due to using a standard rate, should not have a significant impact on inaccuracy of job estimates as maintenance is more concerned with the cost of equipment. Even though a CMMS system can more accurately provide costs for different Crafts caution should still be taken so as not to incite jealousy.

The planner would generally first calculate the cost of all the parts and indicate the cost of individual items. If an inventory system is available the cost of the last order should be used and if there is no available cost an estimation should be done. The costs of special tools or skills should only be included if the tool or skill is not in available and special costs will be incurred. The total cost for labour, parts and special tools or skills needs to be considered as it may exceed cost guidelines and require approval.

Contracting Out Work

Contractors are hired to carry out specific work. The contracting strategy may differ between organisations as certain organisations may prefer to outsource while others try to contract out as little as possible. Scenarios exist where planners need to coordinate with external contractors. Contracting is a significant consideration, but the intricacies will not be discussed as part of this thesis.

Column AB of the COFCATs worksheet (see appendix B figure B.5) identifies the Craft, number of persons, work hours, job duration, spare parts, special tools and estimated cost of performing the maintenance task.

4.5.4.6 Build the SJ within the CMMS system – 2.4.6

All the steps within this section 4.5.4 are geared towards using the availability of the ACPD team to develop the SJ in as much detail as possible. This process will help develop the SJ database that can assist in defining the job scope, sequence of tasks, materials and spares requirements, estimated time and costs, etc. SJs need to be stored in the CMMS and should contain all the required information that is needed to perform a maintenance job and assist the planning department and technicians. An extensive library of SJs is important to the planning department, especially in an centralised environment where the planners are removed from the site activities and potentially have limited knowledge due to the scarce skills and lack of information sharing in the SA RE industry.

Once the SJs developed by the ACPD team are completed and reviewed these SJs become a credible template to save time once the job needs to be planned again. The SJs should be loaded into the central CMMS and can be accessed by the individual plants and from the RMC-based planning team.

Column AC of the COFCATs worksheet (see appendix B figure B.5) is used to note progress or make any comments related to the process of loading the developed SJ into the CMMS.

4.5.5 Follow-Up Tasks – 2.5

Once the analysis process has been completed, follow-up tasks have to be executed to ensure the quality of work and to see that the implementation is followed through. Section 2.2.2.1 mentions that often RCM programmes do not follow a continuous RCM review process. This step addresses these requirements.

4.5.5.1 Checking for completion – 2.5.1

Once the initial analysis process has been completed, a review of all the identified component functions and respective failure modes needs to be completed to ensure that no major functions and failure modes have been missed. Furthermore, a check should be made that all the hidden failures have been correctly identified.

Hidden failures are regarded as a failure of a component where the failure is not evident and the immediate operation of the plant is not affected. In the case of the RE sector, for example, this is the main power plant controller that receives commands from the network operator to reduce power output. In the event that the plant controller fails, the plant could still operate but not respond to commands from the network operator and essentially not be grid code compliant and not allow the network operator to disconnect the power plant from the grid. After all the functions and failure modes have been reviewed the analysis process is complete. Step 2.4.3 also notes a feedback loop between the RCM process, operating procedures and the discovery of new failure modes.

Column AD of the COFCATs worksheet (see appendix B figure B.6) is used to comment on the overall completion of the analysis for the specific component and failure mode.

4.5.5.2 Spell check and proof read – 2.5.2

The analysis document such as the COFCATs worksheet in appendix B is a living document and needs to be reviewed and updated on a continuous basis. The analysis should be professional and accurate and therefore an electronic spell check should be performed and the document should be reviewed externally as well as internally for spelling and grammar errors.

Column AE of the COFCATs worksheet (see appendix B figure B.6) is used to comment on the overall completion, spelling and grammar of the analysis task.

4.5.5.3 Prioritise analysis tasks – 2.5.3

The identified criticality of each failure mode can be used to prioritise the implementation of the associated maintenance task. High criticality items should implemented first. The probability and consequence rating in step 2.3.9 can be used to prioritise the implementation of tasks.

Column AF of the COFCATs worksheet (see appendix B figure B.6) is used to indicate the criticality or priority of the failure mode and the implementation of the maintenance actions.

4.5.5.4 Implement plan – 2.5.4

The analysis process is only the first step. Implementation is the most important aspect, requiring good leadership, structure and discipline. AM leadership and planning are addressed in section 4.4.3. Developing and implementing an RCM-based program can be specified as an AM strategy within the SAMP which will be supported by the AM policy. Furthermore, leadership at operational level could be in the form of an implementation manager who works with the team to develop a suitable implementation plan. The implementation plan should also be SMART and continuously monitored for progress. The structure is already provided by the database (COFCATs worksheet) developed during the analysis process and offers discrete tasks, with a priority, that can be assigned to individuals with a deadline. There should be good discipline within the team to stick to deadlines and ensure that tasks are implemented. Adding a relevant implementation section to the RCM contract or performance review process of each person involved could be a way to facilitate compliance.

Section 2.2.2.1 also notes that one week of analysis could produce 120 tasks that could take up to six weeks to implement. The appropriate resources should be made available to complete the work. This resourcing could include a plan for human resources, capital and operational budgets and should be considered as part of the SAMP and AMP development in section 4.4.3. The ACPD teams should complete the implementation of a single analysis before starting additional analysis.

The SJ development process described in section 4.5.4 requires that the SJ be developed and that all the maintenance procedures, including operational procedures and risk assessments, be developed and documented. All the developed information (maintenance procedures, operational procedures, risk assessments, task descriptions, task frequency, required skills and materials, estimated times and costs) should then be loaded into the CMMS.

The RCM Blitz processes discussed in section 2.2.2.1 suggest six key considerations for effective implementations:

- Identify the implementation manager who will be responsible for driving and reporting on progress.
- Expectations of the level of detail contained within each maintenance task should be clearly communicated.
- Regular implementation meetings should be held at appropriate intervals to report on progress and raise any concerns.
- The implementation manager needs to report progress to the rest of the team.
- Once a specific analysis has been successfully implemented it should be celebrated by the entire team.
- Audits should be performed on a regular basis to ensure that the implemented tasks are being performed.

Column AJ of the COFCATs worksheet (see appendix B figure B.6) is used to comment on the implementation process.

4.5.5.5 Analysis report – 2.5.5

The analysis report should include details related to operational history, component functions and functional failures, all the specified preventative and predictive tasks, all the RTF tasks, specified redesigns, spare parts, troubleshooting guides, spare parts and the implementation plan related to each asset type. For example, all information related to the main transformer can be printed or grouped from the mini-file information.

Column AH of the COFCATs worksheet (see appendix B figure B.6) is used to comment on the analysis report process.

4.5.5.6 Review meeting – 2.5.6

The implementation of any analysis will take time and the progress needs to be communicated in the review meeting. The review meeting provides an opportunity for all the relevant parties to meet and within a short period go through the analysis report, communicate the way forward regarding the implementation plan.

The RCM Blitz processes discussed in section 2.2.2.1 suggest the following key elements that need to be covered as part of the review meetings:

- overview of the systems/assets that are part of the process;

- quick review of the number of system functions, functional failures, failure modes and tasks that were identified during the analysis process;
- review of the implementation plan with a clear indication of the task priorities, due dates for implementation, who the responsible parties are and a clear outline of what the roles and responsibilities of the implementation manager are;
- overview of any major findings during the analysis process;
- feedback from the team regarding the analysis process and the implementation plan; and
- overview of the road ahead once the analysis has been completed and an indication of how the implementation progress will be communicated.

Column AI of the COFCATs worksheet (see appendix B figure B.6) is used to comment on the review meetings.

4.5.5.7 Tracking results – 2.5.7

The success of the analysis process will be dependent on the success of the first few analysis and implementation rounds. Embedding the process will also be dependent on how the process and its success have been perceived. Demonstrating improved reliability of critical assets and optimising long-term maintenance costs and cost per production unit will have significant benefits for the organisation and rally support from management. Communication around the implementation process is key to ensuring ongoing support.

The facilitator or the implementation manager should continuously track and report progress to show managers and other team members the progress that has been made.

Column AJ of the COFCATs worksheet (see appendix B figure B.6) is used to note any results or comments after the implementation.

4.5.6 Related AM Subjects and ISO Clauses

The following clauses of the ISO 55000 series of standards and the GFMAM AM subjects have been identified as being applicable to phases 2 and 3 of the CMF through the review and content analysis of the literature on sections 2.1.3 and 2.1.4 with a detailed description of all the relevant AM subject in appendix A. Phases 2 and 3 are considered together as they are tightly linked.

Relevant ISO clauses:

- Clause 6.1 ISO 55001 – Actions to address risks and opportunities for the asset management system (International Standards Organisation, 2014*b*, 3)

- Clause 6.2 ISO 55001 – Asset management objectives and planning to achieve them (International Standards Organisation, 2014*b*, 4)
- Clause 6.2.2 ISO 55001 – Planning to achieve asset management objectives (International Standards Organisation, 2014*b*, 4)
- Clause 7.1 ISO 55001 – Resources (International Standards Organisation, 2014*b*, 5)
- Clause 7.2 ISO 55001 – Competence (International Standards Organisation, 2014*b*, 5)
- Clause 7.3 ISO 55001 – Awareness (International Standards Organisation, 2014*b*, 6)
- Clause 8.1 ISO 55001 – Operational planning and control (International Standards Organisation, 2014*b*, 8)

Relevant GFMAM AM subjects:

- Capital Investment Decision Making (GFMAM, 2014, 16)
- Operations and Maintenance Decision Making (GFMAM, 2014, 19)
- Life-cycle Value Realisation (GFMAM, 2014, 20)
- Resourcing Strategy (GFMAM, 2014, 21)
- Configuration Management (GFMAM, 2014, 26)
- Maintenance Delivery (GFMAM, 2014, 27)
- Reliability Engineering (GFMAM, 2014, 28)
- Asset Operations (GFMAM, 2014, 29)
- Resource Management (GFMAM, 2014, 30)

4.5.7 Summary – Phase 2

The proposed ACPD process addresses key challenges within the maintenance field and the RE energy industry in SA.

The SA RE industry is faced with the lack of information sharing (documentation, drawings, maintenance and operating procedures) by international OEMs who supply and operate the RE technologies as stated in section 2.3.3. The issue is compounded by the lack of skilled resources who have adequate experience in operating and maintaining these technologies. The proposed ACPD process considers these challenges and attempts to understand what information is available and what is lacking, and also what skills and competency are required to develop adequate maintenance plans. The ACPD process also extends existing RCM processes by requiring that SJs be developed as part of the ACPD process that can be used to assist lower-skilled planners and schedulers to perform their duties. The process also improves the central management function by developing key detail in a centralised manner.

The entire process is also designed to take into account part obsolescence, LCC analysis and to develop document sets such as technical information, maintenance manuals, operating manuals, risk assessments and maintenance history that could be used to build competency in managing these technologies. The process will improve the performance of assets and provides a strategic advantage due to the fact that assets deliver enhanced reliability, and extended life spans, reduced investment and running costs, thereby improving financial performance and improving organisational reputation. The process also ensures that considerations within the ISO 55000 series highlighted by the IAM and GFMAM such as reliability engineering and maintenance delivery are taken into account, thus maintaining alignment with the ISO 55000 series requirements.

4.6 Work Planning and Control – Phase 3

The ACPD process discussed in phase 2 focuses on developing detailed ACPs for plant equipment. After maintenance objectives and strategies have been developed, work planning and control, also known as maintenance planning and scheduling, is one of the key elements that determines the success of the maintenance function. The work planning and control phase is a core function that is used to govern the way resources are utilised and help organisations become more efficient and cost-effective. The following sections all form part of the work planning and control function that is centralised and performed by the RMC.

The *Work Planning and Control* phase consists of a few key elements that are:

- Maintenance Planning – 3.1
- Weekly Maintenance Scheduling – 3.2
- Daily Maintenance Scheduling – 3.3
- Work Order Process – 3.4

These key elements and business process steps will be discussed in detail for the remainder of the phase 3 narrative.

4.6.1 Maintenance Planning – 3.1

The general planning and scheduling process has the objective of improving the productivity and quality of work delivered by the workforce and is discussed in section 2.2.5. This objective is achieved through the proper planning and coordination of people, parts, material and equipment. Maintenance planning and scheduling can also assist in setting schedule expectations which can be linked to the *Resourcing Strategy* and *Resource Management* AM subjects in appendix A sections A.1.2.4 and A.1.3.8.

4.6.1.1 Planning start and work order approval – 3.1.1

The process of starting the planning process and getting approval for WOs can be seen in figure 4.17.

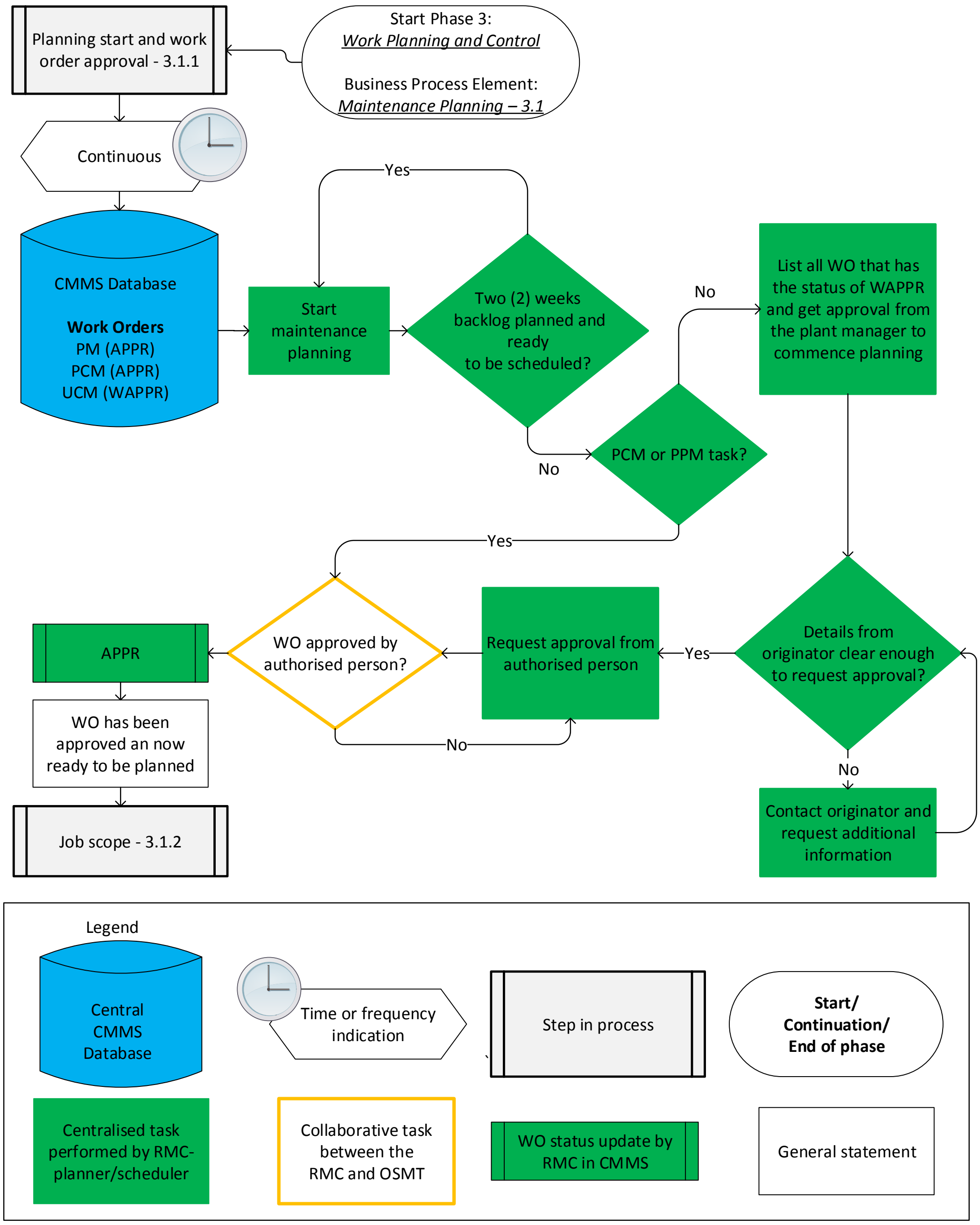


Figure 4.17: Planning start and work order approval – 3.1.1

Planning occurs on a continuous basis and should aim to have at least two weeks of planned backlog, meaning that there should be two weeks of work that has been planned and ready to be executed. The RMC planner starts by looking at all the WOs within the central CMMS that has the status of "approved" (APPR)[1] or "waiting-to-be approved" (WAPPR). These WOs consist of UCM, PCM or PM tasks (CBM, TBPM, FFM). The default status of PCM and planned PM could be APPR as these tasks are developed during the ACPD process and should have automatic approval. All UCM WOs should be in a WAPPR state and need to be approved by an authorised person.

WOs for UCM can be generated from the RMC via a request from the OSMT, or the OSMT can create WOs from the sites using the central CMMS. In the event that the RMC needs to plan work for a WO that was raised by the OSMT and the detail provided when the WO was created is insufficient to perform the planning, the RMC planner will have to request that the originator provides more detail to enable the RMC planner to start the planning and motivate for approval. The person authorised to approve the work could be located on site, like a plant manager, or a higher ranking individual off site with authority who can use the CMMS to approve a WO. After this initial planning stage the WO being processed should have an APPR status and ready to be planned.

4.6.1.2 Job scope – 3.1.2

The process of scoping maintenance jobs can be seen in figure 4.18. The RMC planner first needs to considers the WOs with the status of APPR and assign the appropriate priority codes base on the coding methodology described in appendix E. Additional coding should be applied that relates to the work plan type, outages or how the fault was found. In the case of UCM the RMC planner should consult with the OSMT to understand the priority and apply the correct code assignments. Normally an organisation that has a well-run planning department should not have more than two or three days of unplanned work. WOs should be ranked according to priority and UCM that has an impact on production should receive the highest priority.

The RMC planner also needs to note whether the work is reactive or proactive, minimum or extensive (see appendix E for clarification on minimum or extensive) that will determine the type of scoping. The RMC planner uses the work type as classification along with the work type scoping guidelines to determine how to scope the job. Only if the job is classified as extensive is there a requirement for more detailed scoping. The framework assumes that the RMC planner is centrally located at the RMC based at head office or another central station and does not have direct access to walk the site.

[1]see appendix E for WO status codes

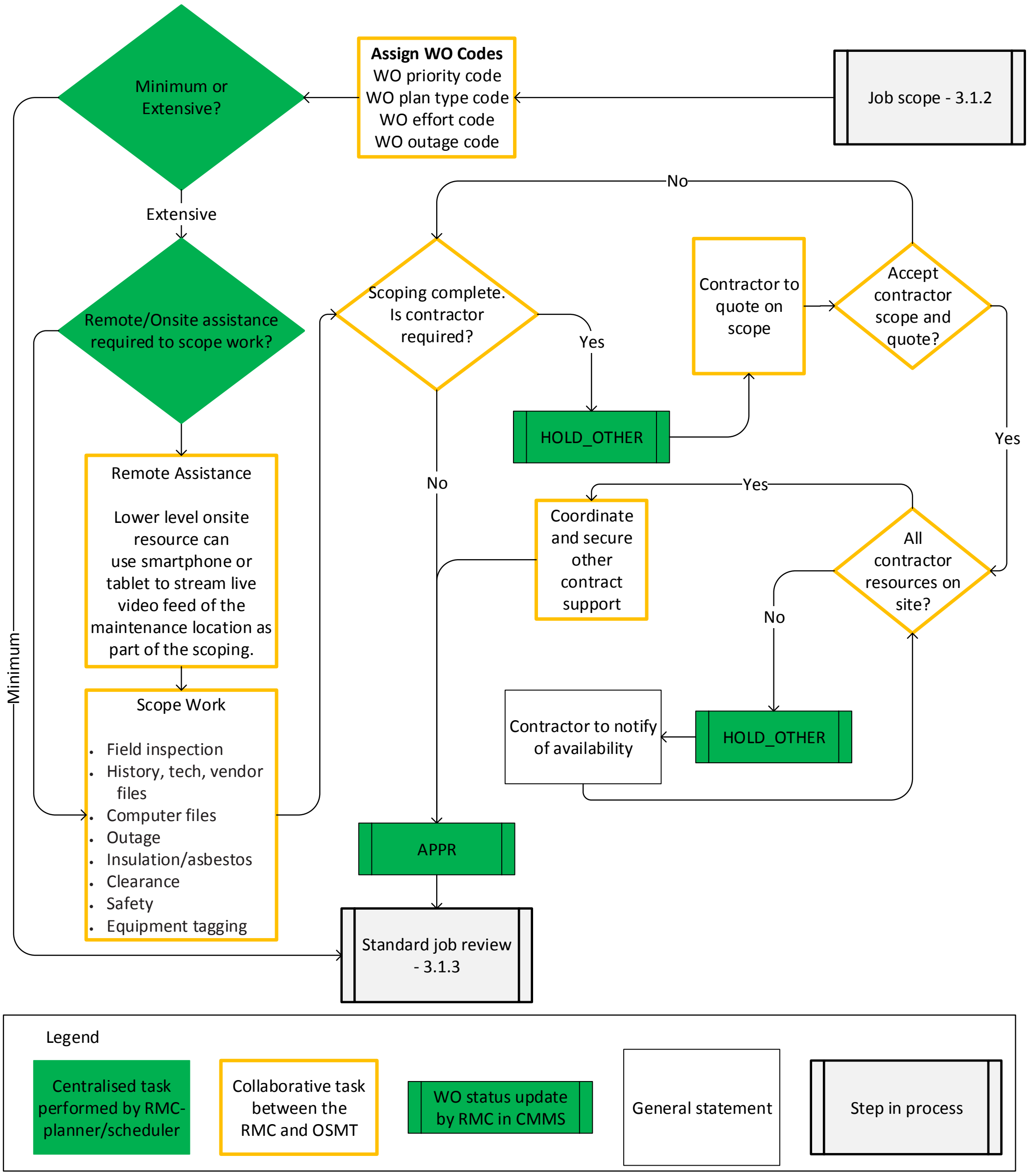


Figure 4.18: Job scope – 3.1.2

However, in the case where technology can assist and the use of field devices such as smartphones and tablets with the availability of high speed communications (Wi-Fi or cellular broadband), it could be possible for a low-level helper or more senior resource to visit the site and stream live video or take pictures at the location while discussing the job with the RMC planner. The RMC planner needs to consider previous jobs at this stage as part of the scoping. Considerations during scoping would typically include considering files related to history of equipment; technical data and vendor information; any other relevant electronic documentation; whether it is an outage of not; any issues related to safety, material safety data sheets, work space, equipment tagging; or assistance required from the maintenance and operations teams.

Once the scoping has been completed the planner in consultation with the OSMT can determine whether an external contractor is required to perform or assist with the job. If the determination is made that a contractor is required the WO status needs to change to "hold-other" (HOLD-OTHER) indicating that the WO planning is placed on hold. Once the contractor can be secured and is ready to complete the job the WO status is changed to APPR.

4.6.1.3 Standard job review – 3.1.3

The process of reviewing SJs for specific maintenance tasks can be seen in figure 4.19. All the steps in section 4.5.4 are geared towards using the availability of the ACPD team to develop the SJ in as much detail as possible and have them loaded within the CMMS system. As mentioned before a SJ is a WO that is stored within the CMMS and contains all the required information that is needed to perform a maintenance job. The ACPD process detailed in section 4.5 and specifically section 4.5.4 aims to provide RMC planners with a high level of detail via SJs when planning maintenance tasks and provides a good base for the RMC planner. In the event of WOs originating from unplanned work, the RMC planner needs to put in more effort in order to correctly plan the work. Section section 4.5.4 also specifically requires that the SJs or WO model be leaded into the central CMMS system that is accessible to the RMC planning team.

The RMC planner needs to check whether a SJ is available within the CMMS system. In the case that a SJ does exist, the RMC planner needs to review the information in the SJ in order to understand what is required from a task, spares, material, safety, manpower and tools perspective and ensure that it aligns with the scope. The RMC planner effectively starts the detailed planning process by planning the actual work and developing the work plan. Considerations during this planning process would typically include ensuring that:

- The WO clearly states the strategy and outline of the work to be completed.
- All required procedures, technical drawings and information are available.
- It has been determined whether it is an outage or not.
- Details regarding the number of persons required, skill levels, work hours per person and total job duration are specified.
- The parts list and parts for the job is available.
- Any special tools or contractors that are required are available.

- Estimates of the costs of the job have been made.
- Any other aspects related to safety and risk have been addressed.
- If relevant, the SJs reflect all the planning requirements.

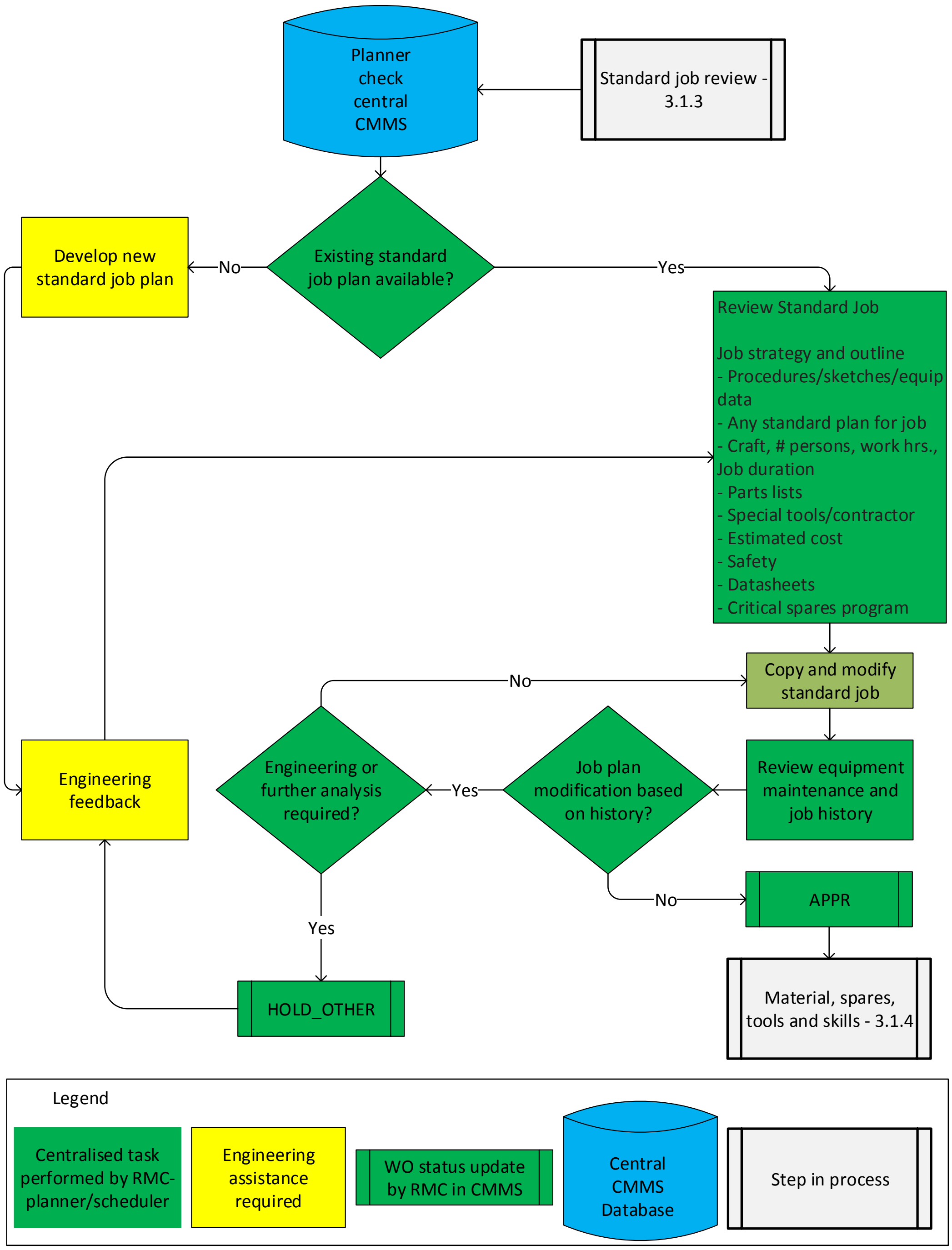


Figure 4.19: Standard job review – 3.1.3

The RMC planner can then continue to review the job history from the CMMS or from the mini-file (refer to section 4.5.4) and try to identify anything that was noted on previous WO feedback or note that will require the SJ to be altered or improved. Should no changes be required to the SJ the RMC planner can continue with the process. However, should the RMC planner identify any changes that are required within the SJ, the SJ needs to be updated. Furthermore, should any input be required from the engineering department with regards to the changes, the WO should be placed on hold, "hold-other" (HOLD-OTHER), until the engineering department has reviewed and advised on the recommended updates to the SJ. Once the recommended updates have been complete the WO status can be change to APPR and the RMC planner can continue with the process.

The overall planning system should incorporate feedback from technicians and RMC planners to improve future maintenance plans. Job plans need to improve systematically over time in order for an organisation to evolve into a procedures-based organisation. At the beginning and at the conclusion of large complex jobs the OSMT and RMC planners need to work together to assemble all the relevant information as the basis of an SJ plan.

4.6.1.4 Material, spares, tools and skills – 3.1.4

Ensuring that all the required resources are in place for maintenance work is one of the core functions of the planning department, as discussed in section 2.2.5.1. The process of scheduling the requirements in terms of spares, materials, tools and skills during the planning process can be seen in figure 4.20. The RMC-based planning function can add significant value in terms of productivity by identifying and coordinating spare parts or materials. The planning function has been noted as one of the key reasons OSMTs buy into the RMC-based planning concept. Section 4.5.4.5 mentions that planning can assist with the parts identification to ensure that the parts are available before the job is executed. In non-centralised environments the planning department can still stage (prepare) parts, but in a centralised planning department this might not be possible. Looking at the SJ can also assist the planners to identify the required materials, spare parts, special tools and skills.

Based on the scope and details of the job, the RMC planner should be able to determine whether any materials or spare parts are required. The planner can check in the centralised CMMS system whether the required material or spares are available on the site (at the REPP) store or a centrally located store. The RMC planner can collaborate with OSMT to confirm the availability or unavailability of items.

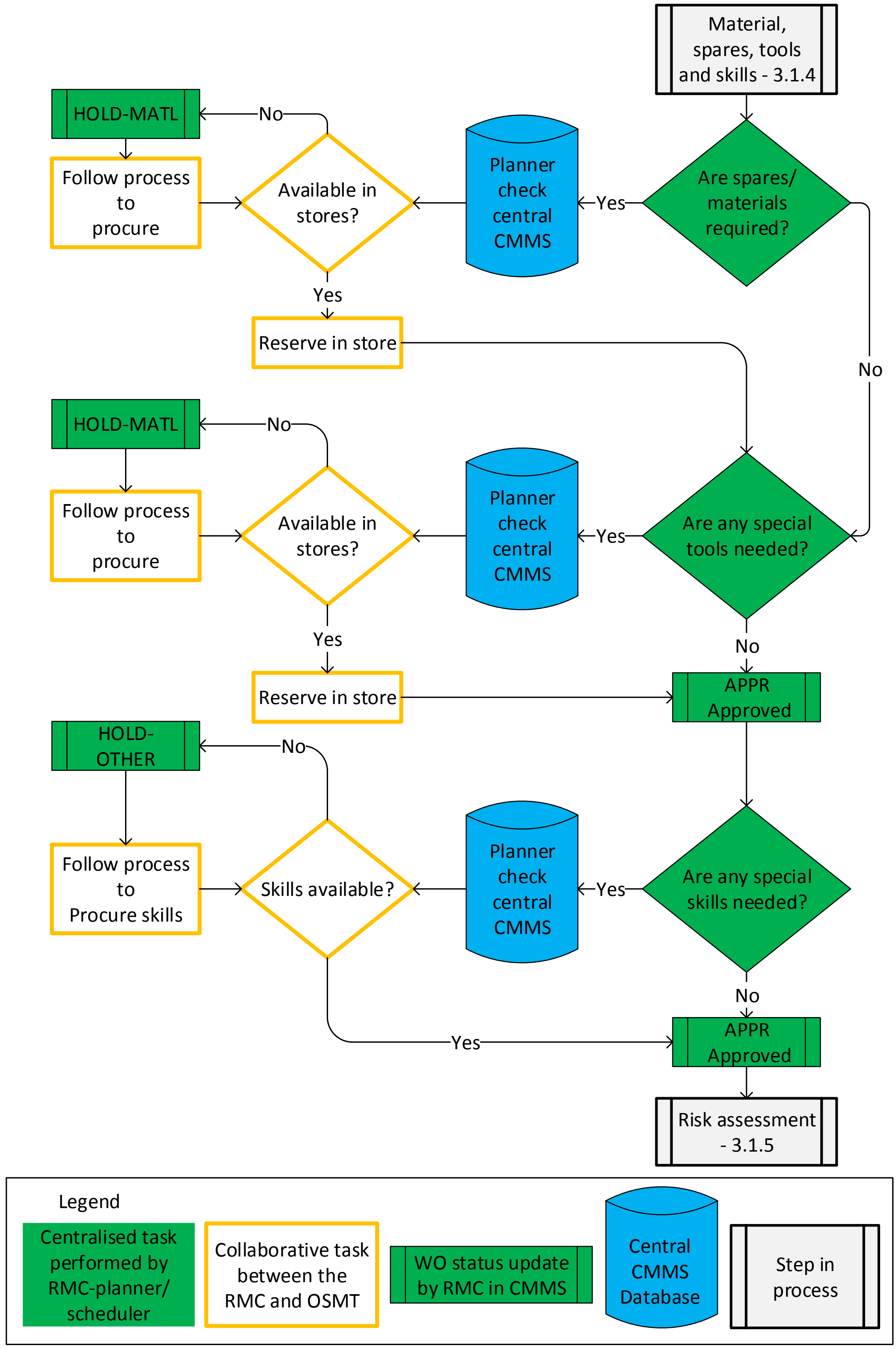


Figure 4.20: Material, spares, tools and skills – 3.1.4

In the event that materials or spare parts are not available the RMC planner should change the WO status to "hold-for-material" (HOLD-MATL) indicating that materials or spare parts need to arrive or be procured before the work can be completed. If the materials or spare parts are in store or have become available the WO status can be changed back to APPR. A similar process would be followed for special tools.

Jobs will also often require that specialised skills be required to perform work. The demand for specialist skills will be very important within the RE sector as skilled people might not be readily available and could take some time to contract or appoint people. The RMC planner needs to be acutely aware of this and if specialist skills are required and not available the planner needs to change the WO status to HOLD-OTHER until the specialist skills have been secured. Once all the spares, material, special tools and special skills requirements have been met the planner can check that the WO status is in the APPR state and can continue with the planning process.

4.6.1.5 Risk assessment – 3.1.5

The process of considering the associated risks and risk assessments during the planning process can be seen in figure 4.21. Risk assessments are discussed in section 2.2.5.4 and section 4.5.4.4 and highlight the need to consider all the risks involved when performing a maintenance job or any other work. Secondly, suitable strategies need to be developed to mitigate risk of something going wrong.

The RMC planner should never under any circumstances take safety for granted and needs to contemplate the possibility that the conditions of the job will have safety considerations for the OSMT. If there are any specific safety concerns the RMC planner needs to attach any relevant information to the WO and update the mini-file. Additional information may also be available in the mini-file of the SJ. The RMC planner can consult with the OSMT to ensure that everyone understands the key risks involved such as confined space, live electricity, gas or chemicals. The risk assessments should be developed as part of the SJ, but in the case of UCM the RMC planner in collaboration with the OSMT will develop the risk assessment and write the process to protect maintenance personnel if necessary. The risk assessment needs to be attached to the WO as part of the SJ. If no special risks outside of the SJ risk assessment are identified the planner continues to define the required permits (permit-to-work).

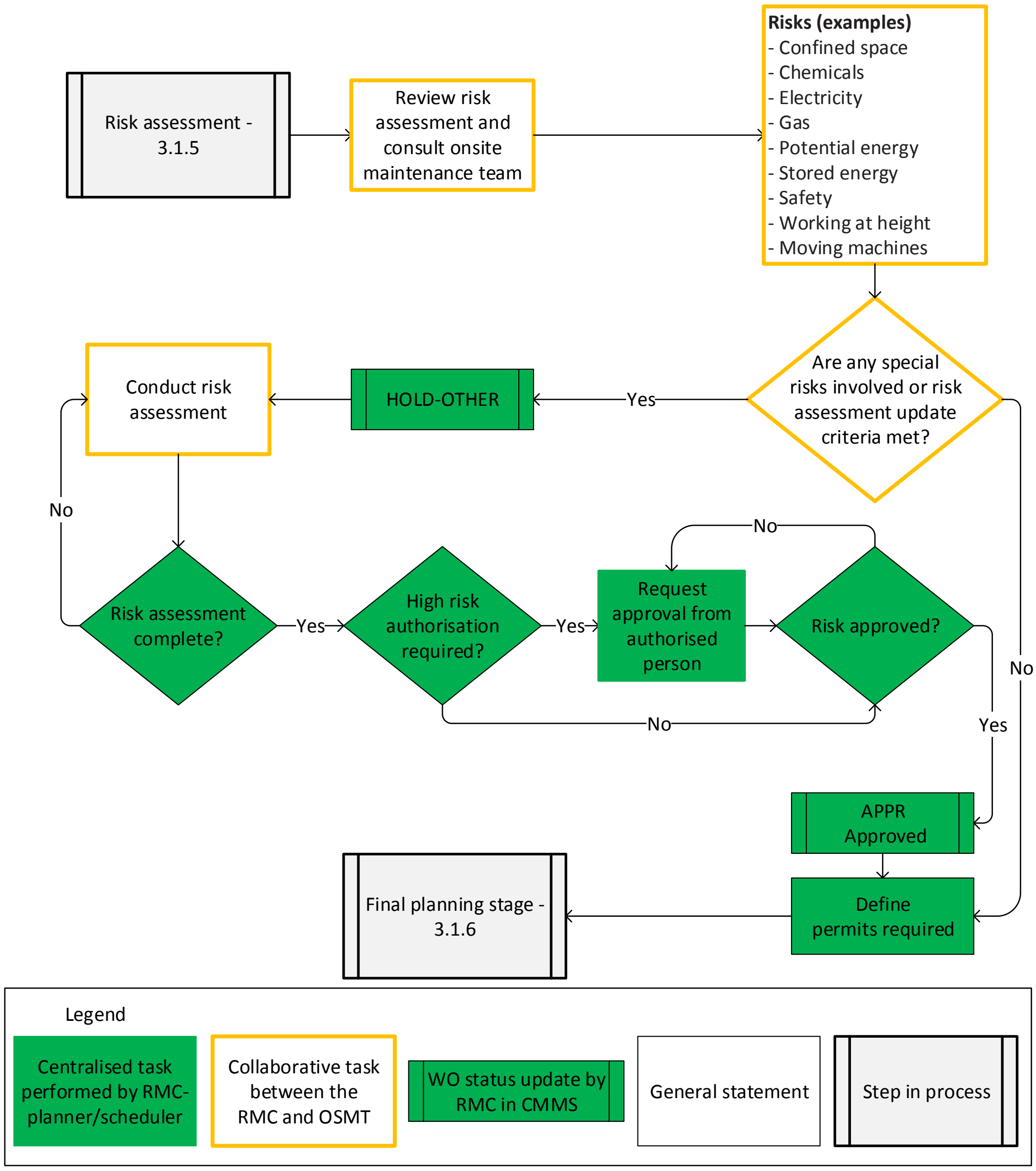


Figure 4.21: Risk assessment – 3.1.5

There may, however, be cases where special risks or changes in normal conditions have been identified that will require an update to the risk assessment. If this scenario occurs the WO status needs to change to HOLD-OTHER. A new risk assessment then needs to be completed and, based on the outcome, the approval of the risk may be escalated to an internal safety authority. Only once the risk assessment has been approved and the go-ahead provided to continue the work can the RMC planner change the WO status to APPR and continue the planning process and define any required permits.

4.6.1.6 Final planning stage – 3.1.6

The process of completing the planning stage can be seen in figure 4.22. The final stages of the planning process require the RMC planner to assemble the complete work package. At this stage if there are any feedback items that need to be presented to the engineering department the RMC planner needs to note them and inform the engineering team. The RMC planner should also have an estimated cost for the job. In the case where the job was not planned and budgeted for the costs need to be approved. The RMC planner then needs to place the WO on hold, HOLD-OTHER, and follow the required procurement or approval process (procurement process not part of the scope of this study). Once the job has budget approval or already had pre-approval the RMC planner can continue to assemble the work package and change the WO status to "waiting-to-be-scheduled" (WSCH).

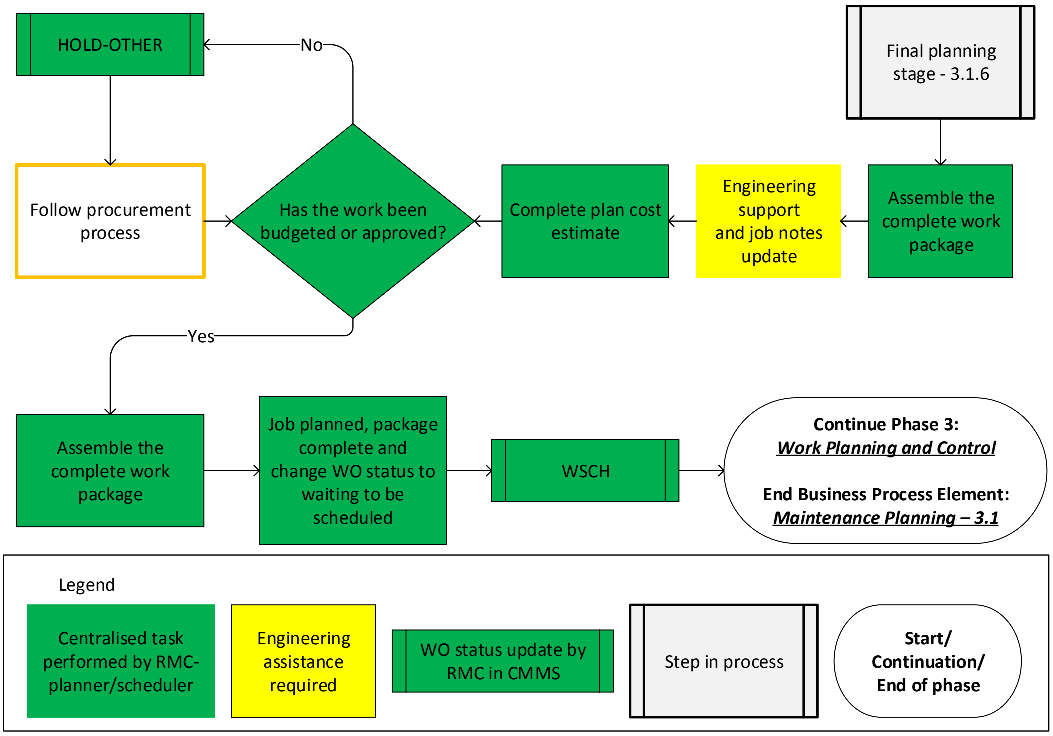


Figure 4.22: Final planning stage – 3.1.6

4.6.2 Weekly Maintenance Scheduling – 3.2

Good maintenance scheduling is part of good maintenance planning as highlighted in section 2.2.5.2. The maintenance scheduling process is key to determining the sequence of maintenance tasks and the resources that will be required. The scheduling function also keeps the maintenance crew from lowering productivity and prevents the OSMT from only focusing on high-priority reactive work. Maintenance scheduling occurs over three dominant horizons:

- (three months to one year) – Medium Range or Master Schedule
- (one week) – Weekly Schedule
- (one day) – Daily Schedule

The following section will deal with the weekly and daily scheduling. The RMC scheduler will drive and complete most of the advance scheduling tasks. However, within the centralised environment collaboration between the RMC scheduler and the OSMT will have to take place to facilitate good scheduling.

4.6.2.1 Start scheduling – prepare WHAF – 3.2.1

The process of starting the OWAS process, part of the scheduling principles described in section 2.2.5.2 can be seen in figure 4.23. During the planning phase (section 4.6.1) the status of WOs are changed to WSCH once they have been planned as well as the WOs that could not be started from the previous week. The RMC scheduler has access to the central CMMS system where all the WOs with the status of WSCH can be viewed. These WOs will be considered during the OWAS.

At the end of each week (Friday, for example) the RMC scheduler needs to prepare the OWAS for the following week. The process starts by the OSMT updating the CMMS to reflect the Work Hours Availability Forecast (WHAF), that is the number of hours that the OSMT has available to perform work. This should be completed by around 09:00 every Friday morning. The RMC scheduler needs to know what the forecast is for available working hours for the following week to help determine how many and what jobs should be selected from the backlog. The WHAF needs to be obtained from the OSMT (email, CMMS, video conference, conference call) or via the central CMMS. Factors such as leave and training can affect the OSMT availability and available working hours for the following week. Carry-over hours from the previous week also need to be considered. Any WOs that were part of the previous OWAS and were not yet started need to have the status changed back to WSCH and become part of the pool of WOs that need to be scheduled.

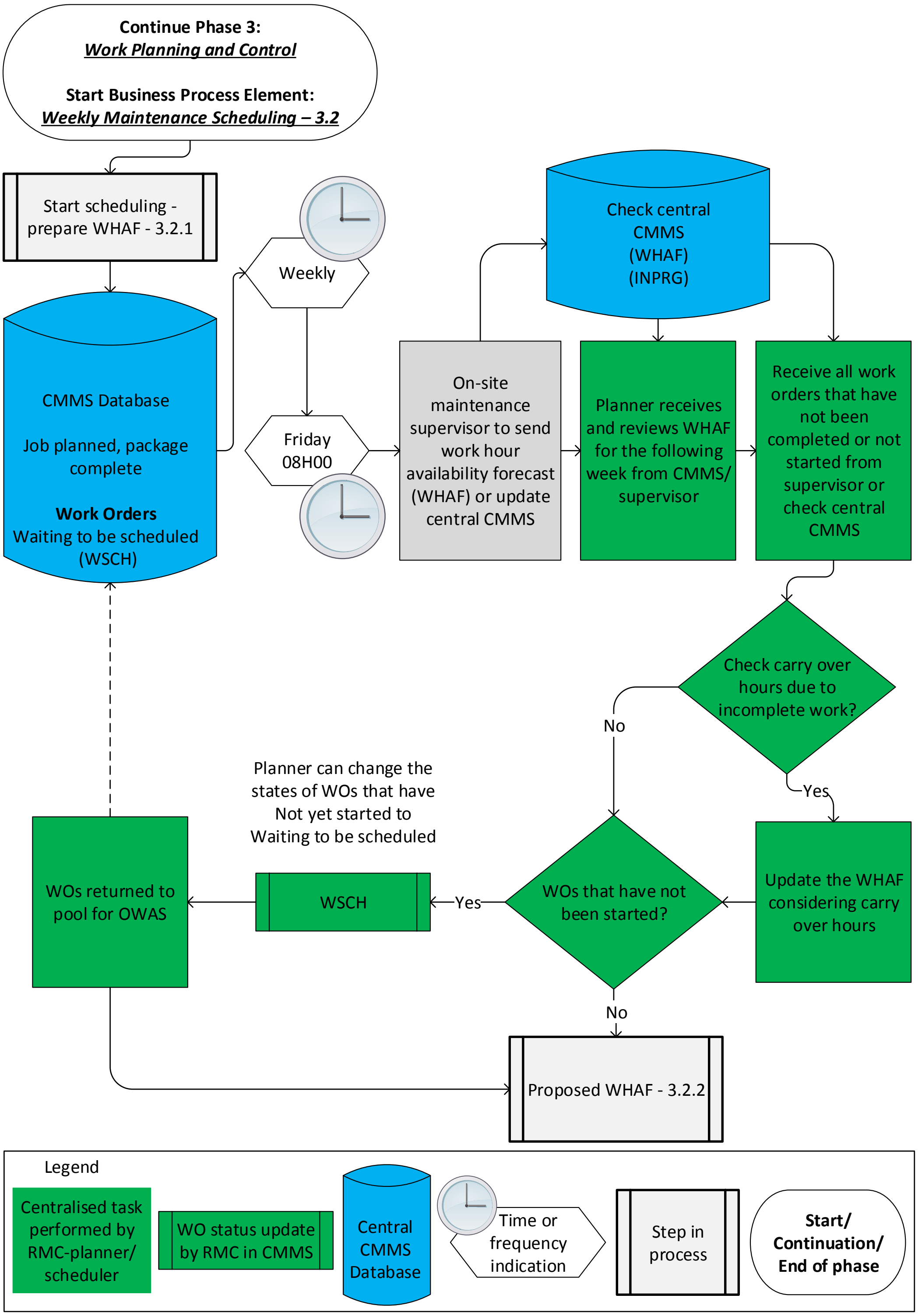


Figure 4.23: Start scheduling – prepare WHAF – 3.2.1

4.6.2.2 Proposed WHAF – 3.2.2

The process of developing an initial proposed OWAS starts by gathering the required information as seen in figure 4.24. The purpose of the OWAS is only to identify the WOs that need to scheduled for the following week and does not specify who will be performing the work or on what day. In the process of preparing the allocation of WOs based on theWHAF the RMC scheduler needs to sort the WOs in the backlog (work that has been planned). The RMC scheduler also has to sort the backlog items that are relevant to a specific REPP. The scheduler needs to assess the amount of available time within the WHAF and the number of backlog hours and only assign WOs equivalent to the number of available work hours (100%), not more (120%), and not less (80%) as per section 2.2.5.2.

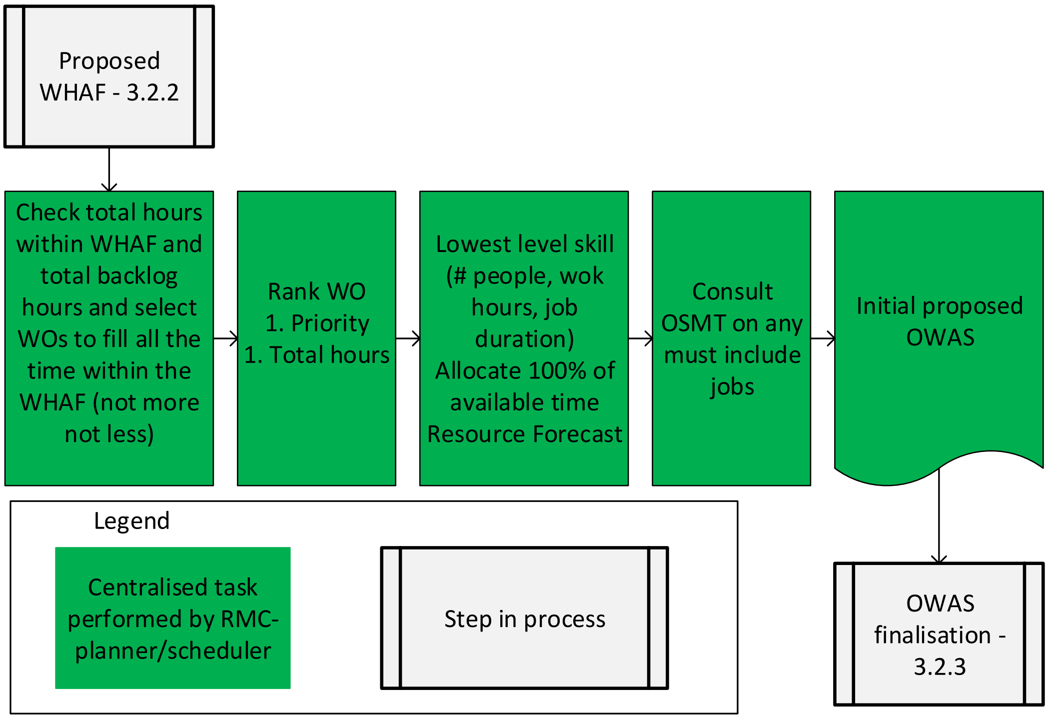


Figure 4.24: Proposed WHAF – 3.2.2

The scheduler then needs to rank the WOs. Appendix E outlines the priority codes for the WO system. All WOs with the priority of 0 or 1 need to be attended to first as this will be emergency or reactive work. In an ideal world only lower priority pro-active work would be available to schedule as this would mean proactive work is being done to prevent emergency or urgent work. Priority-1 work is regarded as urgent and generally needs to be addressed to mitigate or restore lost plant production capacity or a critical HSE-related issue. The RMC planner thus needs to firstly address urgent work, but lower priority reactive work should only be scheduled after higher priority proactive work.

Another means of prioritising WOs is by considering the time they will take to complete. Ideally the jobs with longer required work hours need to be scheduled first as this will enable allocating smaller jobs into remaining time gaps. An exception is made to the time rule when smaller jobs are on the same system as the larger jobs. Scheduling work related to the same system together can improve productivity and decrease downtime as OSMTs do not have to move to a different location, demobilise, travel or move tools and equipment. This scheduling decision means that even though there is a lower-priority job, if it can be associated with a higher priority job it should be scheduled. In the case of a wind farm, work on adjacent wind turbines can be assigned, or work on the wind turbine and its corresponding balance of plant components like the step-up transformer. On a solar site this could mean assigning work to inverters that are in proximity or addressing an issue with the PV field.

A maintenance team that is the correct size to meet maintenance requirements will not be forced to only deal with high-priority jobs. This means that they should be able to complete all work and will not need to use ageing of WOs to surface long overdue maintenance. Understanding the required number and type (skills) of maintenance resources can be obtained through completing the ACPD process outlined in phase 2 of the CMF, section 4.5.

The RMC scheduler completes the initial allocation process either until there are no more OSMT work hours available to schedule, no more qualified labour available or there are no more WOs in the backlog. The RMC scheduler then compiles the initial proposed OWAS that needs to be tabled at the weekly meeting.

4.6.2.3 OWAS finalisation – 3.2.3

The process of finalising the OWAS can be as seen in figure 4.25. Once the RMC scheduler has completed the initial proposed OWAS the second phase needs to be completed that is a more collaborative process towards finalising the OWAS. The collaborative approach is taken as the RMC scheduler is not based on the REPP and does not always understand the challenges, nuances and needs on the REPP.

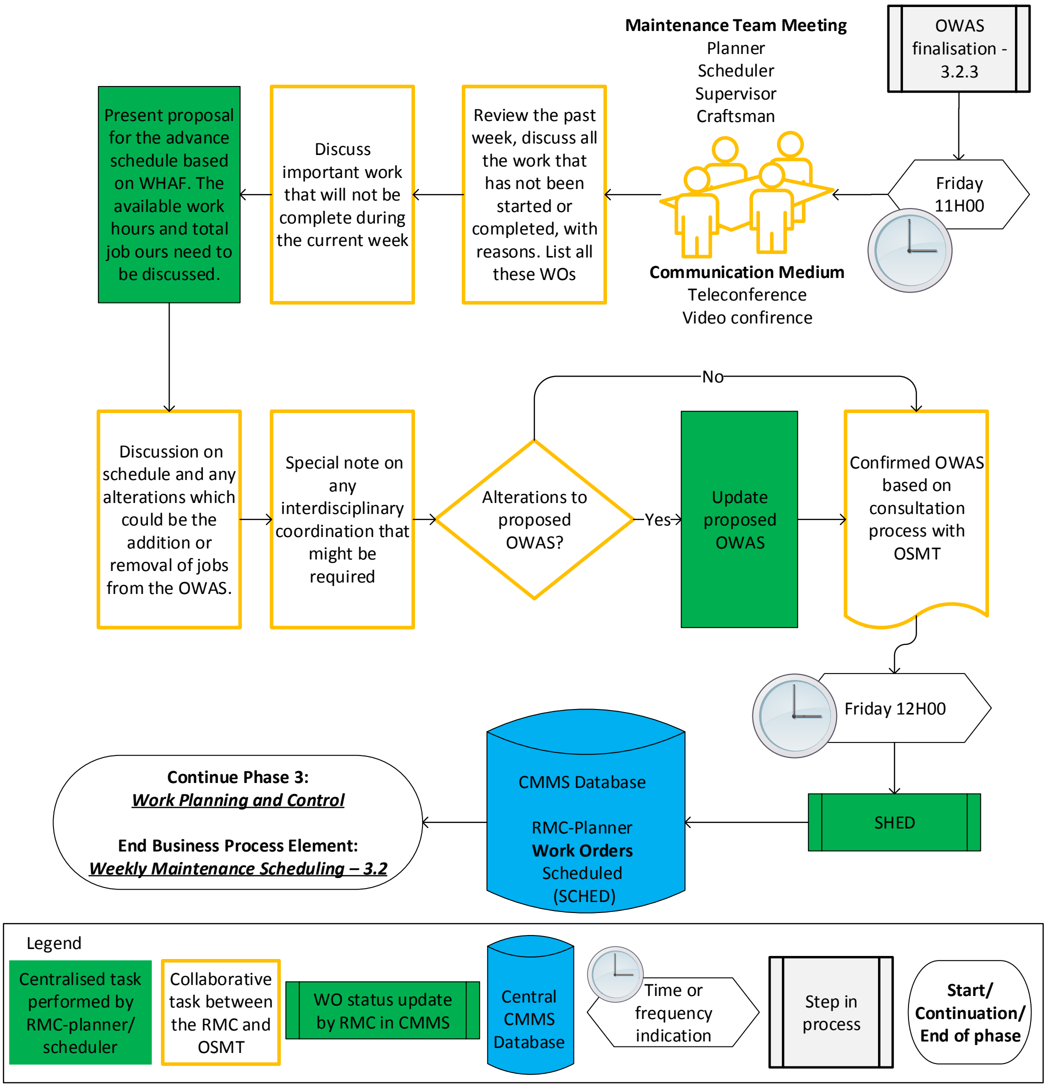


Figure 4.25: OWAS finalisation – 3.2.3

The team meeting can be scheduled for around 11:00 on Friday as it would allow enough time for the RMC scheduler to complete the initial proposed OWAS. The team that meets should consist of the RMC scheduler, planner and the OSMT (technicians, supervisors, maintenance manager, operations representatives, plant manager and plant engineers can also attend if required). The meeting can take place using teleconference or video conference facilities. All members of the meeting should have access to the central CMMS system, email or screen sharing via video conference to see the proposed OWAS. Ideally the maintenance manager (RMC supervisor in absence of maintenance manager role) should coordinate and implement this weekly meeting to legitimise the scheduling process and to ensure that the meeting occurs week after week and year after year. The overall objective of the meeting should be to finalise the OWAS in a collaborative manner. In the event that the required attendees are not able to make the meeting a suitable representative needs to take their place. Based on section 2.2.5.2 the meeting should have a core set agenda that first covers:

1. Review the schedule compliance score from the previous week for each of the OSMTs and identify key reasons why the schedule was not met if this was the case and itemise important jobs that were not completed (10 minutes).
2. Discuss the schedule for the current week and highlight important jobs that will not be completed and why they will not be completed (10 minutes).
3. RMC scheduler presents proposed OWAS for following week for each OSMT with a clear indication of total available labour hours and total hours of jobs scheduled. The RMC scheduler at this stage had already previously discussed any WOs that had to be included with the OSMTs (20 minutes).
4. Discuss and schedule and any alterations that could be the addition or removal of jobs from the OWAS (10 minutes).
5. Discuss any special notice of interdisciplinary coordination among OSMTs if there is a need. Contractor coordination can also be discussed (10 minutes).
6. Review the AM policy, maintenance policy and how each of the maintenance tasks relate to organisational objectives and AM objectives. Doing this step reinforces the Line-of-Sight and lets the crew on the ground understand what their impact is on the OSP (5 minutes).

The meeting should be led by the maintenance managers (RMC supervisor in the absence of a maintenance manager role). If an operations coordinator is available as part of the team, they should be the person to fine-comb through all the listed jobs and comment on what jobs are acceptable, where potential challenges might be, and what jobs to schedule for what day based on plant activities. In the case that an operations coordinator is not available this role can be taken by any of the OSMT that have a key understanding of all the activities and challenges happening on-site for the coming week and how this would impact maintenance scheduling decisions.

The team should highlight any proposed changes to the initial proposed OWAS. In the case where changes are required the RMC scheduler can complete the recommended alterations and publish the confirmed OWAS that is a list of all the WOs that maintenance are required for the following week. Ideally the schedule should be available within the central CMMS and can be published to operations, maintenance, engineering, and plant management as it helps to encourage plant personnel to think ahead and reduce interruptions of the OWAS.

4.6.3 Daily Maintenance Scheduling – 3.3

Work orders need to be scheduled on a daily basis and occur in a continual cycle. The formal process of daily scheduling should assign specific WOs to specific people with the aim of accounting for all available labour hours and completing the work set out within the OWAS (weekly schedule). The process of scheduling is aimed at completing more work but specifically more preventative work, and is also aimed an improving future and present availability of the plant. In an environment where supervisors are available on site, this task should be performed by the supervisors, but in this study the Daily Maintenance Schedule (DMS) will be completed by the RCM scheduler in collaboration with the OSMT.

Daily scheduling is not simply a form filled out at the end of the day for the next day's activities. Even more important, it is not simply handing out WOs at the start of the shift. Throughout each day, the RMC and OSMT use the daily schedules as a tool to control work.

4.6.3.1 Start daily scheduling – 3.3.1

The process of starting the daily maintenance scheduling can be seen in figure 4.26. The RMC scheduler can start the scheduling day, at 07:00, by looking at the central CMMS system and reviewing the proposed DMS composed the previous day (DMS for the following day should be completed at the end of the previous day). The RMC scheduler then either checks the CMMS system to see whether there are any staff that have called in sick or have become unavailable. If the CMMS system does not contain the relevant information the scheduler can consult with the OSMT to confirm team availability for the day and the following day. The RMC scheduler then needs to adjust the proposed DMS based on this information and also take it into consideration for the following day when the proposed DMS will be compiled later in the day. The scheduler needs to assign all available work hours of each technician to specific WOs as outlined in section 2.2.5.2.

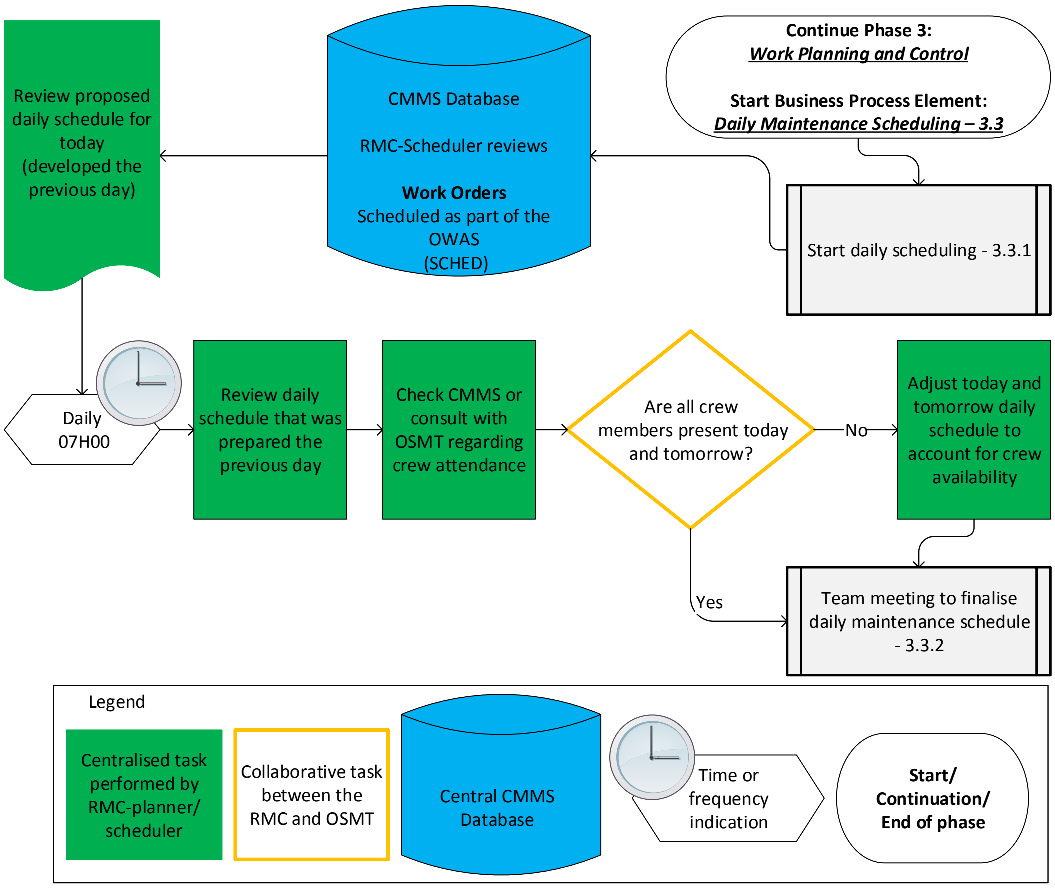


Figure 4.26: Start daily scheduling – 3.3.1

4.6.3.2 Team meeting to finalise daily maintenance schedule – 3.3.2

The process of finalising the daily maintenance scheduling can be seen in figure 4.27. The team meeting can be scheduled for around 08:00 every day as it would allow enough time for the RMC scheduler to complete the initial proposed DMS. The team that meets should consist of the RMC scheduler, planner and the OSMT (technicians, supervisors, maintenance manager, operations representatives, plant manager and plant engineers can also attend if required).

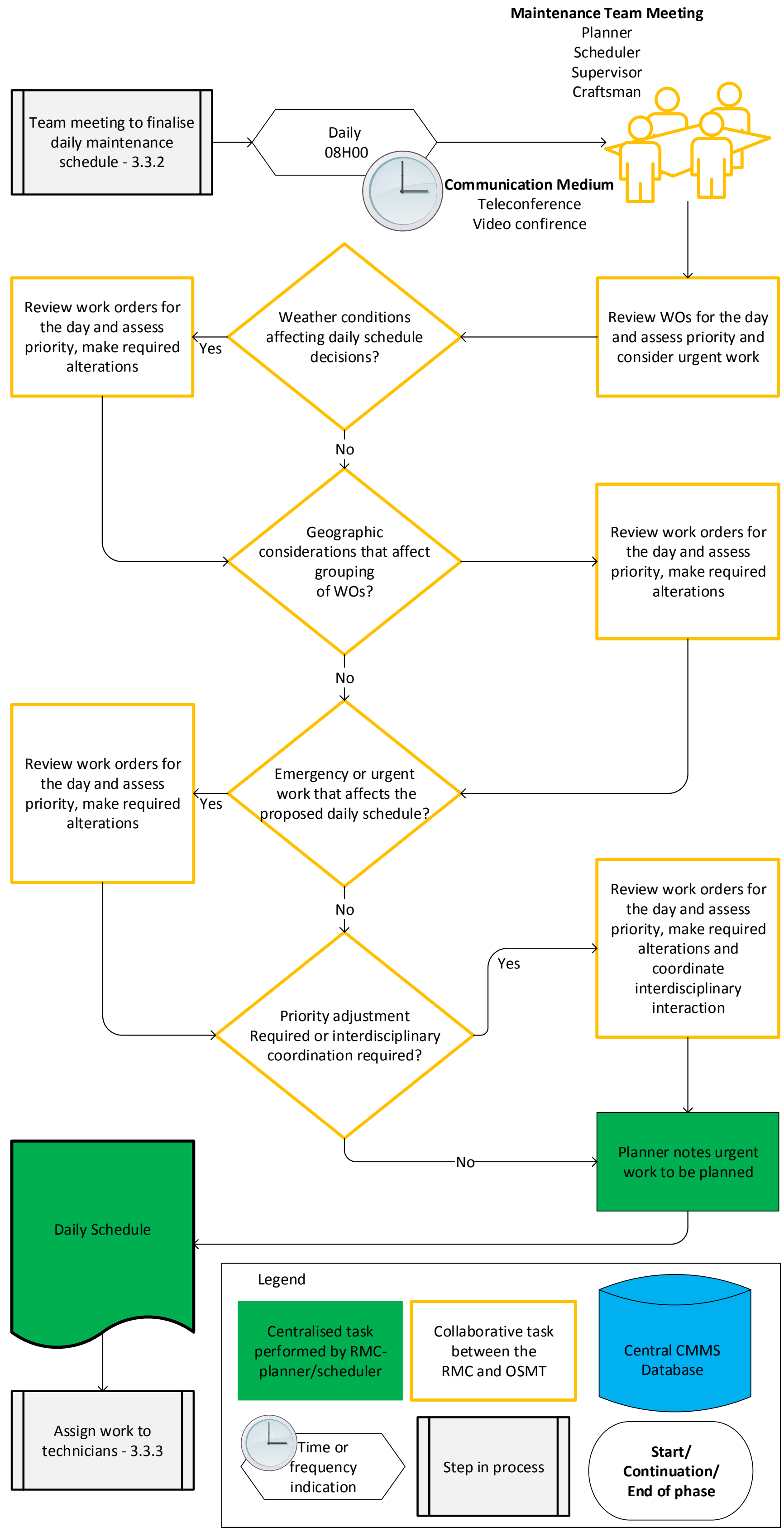


Figure 4.27: Team meeting to finalise daily maintenance schedule – 3.3.2

The meeting can take place using teleconference or video conference facilities. All members of the meeting should have access to the central CMMS system, email or screen sharing via video conference to see the proposed DMS for the current day. Ideally the maintenance manager (RMC supervisor in absence of maintenance manager role) should coordinate and implement the daily meeting to legitimise the daily scheduling process and to ensure that the meeting occurs day after day and year after year. The overall objective of the meeting should be to finalise the DMS for the current day in a collaborative effort. In the event that the required attendees are not able to make the meeting a suitable representative needs to take their place. The meeting should have a core set agenda that first covers:

1. Review of the proposed WOs for the day to understand what they entail and start considering whether they have been set at the correct priority and if there are any other urgent jobs that need to be considered (10 minutes).
2. Discuss the weather forecast for today and tomorrow and determine if any alterations should be made to the DMS based on weather conditions (10 minutes).
3. Discuss the geographical location of all the WOs and determine if any alterations should be made to the DMS based on the location of jobs. It might be beneficial to rearrange WOs to perform jobs in the same area or the same systems (10 minutes).
4. Discuss any emergency work for today and tomorrow and determine if any alterations should be made to the DMS based on urgent work that needs to be completed (10 minutes).
5. Discuss any special notice of interdisciplinary coordination among maintenance crews where there is a need and a final check on all the WO priorities. Contractor coordination can also be discussed (10 minutes).
6. Review the AM policy, maintenance policy and how each of the maintenance tasks relate to organisational objectives and AM objectives. Doing this step reinforces the Line-of-Sight and lets the crew on the ground understand what their impact is on the OSP (10 minutes).

Any urgent work that needs to be planned needs to be highlighted to the RMC planner. After the meeting the DMS is confirmed. Any newly identified work would ideally be started the following week as the current week should already be filled by the OWAS, more planning and coordination could improve the overall efficiency, it is more ideal to complete specified proactive work. Compliance to the OWAS schedule should be promoted to encouraged OSMT to complete more work. The RMC scheduler and OSMT should regard adhering to the OWAS as a high priority. However, if work is really urgent and required to restore production or to improve safety the RMC scheduler should redirect work.

Once the daily team meeting has been completed the scheduler needs to publish the DMS that contains all the required revisions.

4.6.3.3 Assign work to technicians – 3.3.3

The process of assigning work to the OSMT as part of the DMS can be seen in figure 4.28. The morning team meeting should conclude around 09:00 after which the RMC scheduler completes any reassignment (from the proposed DMS) of work to specific technicians based on the outcome of the meeting.

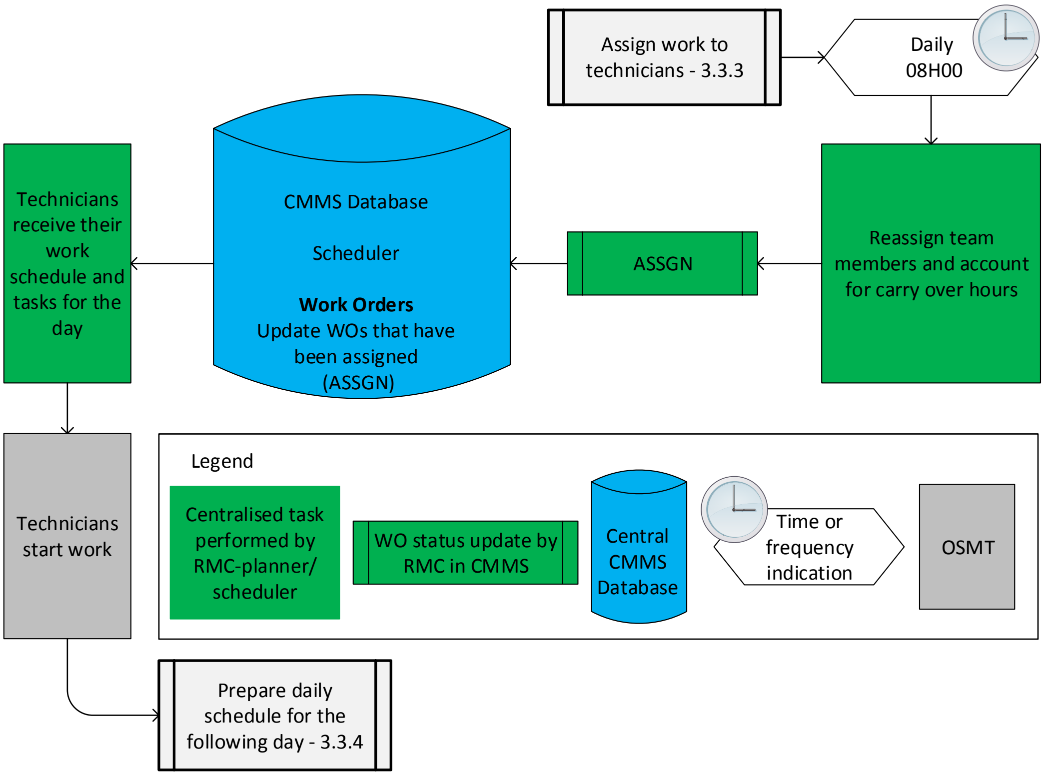


Figure 4.28: Assign work to technicians – 3.3.3

The final assignment of specific WOs to specific technicians and the order in which the jobs should occur for the day are updated in the CMMS and the WO status is changed to ASSGN. The RMC scheduler then provides the technicians with their WOs for the day or the technicians can retrieve the WOs from the central CMMS and start their work for the day. Publishing the DMS timeously allows the technicians to prepare for the work by reviewing the information within the SJ and any related manuals, data sheets, procedures and safety requirements as well as the tools and equipment needed for the job. This can greatly improve productivity.

4.6.3.4 Prepare daily schedule for the following day – 3.3.4

The process of developing the proposed DMS for the following day can be seen in figure 4.29. After the team meeting and the technicians have been assigned their respective work for the day, the RMC scheduler can use the information gathered during the meeting to develop the proposed DMS for the following day.

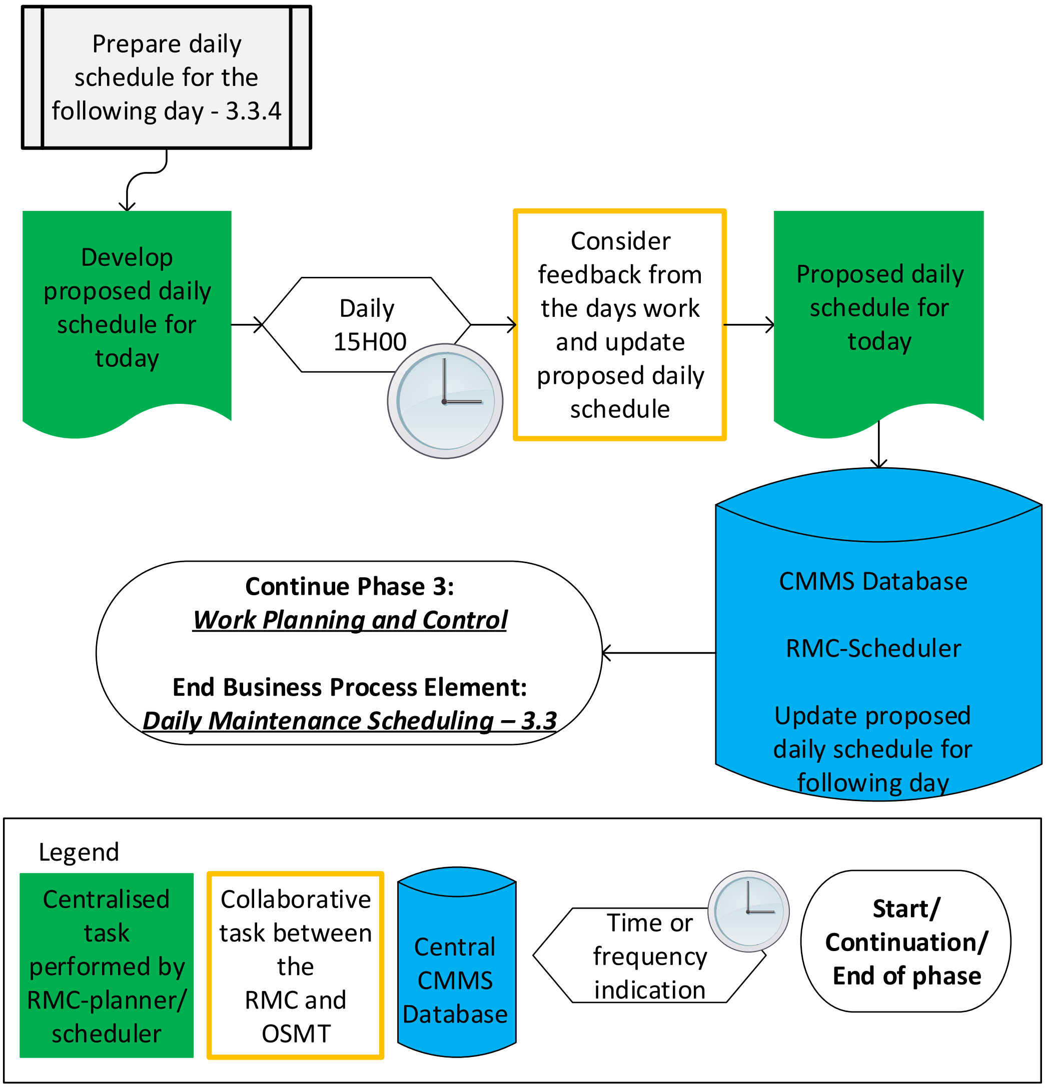


Figure 4.29: Prepare daily schedule for the following day – 3.3.4

Around 15:00 the RMC scheduler can follow up with the OSMT to see how far they have progressed with their work and whether any carry-over hours should be considered for the following day and update the initial proposed DMS for the following day. The CMMS system can be updated to reflect the proposed DMS for the next day.

4.6.4 Work Order Process – 3.4

One of the most valuable tools that can be used to improve the effectiveness of maintenance is a WOS, which is discussed in section 2.2.5.3. Some of the key features of a WOS is that it can assist the maintenance team to obtain important information related to maintenance work; avoid inconsistency in the use of words, statements, and conversations; and provides a standardised format for information and its flow. The term WO is used as it literally translates into a order to work after the required authorisations have been completed. The following sections will outline the WOS.

4.6.4.1 Work order start – 3.4.1

The process of starting WOs as part of the DMS can be seen in figure 4.30. The DMS has been set with all OSMTs receiving their respective WOs for the day that can also be accessed via the central CMMS and printed if required. Modern mobile workforce tools such as tablet computers and mobile enabled CMMS systems allow OSMTs to have access to detailed WO and SJ information while in the field and negates the need for any paper-based interaction. The OSMTs can complete all the required check sheets and WO feedback submissions while deployed in the field without the need to return to the office. The OSMTs would have received their respective WOs during and after the morning meeting and would have time to prepare by reviewing the WOs for the day and understand the job requirements from a time, spares, materials and tools perspective.

The OSMT will start the day with new WOs or continue with carry-over WOs from the previous day. In either case the WO status needs to change to "in-progress" (INPRG) indicating that the work has started. In the event that the WO is not completed during the day, the OSMT needs to notify the supervisor or the RMC to provide feedback that the work will not be completed during the day. The RMC scheduler can take this into account when preparing the proposed DMS for the following day. However, if the OSMT manage to complete the WOs, they need to start the process of closing out the WO before commencing with the following WOs.

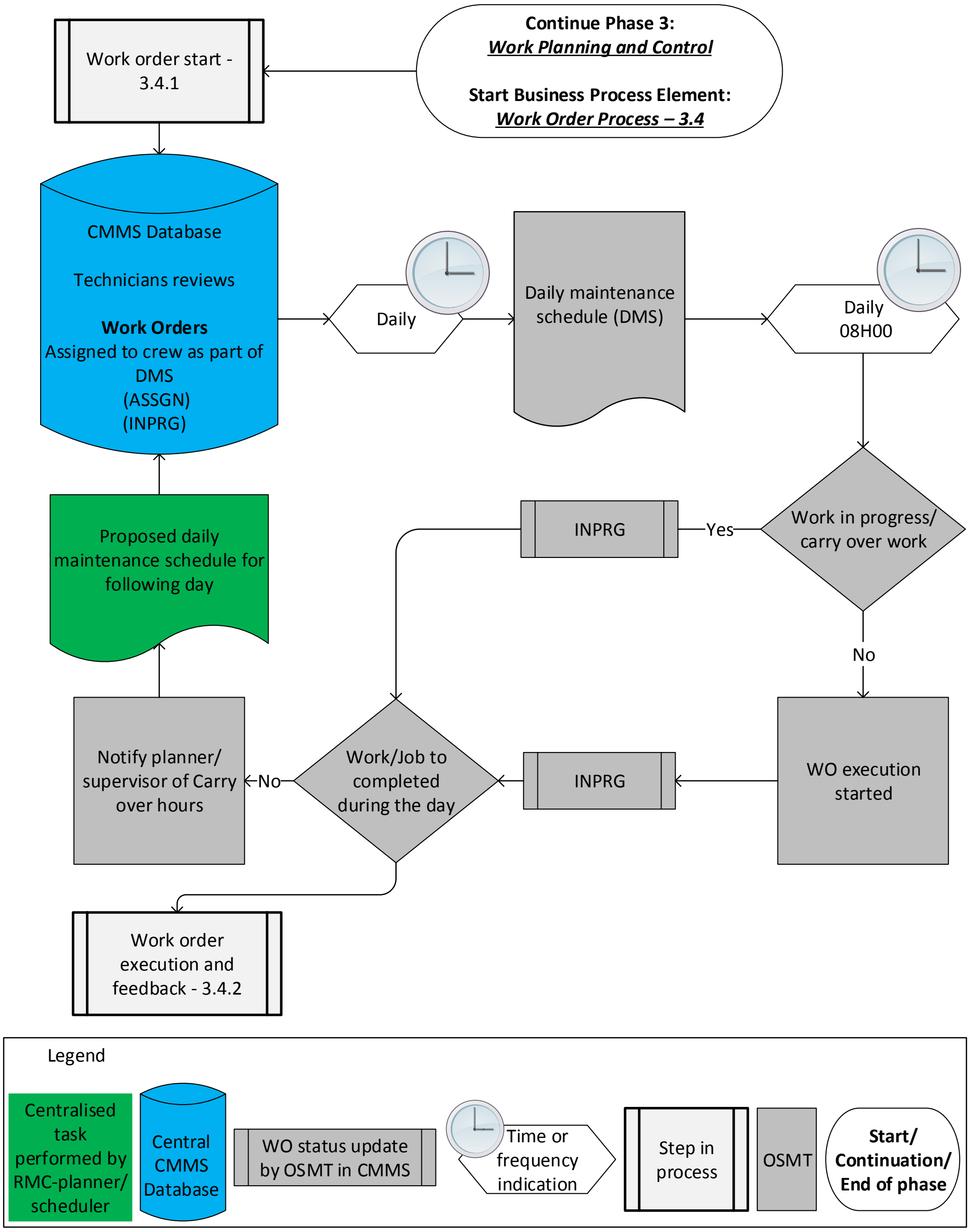


Figure 4.30: Work order start – 3.4.1

4.6.4.2 Work order execution and feedback – 3.4.2

The process of completing WOs and providing the required feedback can be seen in figure 4.31. The OSMT complete WOs during the course of the day and should notify the RMC once a WO is complete and not wait until the end of the day. Situations might occur where emergency work needs to be performed and the RMC or the supervisor needs to redirect work accordingly. All related permits should be returned once a specific job has been completed.

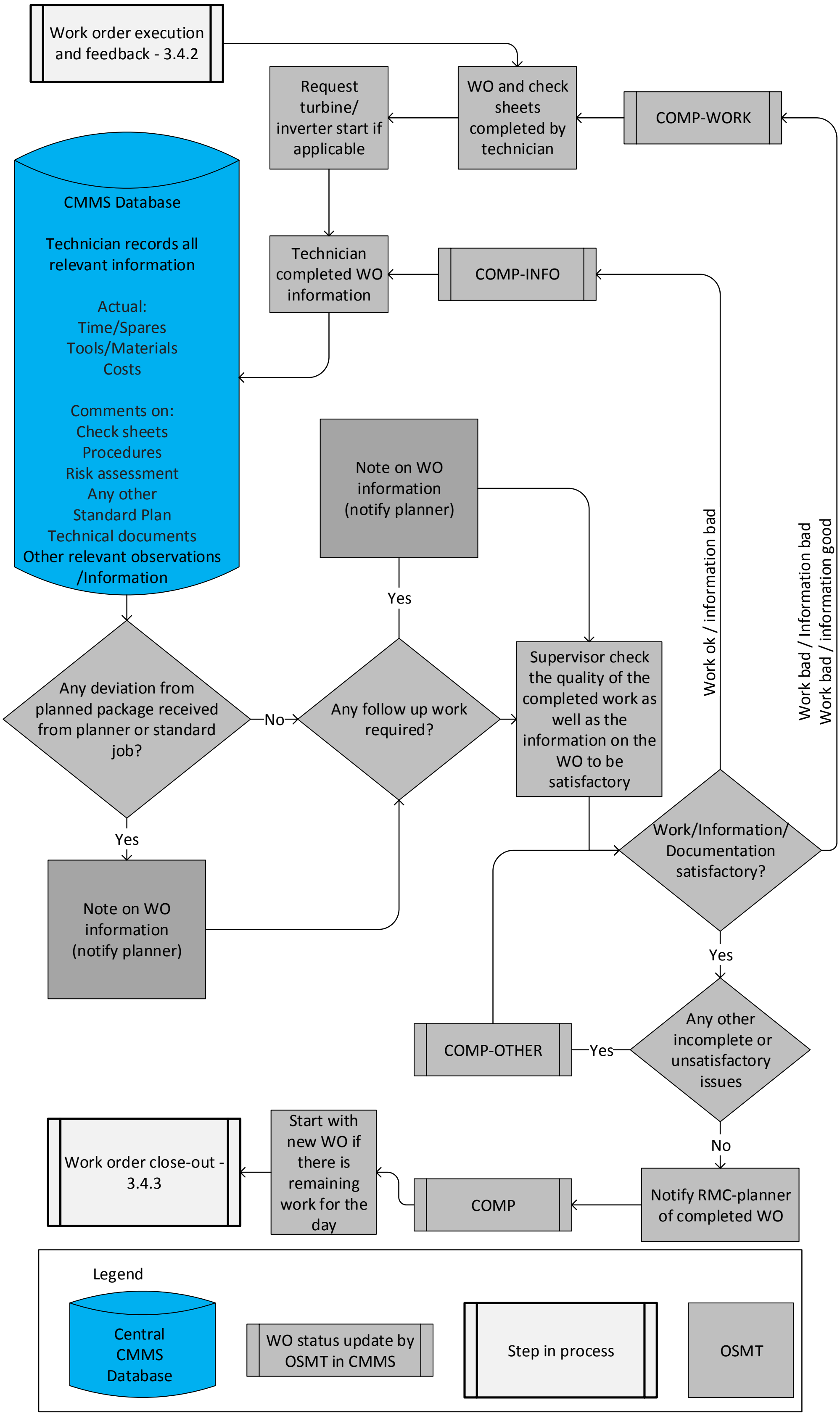


Figure 4.31: Work order execution and feedback – 3.4.2

Once the OSMT has completed the work they can request that the RMC start up turbines or solar inverters that were shut down, if applicable. Other related equipment can also be checked by the RMC or OSMT after start-up to ensure that there are no concerns after the maintenance, to which the OSMT can immediately attend.

The OSMT then has to complete all the relevant data that needs to be updated as part of the WO feedback that could include:

- actual time, cost, spares and materials used;
- adequacy of procedures, risk assessment, technical documentation;
- recommended changes to the PM task or frequency;
- follow-up work to be planned;
- other general feedback regarding the planning, OSMT skills and safety;
- the number and names of people and their specific Craft and grade;
- the number of labour hours for each person on the job with clear start and finish time of the job;
- a clear explanation of any variation on total planned job time estimates if the variance is larger than 20%;
- cases might arise where the problem was not clearly defined within the original plan and if possible be more clearly articulated by the OSMT;
- articulated details of any deviated action that was taken if the job did not run according to the plan with a report outlining any special problems and solutions;
- accurate report on the quantity of spare parts(with part number) and material used that was not part of the planned job;
- feedback on special tools that were required and not part of the planned job;
- sending any marked up drawings to the relevant parties;
- providing feedback on any changes that affect the equipment technical information and indicate new serial numbers, model numbers and return relevant manufacturer literature that can be used for maintenance purposes;
- any other valuable information such as bearing clearances (radial and axial), coupling conditions, temperatures, gap clearances; and
- providing clear feedback on what can be done to improve future plans.

The OSMT needs to make special notes on whether there were any deviations from the planned package received from planner or SJ, if there would be any need to consider changes in the maintenance plan or whether a follow-up WO is required. If there are notes indicating any of the aforementioned items it should clearly be indicated on the WO feedback and the RMC planner needs to be notified should there be any major concerns. The feedback can be directly updated through the CMMS and mobile devices (laptops/tablet PC) or can the written down and provided as feedback though other media such as paper or electronic forms.

Plans that have a history section attached encourage feedback as technicians can see that the plans are being updated using their recommendations. The history information should clearly show the date and which RMC planner made the change.

The supervisor checks the actual work and WO feedback information for quality and completeness. In the scenario where the OSMT does not have a dedicated supervisor the senior person within the OSMT can fulfil the role of checking the actual work and quality of feedback. Should the supervisor find that the work has not been performed and completed in a manner that is satisfactory or shows poor quality the WO should should change the status to “completed-work” (COMP_WORK) indicating the that WO cannot be processed further until the OSMT has completed the work at an acceptable quality standard. Similarly, should the information or feedback supplied by the OSTM when completing the WO status needs to be changed to “completed-information” (COMP_INFO) indicating that the information needs to be sufficiently completed by the OSMT. Should there be another reason that the WO cannot proceed to final close out stage the supervisor can change the status to “completed-other” (COMP-OTHER) until the requirements have been met.

Should the quality of the work and information be sufficient the supervisor can change the WO status to “completed” (COMP) indicating that the work has been completed and that all requirements have been met. The WO is only completed and not closed. Closing the WO is covered in the following phase. The RMC planner should notified, via CMMS notification, SMS, email, telephone or messenger application, that the WO has been completed and ready for close out.

4.6.4.3 Work order close-out – 3.4.3

Closing WOs is one of the most important tasks undertaken by the planning department. Considering figure 4.32, the RMC planner needs to drive the process of ensuring that all the required information and details of the work performed are clear and can be used to improve future maintenance practices and maintain the equipment database.

The OSMT will complete WOs on a continuous basis throughout the day, which forms part of the OWAS and DMS. The OSMT notify the RMC planner directly or via CMMS is that a WO has been completed and ready to be reviewed. The RMC planner can check the CMMS and see all the WOs that have the status “completed” (COMP) indicating the work has been completed in the field and contains all the required feedback.

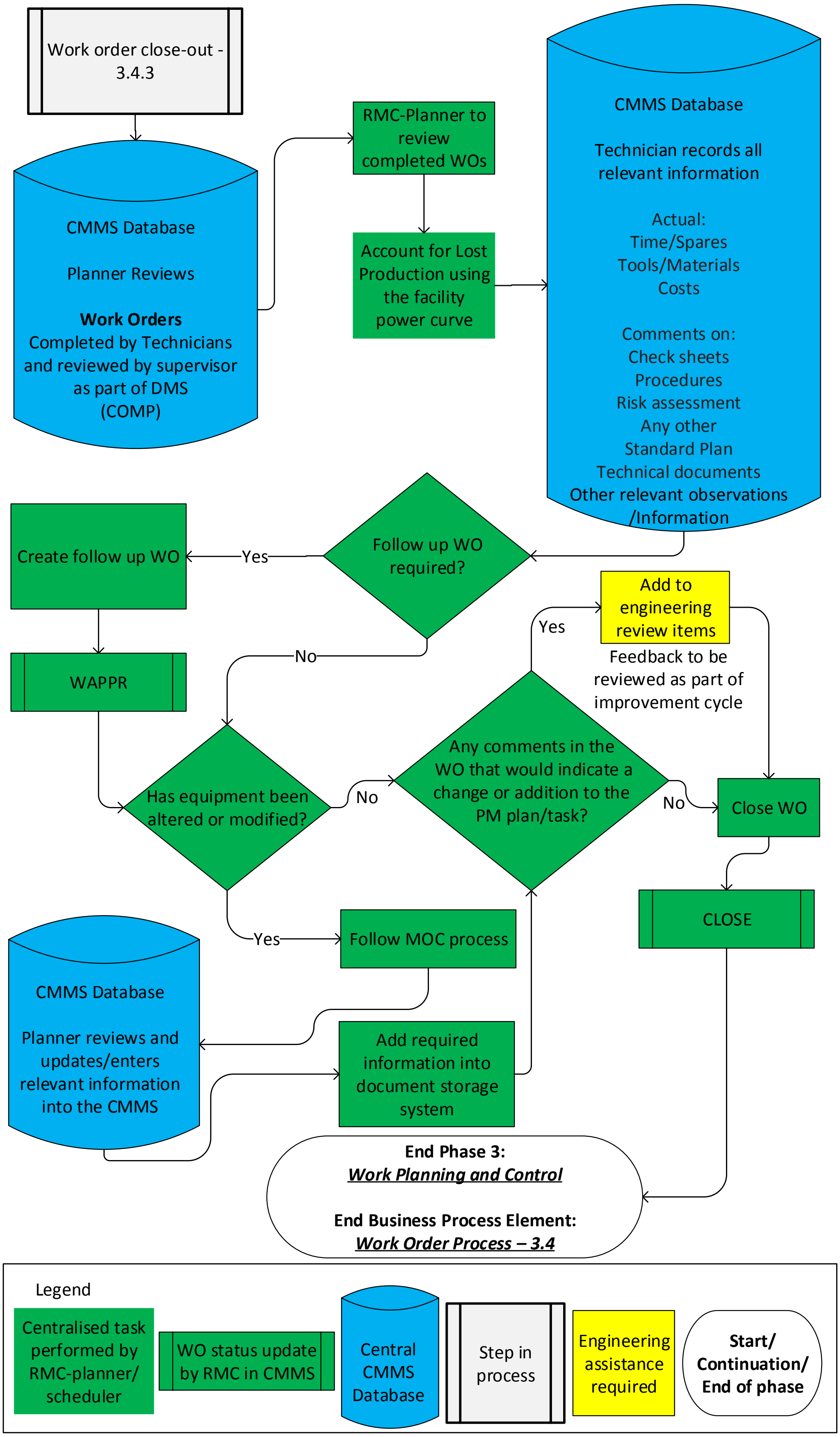


Figure 4.32: Work order close-out – 3.4.3

The RMC planner needs to review the information supplied by the OSMT after completing the WO. The Power Purchase Agreements (PPA) within the REIPPPP requires that an IPP develop a facility power curve that is used to estimate the power production, given specific resource conditions. The RMC planner can use the FPC to estimate the amount of energy production that was lost during the maintenance period.

The RMC planner attempts to move each job further along the learning curve by reviewing all the other information to ensure that it is accurate. On occasion the RMC planner will need to consult with the OSMT to obtain more detail or information to supplement the feedback and job details. The RMC planner needs to review and update information related to:

- actual time, cost, spares and materials used;
- adequacy of procedures, check lists, risk assessment, technical documentation;
- recommended changes to the PM task or frequency;
- follow-up work to be planned;
- other general feedback regarding the planning, OSMT skills and safety;
- the number and names of people and their specific Craft and grade;
- the number of labour hours for each person on the job with clear start and finish time of the job;
- a clear explanation of any variation on total planned job time estimates if the variance is larger than 20%;
- cases that might arise where the problem was not clearly defined within the original plan and if possible be more clearly articulated by the OSMT;
- articulated details of any deviated action that was taken if the job did not run according to the plan with a report outlining any special problems and solutions;
- accurate report on the quantity of spare parts(with part number) and material used that was not part of the planned job;
- feedback on special tools that were required and not part of the planned job;
- sending any marked-up drawings;
- providing feedback on any changes that affect the equipment technical information and indicate new serial numbers, model numbers and return relevant manufacturer literature that can be sued for maintenance purposes;
- any other valuable information such as bearing clearances (radial and axial), coupling conditions, temperatures, gap clearances; and
- providing clear feedback on what can be done to improve future plans.

OSMTs want to provide good feedback if it supports the management and communication around the planning function. Good feedback from the OSMT can be supported by making it mandatory to provide feedback, providing training to the maintenance team and emphasise the importance of the OSMT feedback in improving the maintenance programme, ensuring that planners and schedulers attend all the daily and weekly meetings to emphasise the role that the OSMT plays in scoping and planning work and create a team environment.

The RMC planner also needs to note any routine failure to provide quality feedback by members of the OSMT. The behaviour can be noted in the CMMS, tracked and should be brought to the attention of management if there are any serial offenders. The RCM planner directly updates the information in the CMMS.

The planner needs to take note if any follow up WO is required and create the WO that will go into the WAPPR WO pool and needs to be planned by the RMC planner at a later stage.

The RMC planner then needs to note any major changes that have occurred or are required. Technical information such as parts used or drawings, procedures, SJs, risk assessments might need to be updated and need to be part of a larger Management of Change (MOC) is not part of the scope of this study). The MOC process is core to *Configuration Management* AM subject as per appendix A section A.1.3.4. After the MOC process has been completed the RMC planner can update the relevant information in the CMMS that could relate to the asset register, parts inventory or other relevant technical and financial information held within the CMMS. Furthermore, should any drawings, data-sheets, procedures, risk assessments, SJs be updated they might need to be stored within the central document repository and linked to the relevant SJ.

One of the key considerations is whether there is a change required to the maintenance plan (task type or actions) or frequency of maintenance intervals. These changes should be noted and addressed with engineering as part of the continuous improvement process discussed in phase 4, section 4.7.2 of the CMF (continuous improvement process is treated as a separate process).

After all of the feedback and required changes have been actioned or noted for action and the RMC planner is satisfied that the quality of the WO feedback and information the WO can be closed and the status changed to "completed" (COMP). The WO is then considered as closed and completed.

4.6.5 Summary – Phase 3

The work planning and control (planning and scheduling) is a critical element within the maintenance function and governs the manner in which resources are used. The process is developed to support the preceding ACPD process and the following phase, phase 4, is related to the continuous improvement process. The proposed process focuses on a centralised management, considers the skills scarcity and depends on the ACPD process to develop very detailed maintenance plans and SJ that could be planned by a lower-skilled planning and scheduling department. The process also further enforces the Line-of-Sight through reviewing the AM policy, AM objectives and how they relate to the maintenance tasks and how they impact on the OSP.

4.7 Competency Management and Continuous Improvement – Phase 4

The *Competency Management and Continuous Improvement* phase is intended to address key skills challenges within the SA RE industry, reinforce a culture of AM, integrate feedback from the work planning and control as well as management reviews into the improvement cycles to enhance the ACPD process and general AM practices. Phase 4 fulfils requirements of the ISO 55000 series and GFMAM 39 subjects that are related to the practice of competency management and continuous improvement. Phase 4 also focuses on the management of organisational culture, competency of employees and competency of the organisation related to AM. Phase 4 thus draws on the IAM subject groups of Organisation and People (refer to section 2.1.4.5) and Risk and Review (refer to section 2.1.4.6). Key subjects contained within these sections relate to leadership, organisational culture, organisational structure and competency management (refer to section A.1.5 in appendix A), risk assessment and management, asset performance and health monitoring and AMS monitoring (refer to section A.1.6 in appendix A).

Phase 4 of the CMF is key to adopting the "Plan-Do-Check-Act" approach to the entire AMS. Furthermore, understanding the performance of the AMS requires measurement at varying levels of granularity to provide insight on the AMS performance. The top management level information is summarised while the detail increases within the rest of the organisation based on the decisions and issues that are being managed. Having accountabilities for reporting of measures, acting on them and managing individual performance are clear requirements for good practice.

The *Competency Management and Continuous Improvement* phase consists of a few key elements that are:

- Competency Management – 4.1
- Asset Care Plan and Asset Management System Improvement – 4.2

These key elements and business process steps will be discussed in detail for the remainder of the phase 4 narrative.

4.7.1 Competency Management – 4.1

The challenges in the SA RE industry have been highlighted in section 2.3.2. These challenges not only affect SA – the global RE industry is faced with similar challenges. Effectively and actively managing competency can help address the skills challenges over time.

The organisational culture has a significant impact on AM practices and the overall performance of the organisation and needs to be actively managed. The work force related to the scope of the AMS are responsible for the overall AM activities and managing the performance of assets. Prudent AM requires a competent work force, who are adequately trained and skilled to deliver on the OSP, SAMP and AMPs. Managing employee and organisational competency requires a competency framework that can be used to identify competency gaps and develop improvement plans. The identified competency requirements and competency status need to be reviewed periodically as part of a continuous improvement process.

4.7.1.1 Organisational Culture – 4.1.1

The importance of organisational culture is discussed in section 2.1.4.5 and further expanded in section A.1.5.2 in appendix A. Competency management needs to consider employees who are responsible for anything that falls within the scope of the AMS. The workforce on the plants is responsible for O&M, ensuring that the plant performs according to the required standard and performance targets. Management teams are often based at a head office location and removed from the day-to-day operations while having to make key strategic decisions. Irrespective of what the functional roles are, having a common culture is key to achieving cohesive AM practices.

Discussions in section 2.1.4.5 and section A.1.5.2 in appendix A highlight that all aspects of the organisation and its performance is affected by the culture that exists within. Culture influences AM, safety, performance, financial management and reputation. Proactive management of organisational culture is one of the key elements required to nurture good AM practices. There needs to be a clear stance from the organisation on what type of culture it would like to foster and instil to ensure success. Extracting the real benefit from AM requires that the culture moves away from short-term thinking, being risk averse and closed to innovative thinking. Gaining the benefit from AM will require that the culture fosters long-term strategies, develops and values business processes, makes the effort to benchmark the organisation against best practices and is innovative. The process of managing culture is shown in figure 4.33 and is part of the overall competency management process.

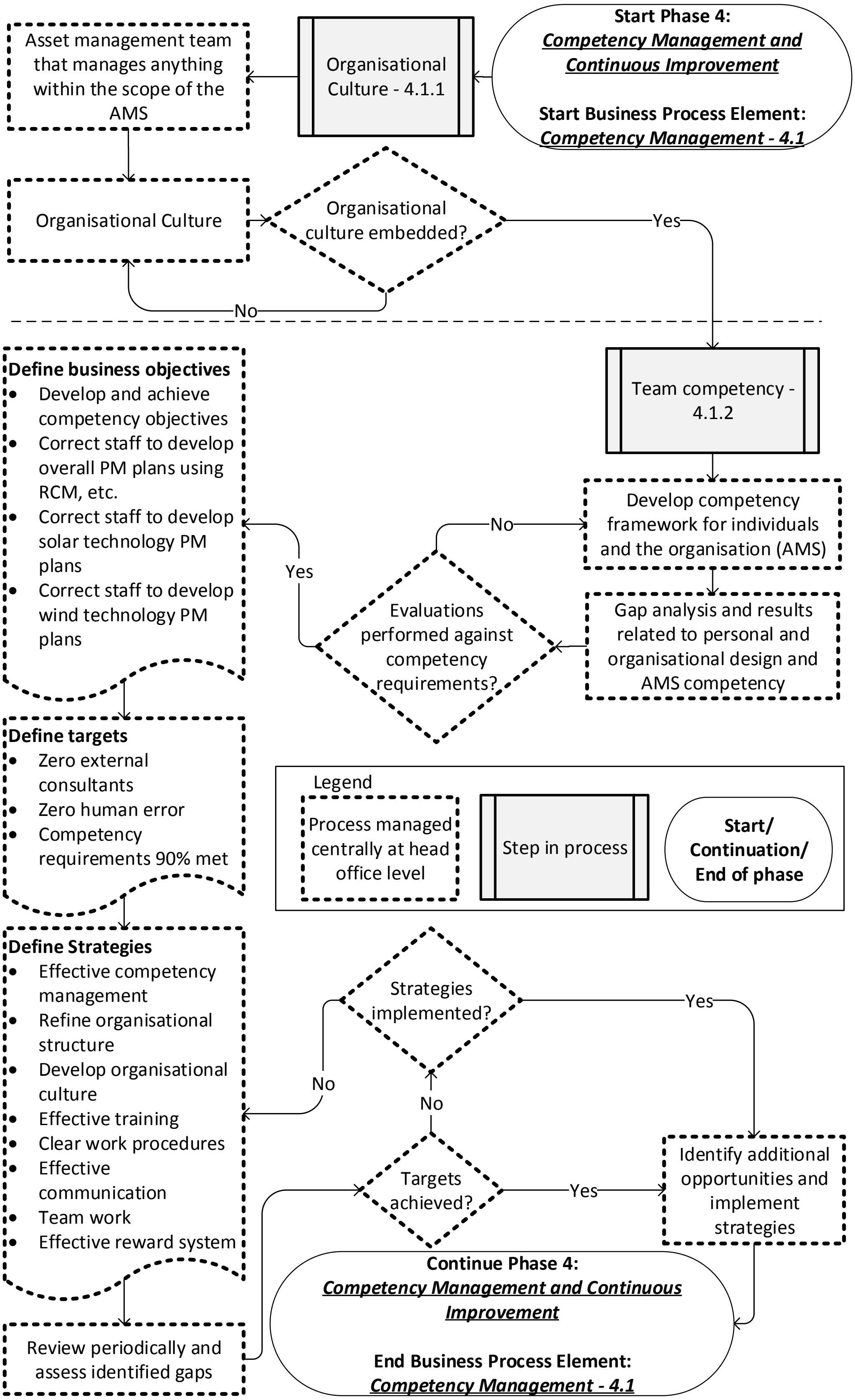


Figure 4.33: Competency framework – 4.1.1

Top management needs to project a clear view of what they would like to achieve in terms of culture and it needs to be aligned to the AM objectives, strategies and the OSP. There are some basic guidelines that can be followed when trying establish an organisational structure and culture as stated in section appendix A section A.1.5.3:

- Provide clarity of what the purpose of the organisation should be.
- Foster the same culture across the entire organisation.
- Provide clear boundaries of responsibility, accountability and have sufficiently motivated staff.
- Provide clear chain of command and escalation criteria with communication channels and flows.
- Provide visibility, transparency and clarity around decision making.
- Provide visibility and transparency regarding the support of top management for any AM changes and improvement projects.

4.7.1.2 Competency – 4.1.2

Competency management is discussed in section 2.1.3.9 and section A.1.5.5 in appendix A. The process of managing culture and competency is continued in figure 4.33 after addressing organisational culture.

As per section 2.1.3.9, competency needs to be maintained. One method of achieving this is by developing a competency framework for each role. The organisation is responsible for ensuring that competent people are employed to undertake AM activities. Top and senior management need to understand the implications that the AM objectives and strategies have on the competency of the workforce. A competency framework needs to be used to define specific competency requirements and build competence management systems around these requirements. Although no set structure for competency frameworks exists, literature indicates that the competency framework should cover individual and organisational competence related to the AMS. The competency framework development can also draw from the *Asset Care Plan Development* (CMF phase 2 – section 4.5) and *Work Planning and Control* (CMF phase 3 – section 4.6) to identify the type and number of skills required to manage maintenance for a REPP.

Once a competency framework has been established a competency gap analysis needs to be performed to map the existing competency against that required by the organisation or individual roles (refer to section section 2.1.3.9). Having an effective team requires that every person involved in activities within the scope of the AMS needs to be competent to perform their role at a specific standard within their responsibilities, knowledge, understanding, skills and experience. Competency requirements should be addressed at all levels of the organisation. Furthermore, all competency levels should have a Line-of-Sight between their tasks, competency requirements, AM objectives, AM strategies and the OSP.

There should also be an acute awareness by business regarding the interdependencies between the AM competences, the organisational design, and the business processes. A gap assessment should also be performed regarding the organisational design/structure (refer to section A.1.5.2) and business processes in order to generate improvement plans. The gap analysis could discover issues such as a lack of succession planning (a dangerous situation where knowledge is held by a single person) or misalignment between competent people and other business planning functions, such as budgeting, that could have major implications for long-term planning and investment decision making.

The outcome of the gap assessment should be used to develop improvement actions and plans. These plans and should consider AM competency improvement and may include (International Standards Organisation, 2014*c*, 13):

- assessment of competencies for roles and responsibilities;
- developing processes for managing competences of people who undertake AM activities that affects the performance of assets and the AMS ;
- considering aligning existing HR processes with newly defined competency management frameworks;
- alignment between competency requirements, OSP, AM policy, SAMP and AMPs;
- creation of personal development programmes;
- providing suitable training mentioning or study material;
- knowledge transfer, succession planning and relevant training;
- management of competency levels thought monitoring and reporting;
- evaluating obtained training against the requirements with the purpose of verifying the conformity with needs of the AMS; and
- developing and establishing processes to review and update competency frameworks and any plans related to AM competency and training.

Competency evaluations should be performed against the competency framework and all persons assigned roles and accountabilities within the organisation that can have an impact on the AMS should have those roles and accountabilities communicated to them, be provided with the training, education, development and other support needed to perform their role, and be able to demonstrate the competences required.

The organisation can also set targets based on the gap analysis. Competency objectives can be set, such as having the appropriate internal skills to develop ACPs (maintenance plans) for wind turbines and solar inverters, or adequately trained personal to perform infra-red scans on PV panels and other plant equipment. More specific targets can also be set such as having zero human errors during operations, zero consultancy procurement when developing ACPs and completing all competency training requirements. Strategies should then be defined to meet the objectives and targets that could include developing a competency framework, providing effective training, having an adequate reward system and nurturing the organisational culture aspired to. Periodic reviews of the targets and strategies can be used to understand whether targets have been achieved and to ensure that strategies are being implemented. Competency management reviews are part of the continuous improvement process which will be discussed in section 4.7.2.

4.7.2 Asset Care Plan and Asset Management System Improvement – 4.2

The importance of review and continuous improvement is discussed in section 2.1.4.6 and further encapsulated in AM subjects such as risk assessment and management, asset performance and health monitoring, AMS monitoring (refer to section A.1.6 in appendix A).

Section 2.1.4.6 discussed the importance of measuring the correct aspects within the review process and that traditional performance measures would concentrate on return on investment (ROI) and asset performance with insufficient regard for aspects related to employees, stakeholders, the environment and social. Organisations need to decide which aspects are the most important to measure and should be part of the strategy and planning discussed in phase 1 of the CMF with specific consideration when developing the AM policy, OSP, SAMP and AMPs (refer to section 4.4). Lagging performance measures considers part performance of assets while leading performance measures are intended to predict the future performance. These two indicator types are generally combined to see how the processes are performing and how which outcomes are being achieved.

In order for the organisation to consistently manage good scores on the identified performance measures will require the organisation to continuously consider how it can improve. The performance of people towards their objectives, how effective processes are, customer feedback and continuous improvement on risk profiles are all areas that should be reviewed on a regular basis. Management Review Audit and Assurance is part of the collection of processes that help to close the loop in the “Plan-Do-Check-Act” cycle of management system design.

4.7.2.1 Performance Review/Continuous Improvement – 4.2.1

The overall continuous performance improvement process involves the periodic review of aspects related to ACPs, competency, asset performance and the

AMS performance. The process is illustrated in figure 4.34.

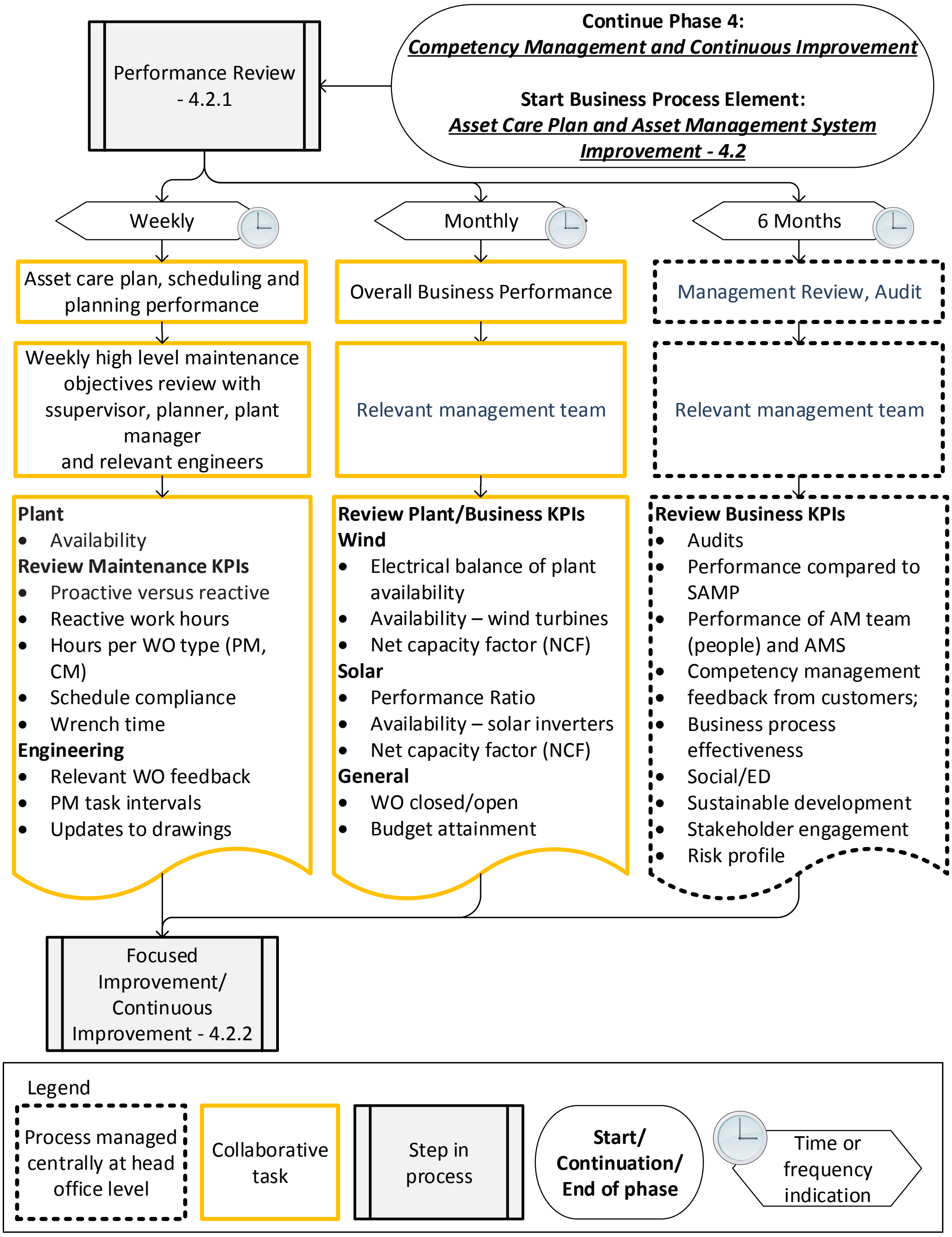


Figure 4.34: Performance review – 4.2.1

The process in figure 4.34 suggests certain review periods such as a week, a month or every six months for various areas of the business. However, these are merely suggestions and should be tailored to meet the needs of each organisation.

Weekly Review

The first review type is very focused on asset performance and also linked to AMS health monitoring (refer to sections A.1.6.5 and A.1.6.6 in appendix A). A weekly review could be used to review the performance of the plant, maintenance system and covers aspects such as the ACPs, planning and scheduling and the WO system. Understanding the performance creates a measurement framework that considers asset performance and elements of the AMS. This meeting should be attended by all relevant parties such as the RMC planner, RMC scheduler, plant managers, engineers and members of the OSMT. Maintenance specific KPIs as covered in section 2.2.7 that can offer insight into the performance of the maintenance system need to be reviewed. KPIs that are selected are on a tactical and operational level and these performance measures and targets need to align with organisational objectives, stakeholder requirements which are expressed within the OSP and the AM objectives and strategies (maintain the Line-of-Sight). Examples of KPIs that need to be measured, reported and reviewed could include 2.2.7:

- overall plant availability (EBOP, solar inverters, wind turbines);
- proactive versus reactive maintenance hours;
- reactive maintenance work hours compared to maintenance plan;
- hours per WO type (TBPM, CBM, CM);
- maintenance schedule compliance (compliance to OWAS);
- wrench time;
- maintenance budget attainment; and
- maintenance budget forecast.

Throughout the CMF there is reference to input and feedback that is generated, specifically within the *Asset Care Plan Development* (CMF phase 2 – section 4.5) and *Work Planning and Control* (CMF phase 3 – section 4.6). Any issues that were raised during these processes that require input and feedback from engineering should be reviewed and could include aspects such as:

- feedback from WO regarding the PM task intervals;
- updates to drawings, procedures, manuals, etc.;
- updates to SJs and work plans; and
- frequently failing equipment.

Monthly Review

The second review type is very focused on asset performance and also linked to AMS health monitoring (refer to sections A.1.6.5 and A.1.6.6). However, this review is more at plant management level. A monthly review could be used to review the performance of the assets compared to selected KPIs that form part of the AM objectives as developed in phase 1 step 1.2.3 (4.4.3.2). The performance measures consider the desired functional performance, level of service and condition of assets as defined within the AM policy and SAMP. Asset systems such as REPPs typically have specific performance criteria as discussed in section 2.2.7. Monitoring at the asset and AMS level is required to understand and manage performance in support of strategic and tactical decisions.

Measuring the performance of the AMS is just as important as measuring the performance of the assets and involved understanding how effective and efficient the organisation AM processes and activities are. Performance measures and the management thereof is integrated within business processes and the documented AMS.

This review meeting should be attended by all relevant members of the AM team. Examples of KPIs that need to be measured, reported and reviewed could include:

- Availability
- Reliability
- Time-based Availability – Wind turbines, solar inverters
- Net Capacity Factor
- Performance Ratio
- Revenue budgets
- Maintenance Budget attainment
- Work orders closed
- Work orders reworked

6 Monthly Review

The last proposed review type entails a longer term review (six months as an example), could be used as the management, audit and assurance review that is a requirement of the ISO 55001 standard discussed in section A.1.6.7 appendix A. This review type is a key part in the group of processes that assist in closing the loop in the "Plan-Do-Check-Act" cycle of management system design.

Audits, asset health monitoring, and AMS monitoring are key processes that an organisation can use to check whether processes are being followed and standards or specifications adhered to. These activities offer some assurance to the organisation that the processes responsible for managing risk are in place and in use. Audits are an important way of performing this ongoing monitoring and should include internal and external audits.

Information management (as discussed in section 2.1.4.4) is key to performance measurement and linked to data management and will require information systems that can monitor, predict and detect trend performance on an ongoing basis. Information management is an important part of the AMS and to all the review processes and at all levels and needs to be functional. The monitoring of the AMS considers feedback mechanisms from all areas of business which are compared with anticipated performance in order to effect changes in objectives, risk control and the AMS to optimise the direction of the organisation.

The efficiency of processes is monitored through internal efficiency measures while actual delivery of the business is determined via output measures. Proactive, reactive, leading, lagging, qualitative and quantitative measures can be used for performance evaluation requirements which are aligned to other management standards. Performance measures and the management thereof is integrated within business processes and the documented AMS.

This review should deal with ensuring that the AMS remains suitable, adequate and effective while considering aspects such as leadership, organisational culture, organisational structure and competency management (gaps identified within step 4.1.2), risk assessment and management, asset performance and health monitoring and AMS monitoring. This strategic meeting should be attended by all relevant members of the AM team with the purpose of taking stock of the organisations AM activities and should typically cover:

- status on action items of the previous meetings;
- performance of the assets compared to what is stated within the SAMP;
- summary of AM activities;
- performance of AMS ;
- performance of AM team (people);
- competency management;
- business process effectiveness;
- revenue budget compliance and concerns;
- risk profile of the organisation; and
- identified areas of improvement and the general continuous improvement process.

Importantly, personal performance management should also part of the review process and should have the objectives of motivating, communicating with and developing people. Secondly, audit programs, review processes and key performance indicators need to be linked to the overarching organisational strategies and objectives. Linking performance measurement with OSP maintains and reinforces the Line-of-Sight and achieving this alignment provides a feedback mechanism to provide stakeholders with assurance and management the opportunity to improve efficiency.

4.7.2.2 Focused Improvement – 4.2.2

The previous step (4.2.1) is very focused on continuous improvement. However, this step is more focused on addressing issues in a structured manner following a process. Should any of the three review types mentioned in step 4.2.1 (section 4.7.2.1) provide evidence that the required targets are not being met, the actions, as seen in figure 4.34, should be taken, based on the Six Sigma DMAIC method described in section 2.2.6.4.

- Define the problem clearly, identify the team members, target improvements and time scales.
- Gather information about the problem, such as specifications, historical data, interviews, etc.
- Identify root-cause by analysing and verifying cause-effect relationships.
- Select and implement improvement actions and confirm that the problem has been solved.
- Make the solution sustainable through procedures and training, with roll-out to other similar areas.

In the event that maintenance-specific KPIs are found to be below the required targets, and information indicates that there are frequently failing components or feedback from the maintenance teams have indicated a requirement to alter the planned maintenance interval the following steps should be considered:

- Gather and organise data to perform analysis.
- Rank frequently failing equipment.
- Analyse information using tools including RCA, COFCATs, and engineering analysis.
- Calculate appropriate maintenance intervals using the DTMM (refer to section 2.2.6.3) or based on experience.
- Review and update to master maintenance plan by engineering department.
- Update all relevant documentation in CMMS and other related technical documentation.

Should there be any requirements coming from the maintenance teams to update SJs, the engineering department needs to consider the request and complete the required SJ updates through the following process:

- Gather and organise data to perform analysis.
- Review and update SJ, master maintenance plan by engineering department.
- Update all relevant documentation and information in CMMS and related technical documentation.

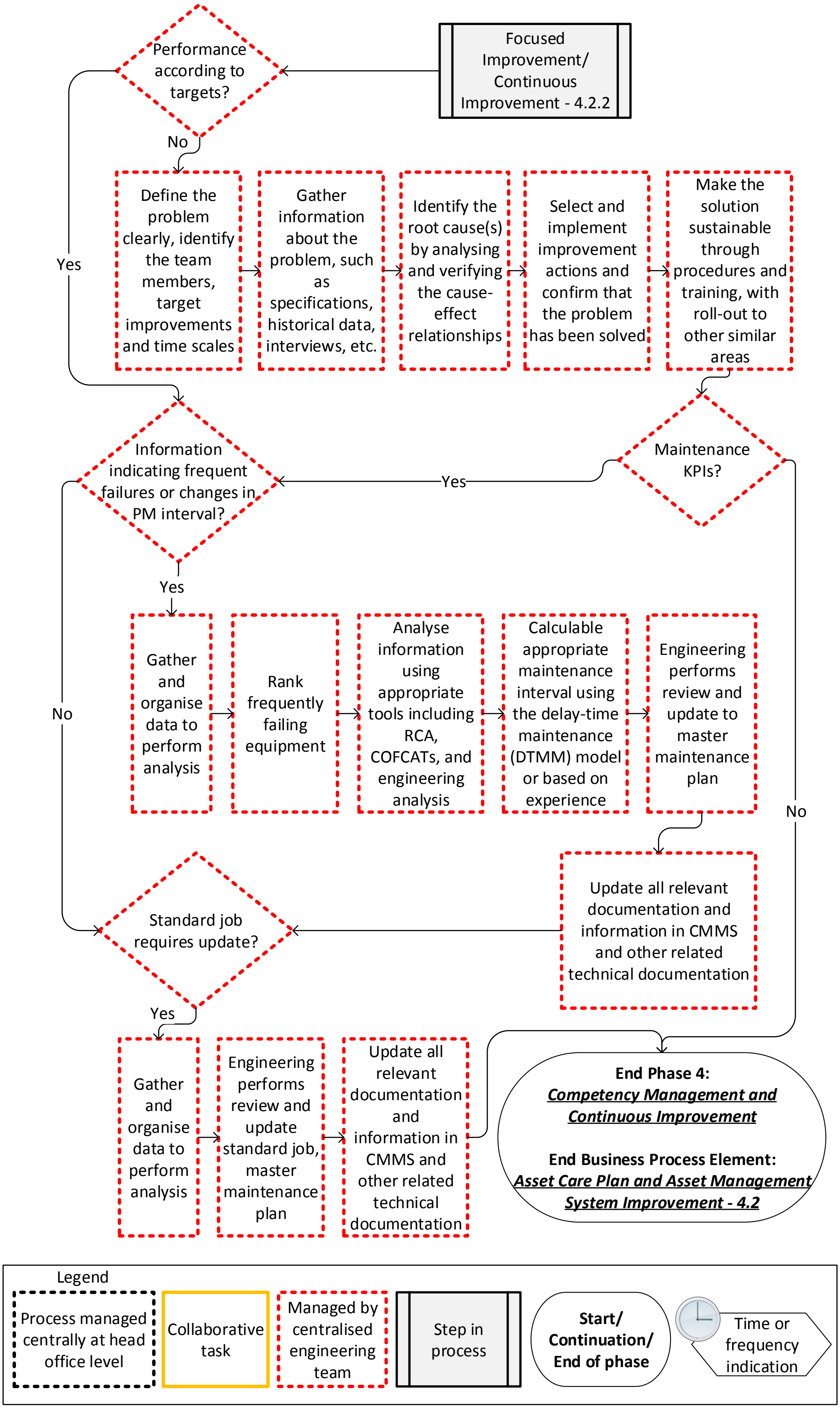


Figure 4.35: Focused improvement/continuous improvement – 4.2.2

4.7.3 Related AM Subjects and ISO Clauses

The following clauses of the ISO 55000 series of standards and the GFMAM AM subjects have been identified as being applicable to phase 4 of the CMF through the review and content analysis of the literature on sections 2.1.3 and 2.1.4 with a detailed description of all the relevant AM subject in appendix A.
Relevant ISO clauses:

- Clause 4.1 ISO 55001 – Understanding the organisation and its context (International Standards Organisation, 2014*b*, 1)
- Clause 7.2 ISO 55001 – Competence (International Standards Organisation, 2014*b*, 5)
- Clause 9.1 ISO 55001 – Monitoring, measurement, analysis and evaluation (International Standards Organisation, 2014*b*, 8)
- Clause 9.2 ISO 55001 – Internal Audit (International Standards Organisation, 2014*b*, 9)
- Clause 9.3 ISO 55001 – Management review (International Standards Organisation, 2014*b*, 9)
- Clause 10.3 ISO 55001 – Continual improvement (International Standards Organisation, 2014*b*, 11)

Relevant GFMAM AM subject/s:

- Organisational Structure (GFMAM, 2014, 39)
- Organisational Culture (GFMAM, 2014, 41)
- Competence Management (GFMAM, 2014, 40)
- Asset Performance and Health Monitoring (GFMAM, 2014, 47)
- Asset Management System Monitoring (GFMAM, 2014, 48)
- Management Review, Audit and Assurance (GFMAM, 2014, 49)

4.7.4 Summary – Phase 4

The processes defined in this section address the competency shortage related to the holistic AM of REPPs in SA. The phase firstly considers organisational culture as managing and nurturing the type of culture the organisation would like to establish, which will directly influence the AM practices, HSE practices, team and asset performance, financial management, organisational reputation and ultimately success. The culture also needs to adopt long-term strategic thinking that will directly link to the overall competency management process.

Competency needs to be managed through an effective competency framework that considers the organisation and individuals. The framework needs to ensure that people involved in activities within the scope of the AMS are competent to perform their role within their responsibilities, knowledge, skills and experience. Top management needs to understand the implications that the SAMP has on the competency requirements of the workforce.

4.8 Chapter Summary

The chapter discusses the development of an ISO 55000 series-aligned CMF supported by business processes that can be used to manage ACPs within a multi-technology portfolio of REPPs. The CMF is based on a thorough and broad literature base presented in Chapters 1 and 2. The framework and business processes are developed through an iterative process and influenced by literature study fields of AM and maintenance management. The GFMAM AM subjects (see figure 2.8 for all 39 subjects) covered by the CMF are shown in figure 4.36.

Figure 4.36: CMF 39 AM subject mapping

The proposed CMF has four key phases that are represented and supported by a set of business processes. The four phases in the framework are:

- *Asset Management Framework – Phase 1*
- *Asset Care Plan Development – Phase 2*
- *Work Planning and Control – Phase 3*
- *Competency Management and Continuous Improvement – Phase 4*

The CMF and supporting business processes are practical, provide a structured guideline and give a holistic approach to the problem and could be used to support Asset Managers, owners and operators of REPPs to implement the framework and features. Asset Managers, owners and operators of REPPs in SA also require structured guidance on how to apply the requirements of the ISO 55000 series when developing strategy and planning and developing a maintenance management framework. The proposed solution provides an ISO 55000 series-aligned CMF, consisting of four phases with key features that are expressed using supporting business processes that can be used to centrally manage ACPs.

The framework and the phases are unique and provide a holistic approach to managing ACPs that encompasses a LC perspective and the decision-making process as an interacting mesh of activities.

This chapter contributes towards the sixth and seventh research objectives stated in section 1.3:

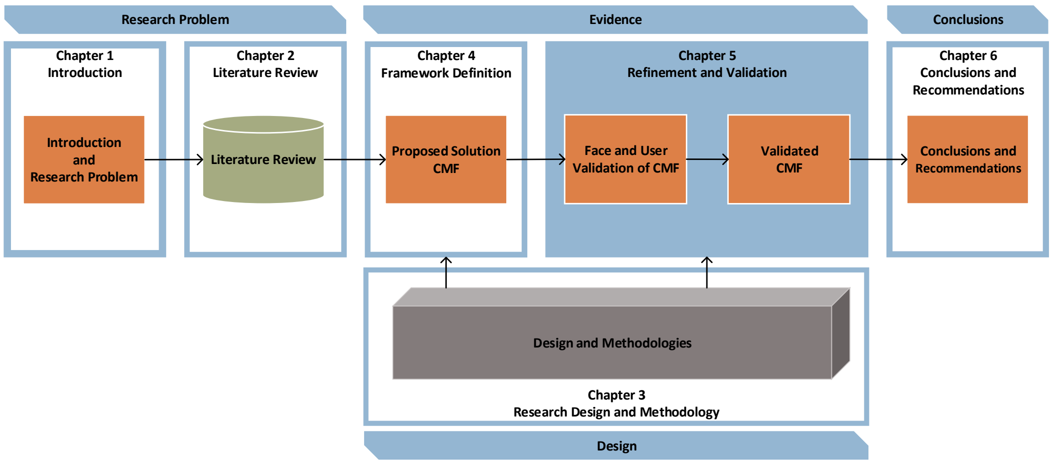
6. Construct an ISO 55000 series aligned generalised CMF for ACPs in the RE industry and determine a suitable philosophy to develop ACPs for RE power plants in SA.
7. Determine which of the 39 GFMAM AM subjects are applicable within the framework and how they need to be applied within the framework to obtain alignment with the ISO 55000 series.

The chapter to follow, Chapter 5, will validate the CMF and business processes using face and user validation within SA RE and AM industry and includes a SA IPP who owns and operates a portfolio of multi-technology REPPs.

Chapter 5

Validation of the Central Management Framework

One thing I have learned in a long life: All our science, measured against reality, is primitive and childlike – and yet it is the most precious thing we have. – Albert Einstein (1879-1955)



The objective of this chapter is to validate the conceptual CMF proposed in Chapter 4. Quality assurance can be conducted by validating the model and assessing whether the conceptual CMF and associated business processes could add value to the industry. The chapter's departure point is an introduction to the background of the validation process. Considerations leading to the determination of the validation approach for this study are presented. The CMF is validated using face validation which is strengthened with user validation using semi-structured, face-to-face interviews with various experts in the

RE and AM field. The validation approach and the outcomes are presented in detail and the framework improvements resulting from the validation are presented.

5.1 Introduction

The study was conducted with limited resources and funding. The human resources available for designing, testing, data collection and analysis of the research were limited to the researcher's available time after normal business hours, with ad-hoc time available from RE and AM experts. The research time-line foreseen for this phase of the research is two months, of which one month is planned for data collection.

Validity can be regarded as the most important criterion of research (Bryman *et al.*, 2014, 25). Validity is a reflection of the integrity of the conclusions derived from research. Validity also checks that the research output correctly addresses the concept under investigation and offers credible answers. The focus point of validity is on the connection between the research project's purpose, context and conclusions (Gaber 2010, 3; Robinson 1997). Validation is thus regarded as the process of confirming that the proposed model or framework is adequate to address the problem in the context it has been designed for. Therefore, validation is regarded as a process that ensures the proposed model has sufficient accuracy to address the intended use (Beecham *et al.*, 2005, 2).

The validity of a study can be checked through testing the observations made during research against pre-existing knowledge (Gaber, 2010, 3). This testing offers the opportunity for the research output to be proven as incorrect. Validity testing should be context-specific and cannot be regarded as an absolute assessment. Confidence that the identified research problem has been addressed is diminished with the lack of validation (Gaber, 2010, 3). Part of the validation process is to understand whether the correct model has been developed (Robinson, 1997). Therefore, the aim is not to verify if the proposed CMF results in enhanced Line-of-Sight and alignment with the ISO 55000 standard but has the potential of guiding and assisting Asset Managers and owners of REPPs in SA to centrally manage ACPs in alignment with the ISO 55000 standard. The validation is focused on substantiating whether the CMF and each phase of the CMF are consistent with the expected application as well as ascertaining their respective strengths and weaknesses.

The suitability and applicability of the proposed CMF to the RE industry is validated by gathering the thoughts and perceptions of experts in the field of AM and RE through questions posed during semi-structured interviews. Furthermore, the chapter complies with the ethics requirements of the University of Stellenbosch and in accordance with the University of Stellenbosch's ethics policy the identity of the panellists remains confidential.

5.2 Types of Validity

Validity can be categorised as external validity and internal validity (Gaber, 2010, 3). External validity considers how generalisable the research outputs are when the observations are compared to other similar and relevant situations outside the context of the specific research (Gaber 2010, 3; Bryman *et al.* 2014, 26). Internal and external validation are important and consider the legitimacy of research by looking at detailed aspects such as the researcher's bias or sampling errors (Bailey 2008; Gaber 2010, 4). However, the current study only aims to validate the proposed CMF in the context of the study and therefore will not consider assessing external validity.

Internal validity considers whether the correct conclusions were reached by considering the data that was available and is a question of causality. Face validation can be categorised as internal validation (Gaber 2010, 3; Bryman *et al.* 2014, 26).

Rupp and Pant (2007) state that well into the 1970s validity was grouped into three types: criterion validity, construct validity (Bryman *et al.*, 2014, 39) and content validity/face validity. Establishing construct validity would require that suitable test criteria be available against which to measure the framework in order to use criterion validity. No similar test cases could be found against which to measure the framework and business processes for this study. Establishing construct validity of the study would require that the framework be tested to see whether it is actually measuring the primary construct it is intending to assess. Using quasi-experimental intervention studies could be a possibility for establishing construct validity (Markus and ying Lin, 2010, 234).

Face validity or content validity could be completed by conducting interviews to assess whether the CMF addresses the relevant problem. Gaber (2010, 6) discusses the relationship between content and face validity and notes that face validity is often used to test the study with laypersons, while on the other hand content validity makes use of subject matter experts. However, face validity does not specifically exclude the use of experts. Both face validity and content validity are interested in whether the research problem is being addressed by the research output. Therefore, this study will refer to face validity instead of content validity (Gaber, 2010, 6).

There are various other strategies that can be used to test the validity of research outputs such as case studies (Bryman *et al.*, 2014, 113) (often used in business research), quasi-experiments (pre-post intervention studies) (Harris *et al.*, 2006, 16).

5.2.1 Validation of Decision Support Systems

According to Bhatt and Zaveri (2002, 300) a Decision Support System (DSS) can be characterised as a computer-based software system that can assist the organisational decision making process through the collection of large datasets that are then transformed into meaningful information which could be in the form of comparisons, graphs or trends. The proposed CMF does not strictly represent a DSS, but the phases and business processes collect and structure information and therefore in principle support decision making and overall management. Reviewing DSS validation could be helpful in identifying potential validation methods for this study.

According to Finlay (1994) the objective of DSS validation is not aimed at the impossible task of proving a truthful representation of a real-world system. The purpose of DSS validation is to demonstrate that the DSS has the required supporting relationships that offer an adequate representation of the specific real-world system (Finlay, 1994). A two-stage procedure is used to validate a DSS and can be seen in figure 5.1 representing the DSS LC model. The first stage is laboratory testing that includes considering face validation, subsystem validation, predictive validation and user validation. The second phase is field testing (O'Leary *et al.*, 1990).

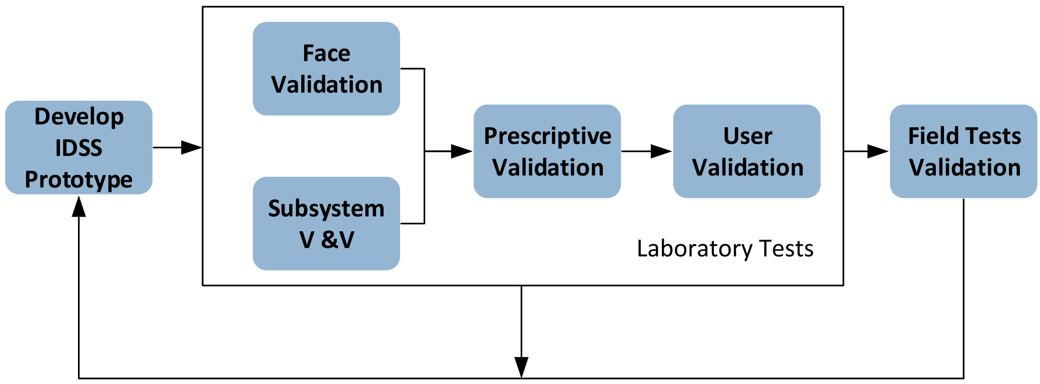


Figure 5.1: IDSS validation process (Adapted from Borenstein (1998, 229))

The laboratory testing involves tests done by the developer or development team. These tests may include potential users and involve the use of interviews and questionnaires. Laboratory testing consists of face validation, sub-system validation, predictive validation and user validation. Field testing is the second phase of the DSS validation process and entails the application of the model in the field (Borenstein 1998, 229; Keefe *et al.* 1987, 86).

Face validation and user validation can be an applicable approach to test the internal validity and of the proposed CMF and supporting business processes. Resource constraints, as discussed in section 5.1, limit the success of undertaking field testing. The validation of the proposed CMF is to ascertain its strengths and weaknesses as well as substantiate whether the components and steps embedded in the framework are consistent with its expected application.

5.2.2 Face Validity

Based on the review of potential validation methods, face validation is identified as the best approach to test validity of the proposed CMF. Face validation is a subset of the qualitative validation method developed by (Borenstein, 1998). Borenstein (1998, 229) has the view that face validation can be used to ensure that the perception of the framework developer and the user are aligned, and can assist in achieving this in a manner that is timely and cost-effective. The face validation process can guide the process of model refinement, by detecting flaws or misconceptions held by the framework developer regarding the industry and potential users in order to address the issues before implementation (Borenstein, 1998, 229).

Face validation investigates whether a measure or framework that was developed as a research output is capable of addressing the intended purpose. According to Sargent (2003, 41) face validity concerns asking people who are knowledgeable about a particular system whether the proposed model and/or its behaviour is sensible. For example, this could be trying to understand whether the logic inherent in the conceptual model is correct and the model's input-output relationships are sensible.

According to Bornstein (2004, 368), "face validity is an estimate of the degree to which a measure is clearly and unambiguously tapping the construct it purports to assess". Face validity tests the internal validity through establishing whether the developed prototype or concept measures what it is intended to measure. Mostert (2007, 338) also provides a definition for face validity by stating that:

> *Face validity is most often understood as a subjective and cursory judgement of a concept, assessment instrument, or any other conceptualisation to ascertain whether, on its face, it appears valid, without further regard to the underlying legitimacy of the nomological network, concept, instrument and test items, or the construct it purports to measure.*

Mostert (2007, 337) states that face validation can demonstrate "reasonable, consistent, and understandable surface connections between the instrument and test items on the one hand and their underlying construct on the other". The premise is thus that if face validity is not established there is a diminished possibility that other validity criteria are viable.

The expertise of the individuals who participate in the face validation process has a significant correlation to the accuracy of face validity. According to Shuttleworth, M. [Online] (2009) face validity is regarded as a measure of how significant a research undertaking is at face value through the evaluation of experts in the relevant field of application. Face validation is therefore underpinned by assessing the logic of a developed framework or method through expert review to assess its value and viability for industry (Sargent, 2003, 42). Tashakkori and Teddlie (2010) state that the quality of face validity can be improved by using subject matter experts in the industry to judge the particular research outcome, as opposed to laypeople. The authors further note that it is important to ensure that the attributes of the measure or programme as well as the research outputs that have to be assessed are clearly defined. The value of using experts to review and criticise work has also been recognised by Rosqvist *et al.* (2003) to evaluate software quality. Furthermore, Lauesen and Vinter (2001) also showed the reliability of utilising expert judgement.

5.2.3 User Validity

User validation can be used to understand how applicable the CMF is to potential users and assess the impact of the CMF assumptions, simplifications, methods, and generic structure from independent users.

User validation can be defined (Gass, 1983, 617) as

> *the process by which interested parties (who were not involved in a model's origins, development, and implementation) can determine, with some level of confidence, whether or not the model's results can be used in decision making.*

According to Borenstein (1998, 230) the objectives of user testing or user validation are:

1. to understand the perception of potential users regarding how applicable the proposed system is; and
2. to assess, using independent sources, what the impact is of the assumptions, simplifications, methods, and generic structure made by a system.

User validation is used significantly in the computer-simulation field. Archambault *et al.* (2015) conducted a user validation study by using eight power wheelchair users to validate the selections of simulations tasks (driving tasks) for new power wheelchair users. The study used eight power wheelchair users who were interviewed after using the simulation. Users were requested to rank aspects of the simulation on a scale of "liked" or "disliked" which was converted to a qualitative frequency distribution. Borro-Escribano *et al.* (2014) performed an "Expert User Validation of Transplant Management Procedure Simulations". The study used 15 experts to validate how accurately knowledge had been transferred through simulations. Semi-structured interviews were used to obtain the views of the expert participation, which was coded, after which a qualitative analysis of the interview data was performed.

Jooste (2014, 211) states that the objective of user validation is to determine, using impartial potential users who were not part of the development process, to understand whether the DSS's results provide sufficient assurance for decision making. User validation attempts to confirm the usability by potential users and evaluate the simplification considerations from the selected impartial users.

5.2.4 Validation

The combination of face validation and user validation selected as a method of validating this study and as a means of investigating the proposed solution that aims to provide an ISO 55000 series-aligned CMF that consists of four phases that are expressed using business processes that can be used by Asset Managers and owners to centrally manage ACPs.

Structured expert assessments are used by Klügl (2008), Archambault *et al.* (2015) and Borro-Escribano *et al.* (2014) as part of face and user validation exercises to evaluate simulation models. The face validation approach has also been used in the field of AM by other scholars related to AM services (Jooste, 2014, 211), management of people in AM Kriege (2015, 105) and Walker (2015, 101). User validation has also been used in the AM field by Jooste (2014, 211) through a workshop with experts from an SA AM service provider.

The CMF and business processes are clearly defined, visualised and narrated and can comprehensively be presented to an suitable target group of experts in the field of AM and RE. Face validity has identified limitations; therefore it is combined with user validity to strengthen the validation process through testing the CMF with potential users who have not been involved in the development process. Therefore the combined approach provides an appropriate method to test for validity.

In pursuit of understanding whether the CMF is suitable and applicable to the industry the proposed CMF has been validated through engaging with experts in the field of AM and the RE industry in SA and collecting their perceptions and through questions posed during semi-structured interviews.

5.3 Data Collection – Semi-structured Interviews

The data-gathering method used to investigate face and user validity was semi-structured in-depth interviews conducted with experts in the field of AM and RE to learn and understand expert opinions regarding the proposed CMF. Face-to-face interviews were adopted as the method of interviewing for this study and aimed to test whether the CMF and supporting business processes are addressing the research questions in the intended context.

Face-to-face interviews are able to achieve a higher response rate from or between 80% to 85% compared to 60% achieved using telephonic interviews (Persaud, 2010, 635). Face-to-face interviews can minimise answers such as “I do not know” as the interviewer can prompt for more specific answers. The interviewer can also clarify any questions that might be confusing. Presenting and explaining the research background and any additional material is easier when conducting face-to-face interviews (Bryman *et al.*, 2014, 219). The author also states that face-to-face interviews deliver a superior data quality compared to telephonic interviews as there is a higher probability that participants will spend more time on the interviews and engage more (Bryman *et al.*, 2014, 218).

Focus groups were initially considered as they provide immediate ideas for improvements and can be very interactive, sparking broader thinking. However, the interviews were conducted as one-on-one engagements, as Bryman *et al.* (2014, 238) notes that group interviews are subject to group effects resulting in individuals’ suppression their perspectives, lack of criticality of the group members’ views and hierarchical relationships causing discomfort. Therefore, interviews were conducted on a one-on-one basis to facilitate open conversation and answers to questions.

DiCicco-Bloom and Crabtree (2006, 315) define semi-structured in-depth interviews as:

> *generally organised around a set of predetermined open-ended questions, with other questions emerging from the dialogue between interviewer and interviewees.*

Semi-structured interviews have predefined questions, but the participants are free to ask questions and make other comments during the interview process. Semi-structured in-depth interviews are generally also only conducted on a single occasion for a specific individual or group and can last up to a few hours (DiCicco-Bloom and Crabtree 2006, 315; Bryman *et al.* 2014, 238).

According to Adams *et al.* (2002, 842) semi-structured interviews can be the only source of data in a qualitative research project. The author further notes that the intense nature of semi-structured interviews enables a qualitative study to be conducted with a limited number of participants Adams *et al.* (2002, 842). The selected method for data collection during this study was semi-structured interview due to the nature and type of data that was required for the analysis. All the interviews were voice recorded and transcribed verbatim.

The process of interviewing participants is structured in the following sequence:

1. Prior to the interview participants were sent, by email, a summary document outlining and describing the proposed CMF and each of the phases, purpose problem statement, research questions, research objectives and the research methodology. The following attachments were also sent:

- Attachment 1: Written consent form as required by the ethics committee.
- Attachment 2: Chapter 4 and relevant appendices of the thesis with narrative of describing CMF and the supporting business processes.
- Attachment 3: Microsoft Visio drawings of the CMF and supporting business processes to supplement the narrative as seen in appendix C.
- Attachment 4: COFCATs worksheet as seen in appendix B.
- Attachment 5: Interview Questions – Face Validation as seen in appendix G.

2. Telephonic meeting was then scheduled with the participant (a few days after sending the material) to briefly review the CMF and clarify any concepts or answer any questions regarding the research and the CMF.

3. The interview was then scheduled about a week or two weeks after the material was sent to the participant. This delay provides sufficient time for the participants to review and grasp the core concepts after having the opportunity to pose any questions. The attached documents provided were used to prepare the participant for the interview process and maintain a similar approach to each interview.

4. The interview was started with a presentation providing the context and the intended purpose of the CMF, problem statement, research objectives and

research methodology. Thereafter, the CMF and the supporting business processes were explained and how they interrelate (planned duration 120 minutes). The presentation was interactive but specifically followed by a discussion to clarify questions or misunderstandings.

5. The semi-structured interview process commenced by working through the list of questions in appendix G to collect the data and information required to validate the CMF and each of the phases. Each of the CMF phases and respective business processes were then explained in detail. Following the explanation of the CMF the structured questions were posed to the participant. The interview questions served as a measure of face and user validity and included questions that aimed to identify whether the research problem was being addressed by the proposed CMF and understand how applicable the CMF was to potential users.

The research problem preceded the initial questions as seen in appendix G. Notes and comments were written down in addition to voice recordings of the questions and answers. Furthermore, participants were encouraged to make any additional comments, observations, ask questions and offer their opinion during any stage of the interview process. Following this process provided the environment where participants could propose new ideas and offer feedback on the CMF related to management policies and frameworks used in their organisation or practised in their capacity as a Asset Manager or Asset Owner.

According to Beecham *et al.* (2005, 10) understanding the perceptions held by the participants regarding the research study and how the participants arrived at their perception is a core purpose of a qualitative research interview. Interview questions were thus defined in a manner that would aim to understand the perspective of the participant regarding the features, structure, strengths and weaknesses and improvement suggestions of the proposed CMF.

The flow of the questions was structured in such a manner that each of the four CMF phases were firstly addressed through a set of questions. These questions were followed by a set of questions that addressed the framework synergy. The first question related to the framework synergy, asking whether in the opinion of the participant the proposed CMF and business processes had the potential to support Asset Managers and owners in centrally managing ACPs while remaining aligned to the ISO 55000 standard. The question was specifically focused at understanding whether the proposed CMF could be regarded as an appropriate solution to the research that was undertaken.

Lastly the architecture and success criteria of the CMF were addressed. The interview questions were defined specifically to determine the participants' perspectives of specific elements of the proposed CMF, Furthermore, these questions were posed to participants as a means of establishing whether the proposed CMF and the respective phases adhered to the defined success criteria as stated in section 5.5 and also served to test user validity.

The structural aspects and general ability of the framework to address overarching themes of each phase of the proposed CMF were addressed in a close question style and measured using a four-point scale similar to that used by Emam and Birk (2000) and Borenstein (1998). Various aspects of the CMF such as the comprehensiveness of each phase, ease of comprehension, the logic of each step, ability to address key areas, efficiency, ability to address core AM standard requirements and structures which aim to understand whether required AM aspects were sufficiently integrated in the CMF, and value it can add to owners and operators of RE power plants, were rated by categories of **poor**, **fair**, **good** and **very good**.

The interviews typically took four hours to complete instead of the two-hour planned time.

5.4 Expert Panel – Background of the Interview Participants

The constraints placed on the study regarding time and resources prohibited interviewing a large representative number of Asset Managers and AM practitioners from various industries and hierarchical levels as a means of testing external validity of the proposed CMF.

Following the recommendations of Lauesen and Vinter (2001, 43) participants from varying backgrounds and industries were used. Seven participants were invited to participate in the validation of the study based on their respective experience, background and active involvement in the field of AM and operations of RE power plants in SA. All the seven participants agreed to participate. Two of the participants occupy positions in one of the most prominent AM consultancies in SA. Three other participants hold key strategic senior management positions in organisations that own and operate a portfolio of REPPs in SA. The other two junior participants also hold positions in an organisation that owns and operates a portfolio of REPPs in SA.

A study by White (2014) used a panel consisting of three experts for content and face validation while Archambault *et al.* (2015) used a panel consisting of eight experts for user validation. Seven experts were therefore considered to be sufficient for determining face and user validity of the proposed CMF.

The organisations that were involved with the study were Pragma (AM and maintenance management practitioners), Scatec Solar (RE asset developer, owner and operator), Globeleq SA Management Services (RE asset developer, owner and operator) and African Infrastructure Investment Managers (AIIM) group of companies (RE asset developer, owner and operator).

The profile of each organisation is presented below.

Pragma Profile: Pragma is a engineering management services and consulting organisation that delivers products and services in the field of AM and maintenance management. Pragma's products and services are aligned with the ISO 55000 and the GFMAMs 39 subjects providing the platform for clients to achieve ISO 55001 certification readiness. Furthermore, they provide a range of AM products and services that include maintenance management software systems, consulting and outsourced Asset Care services. Pragma has also recently been involved in providing consulting services related to ISO 55000, maintenance management and ACP development to the RE industry in SA. Pragma have their own AM maturity assessment methodology called the Asset Management Improvement Planning (AMIP) assessment (Pragma [Online], 2016).

Globeleq Profile: Since Globeleq was founded in 2002, the organisation has become a power industry leader by operating or acquiring interests in multiple power facilities across the world. Today, under the joint ownership of CDC (70%) and Norfund (30%), Globeleq is focused exclusively on Africa and is uniquely positioned to invest in, develop and operate power projects across this region. Its experienced team of professionals have built a diverse portfolio of independent power plants, currently generating more than 1,200 MW in eight world-class plants across five countries. The company has a substantial pipeline of new power projects in development and plans to add 5,000 MW of new power generation in the next 10 years across the continent. Globeleq is the majority shareholder of three REPPs awarded in round one of the REIPPPP in SA. All three REPPs are managed by Globeleq SA Management Services (GSAMS). GSAMS is owned by Globeleq and has the mandate to manage and operate all SA REPPs. The three projects are Jeffreys Bay Wind Farm (138 MW) situated in the Eastern Cape, De Aar Solar PV Farm (50 MW) situated in the Northern Cape and Droogfontein Solar PV Farm (50 MW) also situated in the Northern Cape. GSAMS is thus an Asset Owner and Asset Manager of a multi-technology portfolio of REPPs in SA (Globeleq [Online], 2015).

Scatec Solar Profile: Scatec Solar is integrated utility-scale IPP as they develop, construct and maintain all their own REPPs as part of a long-term ownership strategy. Scatec Solar have an industrial approach to ownership of their REPPs and O&M is key to securing control and maximising performance. Scatec Solar already has an installation track record of close to 600 MW and currently is producing electricity from 383 MW of solar power plants in the Czech Republic, SA, Rwanda, Honduras and the US. Scatec Solar entered the SA market in 2010 and has been awarded three solar PV projects with a total capacity of 190 MW as part of round one and two of the REIPPPP. The three projects that are currently operational and managed by the Scatec Solar team in SA are Dreunberg (75 MW solar PV) situated in the Eastern Cape, a round two project, Linde (40 MW solar PV) situated in the Northern Cape, also a round two project and lastly Kalkbult (75 MW solar PV) also situated in the Northern Cape and the first REIPPPP project to be grid connected and operational in SA. Furthermore, during the month of April 2015 under round four of the REIPPPP, Scatec Solar was awarded preferred bidder status for three projects with a combined capacity of 258 MW (ScatecSolar [Online], 2015).

African Infrastructure Investment Managers (AIIM) Profile: The AIIM group of companies consists of a RE developers and owners or RE project in SA and currently own and operate a total of 275 MW as part of round one of the REIPPPP. The three projects that are currently operational and managed by the AIIM Group in SA are Hopefield Wind Farm (65 MW) situated in the Western Cape and the first wind farm to reach commercial operation in the REIPPPP on 1 February 2014, Cookhouse Wind Farm (135 MW solar PV) situated in the Eastern Cape and lastly Kathu Solar Energy Facility (75 MW solar PV) situated in the Northern Cape.

All these organisations are dependent on the performance of physical assets and require established AM functions, processes, and activities. Furthermore, capability and competency of the teams that manage these assets and AM activities are of key importance. AM practitioners and senior level O&M practitioners were therefore considered as suitable candidates for the validation of this study.

Asset Managers can be characterised as people who are involved in the AM activities of the organisation and are responsible for the managing teams or people. Therefore, their scope of responsibility might involve strategic, tactical, or operational activities. Asset Managers are therefore considered as suitable candidates for the validation of this study.

Participants included two AM consultants and practitioners with combined experience of 47 years spanning the mining, power sector and RE industry. Other key participants included an O&M manager of a portfolio of solar PV REPPs who previously was the plant manager of a wind farm in SA with 10 years' engineering experience, a solar PV plant manager with more than 12 years' experience and a wind farm manager with more than 20 years' experience, and lastly a director of operations for a multi-technology portfolio of

REPPs in SA with more than 20 years' experience. All the participants have significant experience in the fields of engineering, project management, managing people, maintenance and AM activities with various industries and the RE industry in SA. The participants represented Asset Managers and owners of REPPs in the SA RE industry that provided an opportunity to gain judgement of the CMF from different job roles. The range of experience in the AM and RE fields provided the opportunity to ascertain whether the proposed framework might be viable for the SA RE industry at various levels of management.

The profile of each expert follows.

Partner Consultant: Bachelor of Science Engineering (BSc BEng) graduate with more than 35 years' global experience. Specialises in engaging with Asset Owners and Asset Managers of large portfolio of physical assets, to improve the performance, cost and risk management related to caring for their investment throughout the entire LC of the assets.

A Partner Consultant: Bachelor of Engineering (BEng), Mechanical Engineering, holder of a government certificate of competency for mining and labour (GCC) and registered as a professional engineer (PrEng) with the Engineering Council of SA (ECSA) with more than 12 years' experience. Has extensive experience in AM and maintenance management consulting in the mining and heavy process industries, conducting AM maturity assessments around the globe and has been involved with numerous asset and maintenance management improvement projects.

O&M Manager (utility scale solar PV and wind power plants): Bachelor of Engineering (BEng) Electrical and Electric with a Masters in Engineering (MEng) Renewable and Sustainable Energy with more than 10 years' experience. Key experience with the acquisition, design, management and implementation of projects. Core competency has evolved to the O&M of REPPs and has experience in managing wind farms and currently heading up the O&M division of an AM organisation managing a portfolio of four (190 MW) solar PV farms as part of the REIPPPP.

Operations Director (utility scale solar PV and wind): Bachelor of Science (Honours), Mechanical Engineering with more than 20 years' experience. Key experience in the construction and operation of wind turbine fleets in Europe. Most recent experience includes directing the operations and maintenance organisational function in a AM organisation that owns and operates a multi-technology (solar PV and wind) portfolio or REPPs consisting of 238 MW.

O&M Manager (utility scale wind power plants): Bachelor of Engineering (BEng) (Mechanical), Masters in Business Administration (MBA) with more than 12 years experience throughout Europe and SA in the solar (CSP) and wind energy sectors. Core responsibility over the past three years has been managing all aspects of a portfolio of wind farms (205 MW) as part of the REIPPPP.

Operations Engineer (utility scale solar PV wind power plants): Bachelor of Engineering (BEng) Electrical and Electric with one year of experience in the SA RE industry. Key AM experience in the RE field. Team member of the O&M function in a AM organisation that owns and operates a multi-technology (solar PV and wind) portfolio or REPPs consisting of 238 MW.

Senior Remote Monitoring Center Operator (utility scale solar PV wind power plants): N4 electrical engineering (light current) with eight years' experience in the SA power sector. Key experience includes six years as senior instrument mechanician in a nuclear power plant dealing with preventative and CM on plant instrumentation and equipment. Most recent experience includes two years' experience as a senior RMC operator in a AM organisation that owns and operates a multi-technology (solar PV and wind) portfolio or REPPs consisting of 238 MW.

5.5 Success criteria

Criteria for success need to be defined when establishing a measure against which the proposed CMF can be assessed. Criteria can be regarded as a set of conditions or principles by which judgement can be made regarding the whether a project has been successful (Lim and Mohamed, 1999, 244). In this case it is the criteria according to which the CMF can be judged.

A number of criteria were identified against which the proposed CMF could be judged and assist with further developing the CMF. Similar success criteria to those defined and used by Beecham *et al.* (2005) were used as a foundation for the success criteria of the proposed CMF. The purpose of establishing the success criteria is to create the standard to which the outcome of the face and user validation can be measured. Should the proposed CMF meet all the criteria it can be regarded as being successful.

The **perceived usefulness** of the CMF is the first success criterion. Work by Davis (1989, 320) states that a system has high perceived usefulness should there be a positive relationship between the user and use-performance. The perceived usefulness is based on whether people think that applying the framework will assist them at performing their job better. Perceived usefulness can be defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, 320). Users will thus apply the framework in industry should they foresee that there is a potential benefit or a value add for them or the organisation.

The **perceived ease of use** of the CMF is the second success criterion. Irrespective of whether users believe that the application of a system can be useful, its application needs to be simple and optimise resources: this is the perceived ease of use. Perceived ease of use can be defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, 320). This criterion therefore aims to identify whether the framework is usable and maintains a level of simplicity without losing functionality.

The **ease of comprehension** of the CMF is the third success criterion. The purpose of this criterion is to determine whether the CMF is sufficiently clear and well defined to be implemented in practice without confusion, and assessing whether the structure of the CMF and steps outlined in the CMF are logical, unambiguous and functional.

The **flexibility** of the CMF is the fourth success criterion. The CMF needs to be adapted to other environments, based on specific organisational needs. The CMF should, however, maintain its core functionality.

The **achieved objectives** of the CMF are the fifth success criterion. Establishing whether it is true or not that the CMF has realised its objectives should be assessed as a criterion. The objectives of the CMF can be summarised as providing an ISO 55000 series-aligned CMF, consisting of four phases with key features that are expressed using supporting business processes that can be used as a structured guide to centrally manage ACPs. The CMF also attempts to address key industry challenges such as the lack of information from OEMs, competency and skills shortages and inadequate maintenance plans for the RE technology. The overall CMF should add value to Asset Managers in the RE industry in SA. Therefore, establishing experts' opinions regarding the potential for the CMF to be adopted and used in the SA RE industry is regarded as critical to the validation of the proposed CMF.

Lastly critical success factors for AM services developed by Jooste (2014) are selected, depending on their suitability for this study and adapted to more accurately represent the study goals. Based on the 13 critical success factors identified by Jooste (2014, 168) the following four are considered and adapted for this study.

- (A) critical success factor (Jooste, 2014, 167): "The alignment of the Asset Owner's AM service requirements with their overall organisational and business strategies (2c)"

- (a) adapted for study: Creating the Line-of-Sight and alignment of AM activities with the overall organisational and business strategies.
- (B) critical success factor (Jooste, 2014, 167): "An adequate training programme in place for all AM service role players, both in the service provider and Asset Owner teams (4a) "
- (b) adapted for study: Adequate means of addressing competency and training requirements for all involved in the organisational AM activities.
- (C) critical success factor (Jooste, 2014, 167): "The use of performance measurement to monitor, control and improve the AM service (5j)"
- (c) adapted for study: The use of performance measurement to monitor, control and improve the AM activities.
- (D) critical success factor (Jooste, 2014, 167): "A focused and continuous improvement process to improve the AM service through monitoring, analysis and feedback (6f)"
- (d) Adapted for study: A focused and continuous improvement process to improve the AM activities through monitoring, analysis and feedback.

5.6 Validation Results

This section presents the experts' responses to the interview questions in addition to other notes, comments and suggestions that were made by the experts during the interviews. The goals of the interviews were to ascertain if the participants would utilise the proposed CMF or find it useful and value adding to the industry. Findings from the interview data were analysed in order to measure the extent to which the experts' perception of the proposed framework complied with the success criteria.

Interviews were concluded over a four-week period after which the feedback was transcribed from the voice recordings into text, collated and analysed. The experts responses including notes, comments and suggestions to the interviews are presented per phase of the CMF followed by the CMF synergy and then a discussion on the architecture and success criteria.

Questions, preceded by problem statement and the objectives of the face and user validation, were asked in a semi-structured open manner and participants would often make comments which addressed aspects related to prior or later questions. The complete questionnaire and response of each participant are provided in appendix G and reflect verbatim responses of each participant.

The goals of the interviews were firstly to ascertain if the expert participants saw any value for industry in the CMF and would utilise it. Face validity was tested by gauging whether the CMF (research output) was capable of addressing the intended purpose and identifying prototype improvement opportunities. User validity was tested by understanding the perception of potential users regarding how applicable the proposed CMF was and assessing, using experts, what the impact was of the assumptions, simplifications, methods, and generic structure made by the CMF.

Lastly the interview feedback and data were analysed to measure the degree to which the experts' perceptual experience of the architecture and how the proposed CMF complied with the success criteria defined in section 5.5.

5.6.1 Asset Management Framework – Phase 1

The overall participant response indicated a complete consensus among all participants that phase 1 of the CMF covers the core strategic considerations of a RE AM organisation and furthermore also complies with the requirements of ISO 55001 in terms of strategy and planning. One participant states: "Yes I think it does. From my experience in my previous role as a wind farm manager and in my current role managing solar farms it covers most of the core aspects." Another participant who is an expert AM practitioner remarks: "Yes I think it covers it excellently and you did a good job in terms of covering the ISO 55001 requirements."

Another general consensus is that phase 1 of the CMF is very detailed and comprehensive with participants stating "that it touches on everything. It tells you of all the things that you need to look at ... and you can take it and apply it to almost any aspect of the business and it will help to pull things together." One participant even went so far as stating: "So if you had to take the view of an [REPP] AM organisation and insuring that you protect the interest of the AM organisation, you would not accept a project unless it has been delivered to a standard that is essentially defined by the CMF ... Then say our policy is that a project has to be delivered with phase 1 of the CMF considered and if it is not built to this standard then we don't want to manage it."

5.6.1.1 Weak Points

The weak points highlighted were specifically related to the challenge of conveying the complexity and also the complexity introduced by the jargon of the ISO 55000 series and the AM discipline. One participant states: "The weak point is not necessarily a weak point of the phase 1 ... it is a weak point in ISO 55000 where the jargon can be confusing ... The challenge is thus the ISO 55000 terminology itself ..." while another participant noted: "Someone that does not understand some of the basics might perhaps not understand what the different areas are." Another weak point which was identified was that the amount of effort, resources and time required to complete phase 1 was not clear and could potentially mislead users of the CMF regarding the total effort required to perform the CMF phase 1 activities. The participant states: "It does not specify the amount of effort that is required to do all of those things [planning and strategy] ... So although it is very nicely mapped to ISO 55000 and when talking specifically about AMPs, I struggle to get the concept that you will not just do it once ... So it would be nice if there is an indication of the amount of effort these actions would require."

Another comment was also that the although the text references the AMS in the SAMP the diagrams do not make it clear enough: "The SAMP splits into two parts – the one part you cover well and is a strong point where you cover the AM plan of the SAMP but I do not see the consideration for the AMS. So although you might cover it in the text it would be good to cover it within the diagrams." Other comments related to the diagrams spoke to the clarity around ownership or responsibility for the described tasks, perspective and outcomes. Concerns around the ownership were raised by a participant stating: "It is also not also clear who is the owner of the specific sections." This is echoed by another participant who also addresses the clarity of outcomes stating: "Having more clearly defined deliverables. As an example you have a step that states a SAMP, is that a document, or is it a high level document, detailed document, or something that needs to be approved by the organisation? Is it something that gets developed and given to the business? Some of this detail is not specified." Lastly the lack of clear perspective, where in the organisation is this process placed, is identified by a participant who states: "I think that it is important to understand from whose perspective you do this and that is not quite clear."

5.6.1.2 Strong Points

The perception of the strength of the framework varies among the participants, but there is a clear trend regarding the level of detail, comprehensiveness and way the phase is structured and flows as a strong point with participants stating: "Very well set out, it makes complete sense to me ... I like the way it is done in flow diagrams." "I think the details you [phase 1 of the CMF] have regarding the AMPs is actually a strong point, it is much more than what ISO 55000 covers ... I think you [phase 1 of the CMF] have lifted it out there every well and structurally given good indication on what is required ... the fact that it specifies the detail in my mind is a strong point." "It is very clear if you take the time to look at it. The details makes it daunting but makes it more useful as a tool." "It is very broad and touches on everything. Other than resources requirements. It touches on all aspects of the business risk management, maintenance policy, culture, etc. ... It is very clear if you take the time to look at it. The details makes it daunting but makes it more useful as a tool ... The flow is very clearly defined. It provides you will a clear process of how to potentially approach this ... It looks very thorough and if you do this and do this comprehensively then it's definitely a solid process.

You will uncover all kinds of things."

5.6.2 Asset Care Plan Development – Phase 2

Overall, the statements from all experts support the potential of phase 2 of the CMF to cover the core requirements of developing an ACP for REPPs. Participants all had a very positive view of phase 2 and some of the typical responses to the question whether phase 2 of the CMF covers the core requirements of developing an ACP for REPPs were: "Yes. I think it covers it in quite a bit of detail the things that is required to develop good ACPs." "Yes I think the core requirements are covered." "I did not see any omission in there. I think it covers it. It seems very comprehensive, sequential and methodical." "This can be applied by any RE AM organisation that has to do maintenance."

There was also a general consensus from all the participants regarding the view on whether the proposed process of developing ACPs in phase 2 of the CMF is more sophisticated and adequate than what is seen in the RE industry in SA. The participant responses stated that the process was "much more detailed and sophisticated that what I have seen thus far". "Yes there are some very specific characteristics that we don't normally see related to ensuring the correct skills and very relevant the question related to obsolescence of component ... there is evidence that there is specific attention paid to the specific industry." "This is more sophisticated than what I have seen within my extensive experience in the RE industry in Europe and in the few years in the SA RE industry." "I do believe it is more sophisticated as what we see mostly is the use of TBM and if something fails they [the OEM] would go and change it." "I would say definitely [more sophisticated], because we are all relying on, at this point in time, multi-national OEMs who are importing – we hope, their tried and tested systems and plans. Often they do not give us the ability to scrutinise the detailed information and we in the SA RE industry are only now just learning what it is that we are looking for." The last statement by one of the participants also highlights the key challenge faced in the RE industry where the OEMs are not sharing critical information to enable local teams to develop good ACPs or understand the technology.

The ability of phase 2 of the CMF to create the Line-of-Sight, between the strategic activities and the ACPD process, is confirmed by the participants, but there are some qualifications with participants stating: "Ya, I think it is better than most in term of achieving the Line-of-Sight." "Ya, so I think there is that provision for the level of service, once again it will be up to the facilitator to ensure that he populates that in line with the AM objectives ... That one column indicating the level of service will at least give you the opportunity to create that Line-of-Sight." "I think it [Line-of-Sight] does exist in the process. However the facilitator will play a key role in bringing the bunch of techno-geeks in the room back to the reality of what they are trying to do as people can easily get side-tracked." "I think that there is a risk of that[creating the Line-of-Sight] not happening...So does it provides sufficient Line-of-Sight, perhaps not in itself if it is not brought up on a regular basis and people are reminded of that ..." The qualifications are thus based on ensuring that the ACPD facilitator/management reinforces the Line-of-Sight throughout the process to ensure that engineers who often get lost in the detail remain cognisant of the link back to the OSP.

Feedback from participants on whether they think the requirement of the ACPD process to consider and procure the appropriate skills to mitigate the risk of not having the correct skills in the room when developing the ACPD process was positive. When asked whether it would mitigate the risk the participants' responses were: "Yes, you would know there is a skill required and you would make a plan." "The point of the process is to identify the most appropriate skill or resource. That will mitigate the risk but does not guarantee the availability of the resource ... So mitigation – yes for sure." "Yes we identify them to say that we need this skill. This needs to be done before the session ..." "Yes, it mitigates to an extent. Thinking about the skills required means you are more inclined to proactive[ly] seek out the skills required or at least have a plan in place to acquire those skills if you need to ..." "It will help but it cannot completely remove the risk. Yes, you can remove a significant amount of the risk that you will not have the skills available. Having the correct people available will definitely help you to understand the failure modes and failures." However, there were some further qualifications to the mitigation strategy and participants voiced their concern by stating "and then from practical perspective it is still a nightmare to get the people together. There might still be a risk that people will not be available ... So I think it reduces the risk, there are still risk[s] that remain." "That will mitigate the risk but does not guarantee the availability of the resource. Especially if it is a scarce resource like an inverter specialist."

Faced with the question of what skills the participants viewed as key skills or competency shortages in the RE industry the responses were: "There are key skills gaps like millwrights that are scarce and inverter specialist ..." "Specifically to wind turbines and PV panels I haven't met any local specialist it is normally fly in guys from the [foreign] OEMs." "We do not have people with skills on specific technologies. In SA you will have an electrical engineer that knows a bit about transformers and a bit of inverters. But you will not find the guy who is the inverter expert. In wind we do not have any skills on the wind turbine itself." "There is no doubt that we have, and will continue for some time to have a dearth of skilled technicians or wind turbine technicians in the industry." "The key skills that we really would be lacking from a wind perspective we are very weak in SA regarding blades, gearbox, control systems and there are not a lot of people who can understand the SCADA system data to perform diagnosis of errors ... So the skills shortage is the experience and the diagnosis of errors. PV modules there is a skills gap, inverters are not too bad. But there are very technology-specific things like control and SCADA, blades, and PV modules. This is just wind and solar there will be more for a technology like CSP." "There is a lack of skills in understanding of metallurgy or skills on PV panels or the structure of a wind turbine. We do not have the skills on the finer details such as why bearings in a wind turbine would fail by having an understanding of the operating environment or metallurgy and lubrication." The view presented by the participants clearly shows that there is quite a significant dearth of competency in the local SA RE industry that will need to be addressed and makes the development of ACPs for RE by local people a challenge. Another participant does not just specifically mention a specific technology skills challenge but a general SA RE industry skills challenge by stating that: "There are key skills gaps like millwrights that are scarce and inverter specialist. You struggle to get guys who understand the mechanical and electrical aspects. You need that all rounder a guy who knows everything. It is an issue and especially in SA, our industry is not geared for that especially due to companies that Eskom that forces you to become a specialist ... So im my mind you need the same core skills for wind and solar PV. You need the combination [electrical and mechanical] and their scarcity makes them more expensive." Interestingly this comment would indicate that a certain competency set can be shared between the wind and solar PV industries. Technical skills are not the only challenge as managerial skills are also identified as an issue and the retention of staff is also raised as these REPPs are often located in rural areas in SA and one participant states "Getting site managers [is] also a challenge. So I think there are a range of skills that shortages of and sometime the locations of the project are a real key challenge. Just because you find the skills in Cape Town or Johannesburg and send them to the rural locations and think they will be settled. You can find young guys who are ok to be out in the rural areas for a year or two but then they get tired of it or bored and want to leave. Even on strategic level there is a challenge – we get approached on a weekly basis with job opportunities, that tells you there is a lack of managerial skills that have been building or managing these projects. There is no doubt about that."

The process of developing ACPs requires that SJs are developed as part of the process to take advantage of having all the skilled staff in the room during the ACPD process. There was a very positive response from all the participants when asked whether this would assist centrally located unskilled planners and schedulers to plan more effectively. The responses would also indicate that developing the SJ during the ACPD process adds significant value. Participants responded by stating: "Yes, for sure [it will assist central planners and schedulers]." "Apart from the CMMS specifics I think this is a very valuable part. I attach a lot of value to the standardisation and repeatability of jobs and to leave that over to the abilities of the planner and schedulers of which you rightly say are more and more in a centralised space with less and less skill this will go along way to address that." "Yes when you are specifying some details for SJs. Yes it will definitely assist the planners and schedulers ..." "I think if you don't do it in the ACPD session – it will take you a lot longer to do and longer to implement. So if you walk out of the session with the experts and have your SJs – all you have to do is make it happen. I think if you are relying on people who don't have the profound understanding of the problem and the solution and not been part of the process to designing it they are going to battle to build a SJ. I think without the SJs the central planners will battle." "I think having all the detail ready within the SJ that was developed by a skilled person already gives the planner and scheduler the ability to quickly see via the SJ what the information is that needs to be provided to the technician on site. I think having that information available in the SJ is critical as planners an schedulers will likely not have the knowledge."

One of the major challenges identified in the SA RE industry is the unwillingness of foreign OEMs to share detailed information – information that could assist with maintaining and optimising these REPPs and could also be crucial in developing good ACPs and also building and establishing well run REPPs. Participants were of the opinion that understanding such a ACPD process could assist in negotiations with EPC and O&M contractors to make the correct information, data sheets, documents, procedures, manuals and access to data available during the contracting stage. When posed the question of whether this process would be of assistance the responses were: "Yes definitely. One of the considerations when we spoke about the total cost of ownership and LCC is to consider all the implications of the Asset Care activities – but actually transferring that to a contractual requirement which is the more difficult part. I think this is clarified by the process and detailed and that is even a further advantage – once it's done for the generic asset types in a REPP then it would be even more valuable in renegotiating or new contracts for new or similar plants." "Yes, I think it is becoming more and more the norm these days to specify contracts up front that contractors have to specify a maintenance plan defended by some FMEA. I think this process will support that. Realistically more and more end users would like to obtain the basic FMEA from the OEM and then just supplement it with region or context specific failure modes ... [G]oing through this process there are many little things that will at least prompt you to say we need to tie that down contractually as there is no easy mitigating action afterwards – so yes I think it will definitely assist." "It can – hopefully they will not claim that it is intellectual property as we currently see in the industry. You can definitely specify more detailed information. Yeah, for sure."

5.6.2.1 Weak Points

Participants state that the weak points of phase 2 of the CMF are "challenging for someone who does not understand the area [of developing ACPs] and the processes well might find it a bit difficult to follow. You will also have to spend a lot of time on this. Ideally would need the skill internally." "I would just emphasise the challenge to get the people together and keep them together for that amount of time to complete the process with all the details that it requires. However, the strengths lie in the details and if you start skipping it you lose all the details." "I think from a purely facilitating perspective it is a daunting task to firstly open that spreadsheet up and you know you need to complete all of those columns. I would say there is some room for optimisation ... So you have to consider how you can make it more practical tool that can easily facilitate the discussions over a typical four day period." "The visual complexity of the Excel sheet. I can understand why you use Excel but I am not convinced that it is the most effective tool." "It might be good to have someone who is more of a generalist and understand the system you are working on not just the component. You might need a oil specialist but having a overall transformer specialist will also be helpful in understanding what the overall transformer criticality is." "Just looking on the face of it – there is nowhere I see the degree to which you assess this [which assets you will analyse]. It seems like you select a competent and apply it to the same degree for each one. The process does look at the prioritisation. I think you need some scale especially consideration [of] the amount of time and people you need to do this as the process is very binary as it currently is."

5.6.2.2 Strong Points

Participants state that the strong points of phase 2 of the CMF are: "It is a very detailed well-structured process." "The development of the SJ is definitely a plus. The risk assessments is important where the risks are prevalent – high voltage high energy situations." "The specific focus on obsolescence. It is often something that we ignore or skip over ... Because there are few asset types you should be able to do this detailed analysis." "A core strong point is that you cover almost everything ... The level of detail is also very good ... This can also help you identify the core skills that you require. Then you can also consider it from a cost perspective to understand the economic viability of subcontracting or bringing the skill in house ... If you go through this process it will help you defend the amount of people and also economically justify it through a skills LCC. It will be difficult for top management to say no." "It is very detailed. Not much left to chance. It also not just based on opinion but using information and experts. It is relevant industry information that is used." "The obsolescence is a very critical point and really a strong point. Also the process is detailed and broad enough to cover all your basis." "It's a very structured process that most of us in the RE industry do not follow but often do in haphazard way and doing it sequentially like that is very thorough. It is very detailed."

5.6.3 Work Planning and Control – Phase 3

Overall, the statements from all the RE AM experts and the AM experts support the potential of phase 3 of the CMF to cover the core requirements of work planning and control. All participants agreed with a participant who stated: "Yes it definitely covers all the core requirements. I cannot think of anything that is not there in terms of our own reference." All other participants had a similar view.

The process requires that the planning, scheduling, WO creation and close out are predominantly centralised with a strong collaborative engagement with the on-site maintenance team, with WO execution and completion decentralised. There was a complete consensus, with some qualifications, from all the participants regarding the feasibility of the central design in the maintenance organisation with participants stating: "Yes it should be feasible. It is feasible in my current organisational environment but I would change one or two things. However, the core idea around the centralisation of the planning and scheduling and decentralisation of the work execution is completely feasible even within my current organisation." Another participant states: "I think it is feasible within the maintenance organisations design. There are one or two activities which one can argue should the decentralised team not do it but that would a function of the tools that they have access to – let's say they have mobile access to the CMMS some things might be easier. I think the good thing is the centralisation of certain activities that we know sites struggle with that does not have massive maintenance complements." The view of another participant is very positive but notes some concerns based on experience that "you need to have some sort of checking of the quality of the information coming back from the field otherwise your CMMS becomes useless ... Yes I think it is feasible – it is something I have seen is difficult initially as technicians see it as micro management but if the relationship between the central planners, schedulers and technicians develop[s] correctly it can be very positive."

Some of the qualifications by participants included the use of a central CMMS and mobile technology to provide decentralised teams to access and update information on an ongoing basis during the day. Furthermore one participation notes the importance of having the resources available to meet the requirements of the organisational design.

During phase 2 of the CMF SJs are developed, while all the expertise is available, and loaded into the central CMMS as part of the ACPD process. There was complete agreement from all participants that this would add significant value to the quality and ease of planning and scheduling. When participants were asked to comment on whether this would add value their comments were: "Yes definitely it will." "I think referring back to the discussion on ACP [to] develop the SJs is a powerful tool, especially where there is quite a distance between the centralised and decentralised teams – a geographical distance but also a skills differentiation between the two – experts on sites and given that standards jobs were done with the input from the experts – I think it is a definite value add." "Yes it will. You can do the scheduling and planning ... this has to be done [basically] by unskilled people but if you have detailed information available it makes it much easier." "Yes of course, if you have a new planner and scheduler and an expert already developed all the detail – the understanding can come later. It definitely adds value – it also takes a lot of the guesswork out of the process." "If you have the knowledge captured it is easy to implement – the quality of the SJs would be good due to the expert creating the SJ and not an inexperienced planner. It also cuts down the time ... It improves the overall efficiency." One participant who has significant experience in the SA and European RE sectors comments on the value it [SJ pre-development] can add notes: "Yes definitely. I can see through one of the European wind turbine OEMs doing the O&M on one of our plants that have challenges with this. So yes it [SJ pre-development] definitely makes it easier to perform planning and scheduling."

One of the participants also raised an important point regarding the ownership of maintenance plans, which touches on organisational culture. The ACPD process can take place centrally or typically at a plant, but not everyone might always be involved, especially the people who actually have to perform the work or the planning. This point was also addressed in the feedback of *Asset Care Plan Development* phase 2 of the CMF with participants noting the value of having broader involvement by including work execution and planning staff as an example. It is important to have everyone take ownership of the maintenance plans, their execution and subsequent feedback and also understand the potential value centralisation can create. The participant noted: "It is very important that the execution team sees it as their maintenance plans and the more detail you define with the ACPD the more the pre planning is in a way done. So it would definitely assist the less technical or skilled resource to provide value – if a lot of the planning work has been done as part of the ACPD process."

The overall view of whether a central CMMS system would play an important role in a maintenance organisation with centralised planning and scheduling and other centralised functions was that it might not be an absolute necessity depending on the size of the organisation and diversity and quantity of the different technologies. However, there was a clear view from all the participants that it would add significant value and in most cases will be required to gain the most value from the centralised functions. The responses from all the participants echoed the value of a central CMMS by statements such as: "It can be done without a central CMMS; however a central CMMS will add a lot of value." "Yes it definitely needs a central CMMS – it is impossible to do with a paper-based system." "I think it does. If you centralised the functions in an operations hub then it would make sense to have a central CMMS in the place where the planners and schedulers are located and also where the plants [REPPs] are monitored and initial faults can be detected." "In one form or another you will need that central system." "If you had one wind warm and one solar farm, the argument might be ya you might get away. But the moment you have more of one type it is so much easier to optimise." "It does not require a centralised CMMS – it could – but I think the value of the centralisation is without a doubt. Especially if the technology repeats on more than one site. Then without a doubt. With common technology – as an example your electrical balance of plant will be similar at all sites – you get the advantage of a commonality at a central site." "Yes, if you get a new site with a new CMMS you will have to re-train people on a new system and load SJs in a new system. When you have a common central CMMS you can carry a lot of the knowledge over in a single system."

5.6.3.1 Weak Points

Potential weak points were raised by five of the seven participants. However, the weak points were very focused on practical considerations which fall outside of the scope of the study. Participants highlighted potential weak points of phase 3 of the CMF which relates to reactive work by stating "The weak point is that when you show this to someone they will ask you so what if something breaks during the day and the schedule goes out the window." "I think that the interaction time will be challenging – what I mean by that is if you have a large portfolio of six plants you cannot have a single weekly or morning meeting. It will take too long and one plant will not be interested in the work happening on another plant. You might have to have a larger central team who can split off into different technologies or attend separate meetings which are manageable and practical." "One weak point that we touched is the initiation of the reactive work. If you describe or include that in your process that would add value..."

Another practical consideration highlighted was the practical day-to-day consideration for operating such a process in a large portfolio of REPPs. It might not be practical to have the meetings as depicted in the process as teams might not be interested in what is happening on other sites. There might need to be consideration for a larger central team to interact with the respective REPPs when participating in weekly and daily meetings.

The coding of feedback as opposed to using free text for technicians or planners to make notes was also raised as practical consideration with the participation noting “a specific element to that which is similar to the SJ is a standard set of terminology of describing a problem so that it is not purely free text. I saw this a lot when I was working with a specific company. It is similar equipment, for instance a pump, that is at 10 different sites, you would have at least five different descriptions of the same problem. Now it gets up to the central point where it is interpreted and then this guy must make the call whether this is the same problem. So centralising or just including in your process for some types for coding problems or failure modes.”

Lastly, one of the participants raised a key point regarding safety and the potential need for a separate WO when authorised operation is required for a maintenance task. Although this is implied in the planning section where specialised skills are identified, there could be more emphasis on this requirement during the planning, scheduling and work execution processes. The participant noted the concern through the following statement: “Through the execution I did not observe a lot of emphasis on the requirement to have someone with special skills to make the work safe. I think it is mentioned somewhere – however for our operating environment safety is a key concern and in most cases you would require a responsible person, according to Operating Regulations for High Voltage Systems (ORHVS), that can authorise the work or must lock-out/tag out and then take over again ... I feel because it is something that is so specialised and needs to be recorded in the event that an accident occurs and someone dies. You have to record and show that the person completed the lockout/tag out correctly. So it could potentially even be a separate WO that you can track.”

5.6.3.2 Strong Points

The strong points of phase 3 of the CMF are very focused around the level of detail and comprehensiveness, consideration for the resource (weather), centralisation and value of developing the SJs as part of phase 3 of the CMF. Participants state that the strong points of phase 3 of the CMF are that: “The process is very detailed. Pretty much almost everything is covered. It is a very good way of informing someone of what his job is. And that the responsibilities are clearly defined, who is responsible for what and which parts are collaborative ...” “[Centralisation] is a definite strong point for technology and equipment that is repeated over sites or a site – I think it overcomes the inevitable staff turnover situation especially with planners and schedulers and in our experience there is a fair amount of turnover – and centralising that you improve the sustainability.” “It provides a good level of safety.” “The strong point is that it is very very complete. It is a very robust sort of process that covers the most type of probabilities.” “A lot of the work is front-end work

– like getting the SJs developed that pays dividends. It is a very thorough process set out by the framework." "There are a lot of feedback loops and review processes which is good. Another strong point is the supervisor and RMC checking on quality of information." "Yes I fully support the view that the centralisation is a strong point ... A strong point is to bring in things which are important in the RE environment like the weather."

5.6.4 Competency Management and Continuous Improvement – Phase 4

The importance of organisational culture was unanimously agreed by all participants to play a key role in the overall competency management and continuous improvement processes. The importance was noted by comments from participants such as: "Yes. It adds to the work being done the way you want it done." "I agree – even more so in a bigger organisational culture or efficiency. It has a specific role in competency management but even more so in the business as a whole." "Yes, as we said in ISO 55000 the whole aspect around leadership and organisational culture is a significant enabler or key success factor so it has a very profound effect in competency management and the bigger asset management subject." "Yeah, how you consider your employees in the organisation makes a great impact on how they perform." "Yes definitely, if one of your culture items would be learning, training and coaching – it would help ... Culture is important to establish the quality of work you would like to experience from your staff." "It plays a huge role – possibly nothing else [is] more relevant [than] that."

Throughout the study the dearth of skills and competency to holistically manage RE assets has been highlighted. When faced with the question of whether phase 4 of the CMF could assist in managing competency all the participant responded positively with comments such as: "Yes it does." "Yes I think that all the core requirements are covered ..." "Yes, I think is nicely mapped to the sort of requirements that you stipulated in phase one to three." "Yes it states the requirement of developing a competency framework to assess the role requirements. And there is the continuous review process which will help keep competency requirements updated and understanding the competency you need in-house. It also help you move people access roles as you will understand how their skills compare with other role competency requirements." "It is important to get the competency matrix and makes sure the roles have been benchmarked. Also when you recruit for roles you know which competencies you need." "It appears to, I think it does." Participants also qualified their views by stating that competency management "can however be represented outside of phase four as a separate phase," and that there should be a "way of assessing the performance of your competency management framework."

Closely linked to the competency management is the potential capability of phase 4 of the CMF to sufficiently address the skills dearth in the SA RE industry over a time period. There was a resounding positive view from all participants who commented on whether phase 4 of the CMF sufficiently addressed the skills issues by stating: “Yes it does.” “It will reduce risk over time, yes.” “Yes it will – as long as you stick to continuously try and understand or assess how well your framework is doing.” “It will help you to find the skills you lack and employ the correct people.” ‘Yes definitely – because where you lack the skills you will provide training.” “Yes, I can see that it identifies gaps and then attempts to close those competency gaps.” Three participants further qualify their view and highlight continuous improvement by stating “Yes so the competency management process as I recall it does not have a specific indication of how frequently to review. It will reduce risk over time yes.” “Yes it will – as long as you stick to continuously try and understand or assess how well your framework is doing.” “It will definitely be over a time period. It is continuous improvement and not focused improvement.”

The view on whether competency management should be managed in a centralised mode is slightly mixed and generally qualified by some participants. The definitive views of participants whether competency should be managed centrally is: “Definitely.” “Without a doubt I think that it needs to be centralised to achieve the standardisation in a sustainable manner.” “You have similar sites and similar competencies at site – if you manage this centrally it would make sense.” “Yes I would fully support that it is centrally managed. Especially if you can share skills between sites ... In a environment where you have multiple sites with similar technology I would manage competency centrally to give that flexibility across the different operations.” However, there is also a strong view that the development of the competency frameworks and the management could be centralised but with a very strong collaboration with the respective REPPs teams. This view is qualified by participants who state: “It is something that should be managed centrally with consultation from the sites.” “Managed centrally yes – you can get input from the sites but it should be managed centrally. It also helps you to manage the competency of the teams better by understanding the level of skill each person has and where they might need to be up-skilled.” “For consistency it is something that you should develop centrally and acted upon and managed at the site level. If you don’t have a central HR department to run this it will be challenging. Depending on the organisation design – but it could be beneficial to develop and manage the competency framework centrally with input from local site teams but actually making sure that the training gets done should be managed at site level or decentralised ...”

5.6.4.1 Weak Points

The weak points identified firstly related to the clear identification of succession planning considerations in the process diagrams. The text related to phase 4 of the CMF does touch on the issue of succession planning, but according to some of the participants this should also clearly be identified in the diagrams and one of the participants states: "Succession plans are not really specifically identified in the diagrams. It might be good to highlight it in the diagrams as it is an important aspect." On a separate weak point there is not a clear link between using the ACPs developed in phase 2 to specify the number and type of skills required as it can be a key input into phase 3 of the CMF.

Although not a weak point, a challenge from a practical perspective was highlighted, regarding phase 4 of the CMF, by one of the participants who stated that: "It is generally very difficult to implement. So the weak point is not the CMF but these softer subjects in the technical areas [are] difficult to deal with."

5.6.4.2 Strong Points

The strong points phase 4 of the CMF are very focused around the guidance of the continuous and focused improvement actions, consideration for the soft issues in AM, and comprehensiveness and refreshing approach towards competency management to address skills challenges. Participants state that the strong points of phase 3 of the CMF are that: "I like the idea that the focused improvement process actually guides you in terms of how you will address the inefficiencies – as it is already explained. Sometimes people say there is a problem but they don't suggest how to fix it. This provides a potential process for how to fix it or address it at least makes it quite a good thing." "The soft issues – the culture is a strong point. We made a point regarding ISO 55500 and the issues around leadership and commitment which was brought out in phase 1 of the CMF." "Emphasising in a framework like this is that you might have the nicest process but if you do not have the people it is not going to work. It is good to see that in the framework there is so much focus on competency and even more so in the RE industry where we know that there [are] technical skills shortages which needs to be addressed centrally." "The frequency at which reviews occur. A lot of organisation say that you need certain skills and they never make the effort to invest in people."

One participant specifically notes the importance of treating competency, skills and people as an asset and notes that: "The strength is the continuous improvement process where you apply the same logic to your competency as you do to your equipment. So you are treating it like an asset – it is essentially an asset – You get the cliché saying that people are our greatest asset but then it just gets forgotten about. Just having this will be a great step for most organisations." Another participant highlights the strength of developing a competency framework based on the skills need for a specific role which could be very helpful during recruitment and states: "Yeah, I think that it actually tries to look at specific needs and attaching a skill to it ... To look at the needs and build up from there is the correct approach. I have not seen any organisation take the time to do so before."

5.6.5 Framework Synergy

The questions in the framework synergy were developed to measure how well all four phases of the CMF cohesively work together to provide a comprehensive guidance framework that is aligned to the ISO 55000 series of standards.

All participants had a very positive view of the potential of the CMF to support Asset Managers and owners in centrally managing ACPs while remaining aligned to the ISO 55000 series of standards by stating: "Absolutely it will." "I think it is excellent, I think there is a lot of potential in here ..." "If someone had to set up a RE company from the start if would give them an idea of some of the key processes and people that is required to be successful ..." "Great potential, you can actually use it and each phase seems to complement each other." "There is a lot of potential and anyone can take this framework and start applying it to their organisation or tweak it to their organisation and implement." "There is definitely an upside. Especially where there are multiple sites and multiple technologies on the generation side." One participant qualifies their answer by supporting CMF but raises the need to be cognisant of how it needs to be applied to each organisation and states, "I think there is great potential for it to be of benefit and an aid. I think that what you have to bear in mind with any system like this is to use discretion as to when and where to apply it. Because it is extremely detailed and the application of it is where you need to apply your skills, experience and knowledge of the organisation ..."

The CMF proposes that a significant proportion of the framework elements are centralised to leverage resources which can be shared across a portfolio of REPPs and optimise efficiency. Although there are a number of elements that are managed centrally, the framework has a strong collaborative element with teams based at the REPPs. The participants' views on whether the centralisation is appropriate are confirmed by their views, like "I believe so. Effectively yes, especially with our sort of specialised field and in a place specifically like SA where we don't have the skills maybe that is required." "Very specific to multiple sites. For me more so if there is common technology ... it just makes a lot of economic sense to handle many things centrally." "Yes, based on my experience working in a organisation with a central head office and distributed REPPs it makes a lot of sense logistically and a smart way to manage these assets." "It makes sense to keep things central when you have multiple sites. It can make things easier to manage and reduce the number of employees required." However, three participants also qualify their view and note that there should be strong collaboration with on-site teams which will also avoid the view that head office is dictating all operations: "Collaboration with the sites is very important as we do not want a us [head office team] and a them [on-site team] situation – and that is the one danger of centralising it especially at a so-called head office ... Even with the continuous improvement should always be collaborative. Everyone should be part of the AMS ." "If you want repeatability and a homogeneous approach to things and then you can set organisation goals you want to achieve you have to create the system centrally with making sure that it can be implemented practically and not do it from an ivory tower." Lastly, one participant was a proponent of decentralising functions and interestingly addressed a soft issue of keeping people engaged and interested in their work by stating: "So I think there are quite a few things you could decentralise. Also just on the decentralisation – something we have to bear in mind that it is not always about achieving the maximum efficiency by centralising, it is also about stimulating and empowering people – because the risk is that you hire these smart people to manage a plant but they are not fully challenged or utilised and then they get bored and leave. The more you decentralise and make them owners of these processes and accountable – the more stimulated they are and grow and surprise you all the time."

The Line-of-Sight, which is highlighted by the AM literature, between the OSP and the daily activities performed by the AM teams is a key theme reiterated throughout the study. Participants were asked to comment on whether the CMF created an environment where the Line-of-Sight between the stakeholder requirements, OSP, and SAMP can be linked to the daily activities performed by the AM teams. The participants' responses confirmed that the Line-of-Sight was created by stating: "I think that's actually one of the strong points – the whole follow through of the objectives from the top all the way to the bottom." "It brings up the Line-of-Sight issue and you [the CMF] showed us in pretty much all of those phases where the Line-of-Sight related activity is present even down to the WO level. So it will definitely enhance that visibility." "Yes it does and helps link them all together. The guys on the ground understand how their work translates to organisational KPIs and can understand the impact of their work." "I think definitely. We try and tell people why we are giving them work but probably not as enough as what is proper. So I think it is a very good process." One participant, however, does not think that it is important that the organisation and leadership keeps the Line-of-Sight visible and states: "As long as it is kept visible yes. The CMF gives you the possibility of creating the Line-of-Sight but then it is incumbent on the organisation that the vision is maintained throughout via communication and understanding and visibility of KPIs ..."

The CMF and all the phases work together to address the competency and skills challenges in the SA RE sector. Competency management is a strategic consideration, while the ACPD process and work planning and control phases can help in identifying core skills that are required which can then be addressed through a competency management and continuous improvement. Six out of the seven participants have a positive view on the potential of the CMF to understand/manage RE skills requirements/shortages using a competency framework by stating: “Yes it will work, it is difficult to say exactly, but yes it does. You might just have to add how many of the skills you require.” “Yes, the ACPD process can assist with identify skills and quantities.” “We did not go into details in the skills assessment – but the number of people you can get from the ACPD process and once you work through the activities you listed you can put roles next to them and identify the skills that are required.” “I think that its a framework that will definitely assist in managing skills and competency requirements.” “It goes a long way in understanding the skills requirements and identify the skills gaps.” “During the whole process the CMF looks at gaps. By looking at those gaps you identify skills gaps which can be addressed.” One participant, however, was not 100% convinced by the effectiveness of the competency framework as it is difficult to capture the human element and states: “There is definitely potential but it might not be the full picture. I do find it interesting to look at the exact needs, attach a skill to it and then build up from there.”

The CMF is placed in the context of the RE industry in SA. Participants were asked to comment on whether they though the CMF addresses sufficient elements related to the RE industry. The responses were positive with participant statements such as: “Yes, I think we saw evidence of this in phase one with the very specific stakeholders and KPIs and in phase two, three and four there were things from the weather to the very specific skills shortage. I would say from what we have seen there is very specific focus on the RE industry.” “Yes, you look at RE skills, obsolescence, the weather resource, planning – so yes.” “Yes, but it addresses power plants in general as well.” Interestingly, three participants confirmed that the CMF addresses RE-related aspects but raised points which specifically touched on the complex ownership and management structures in the SA RE industry by stating: “Yeah, you have to qualify this with the contractual situation [complex management structures] that RE Asset Managers find themselves in. We are not that much different from other industries – the REPP is also just a factory.” “Yes. To me it comes all back to the skills and the way we handle the assets which is a bit different to the other types of assets you get in the country. The way you have a SPV sitting in the one side, contractor here and the Asset Manager in the middle [complex management structures]. It’s different especially here in SA than what people would be used to.”

The CMF is developed for a multi-technology portfolio of REPPs. All of the participants had experience with portfolios of wind and solar PV REPPs with one participant equipped with experience on CSP in Spain. The overall view of the participants was that CMF could be applicable to different RE technologies and stated: "Yes, from my experience it would seem that it fits both solar and wind." "There is no reason why it would not apply to different technologies. And especially where there is multiple of them and there are common technologies and infrastructure." "There are a range of different technologies, CSP, wave technology and what all others but these are all technologies we do not have skills for in SA and this is very relevant and especially where there are multiple sites." "You can pretty much use it on any technology." "It would seem to be universally applicable to any RE plant." "Yes definitely. The process is good and can be applied to other technology." "Yeah completely [it can be applied to different technologies]."

5.6.5.1 Weak Points

None of the participants noted a very specific weak point of the overall CMF. The responses were mostly presented as feedback and potential improvements. The comments were varied with two of the participants highlighting practicality as a consideration by stating: "I cannot specify any specific weak point. So academically it could be good but practically it might not be as easy," and the other noting "I would not say there is an overall weak point. The challenge, however, is always to keep it practical. Like the ACPD spreadsheet, the competence framework needs to be practical. So that is always the challenge."

One participant commented on the initial visual shock and perceived complexity while another participant mentioned that the complexity and comprehensiveness could also be a hindrance if not managed correctly. They stated their views by saying: "The complexity shocks you initially – but once you get through the details it seems logical. So perhaps the initial perception of complexity can be a challenge." "The strong point [level of detail and comprehensiveness] could potentially be the weak point. If you had to give this to a few focused engineers they could spend three years and a lot of time and money."

There was also a concern around the clarity of implementation time and resource requirements to undertake such a process with one participant stating "I think if I was about to start a new RE AM organisation and I picked this up – the questions I would ask is: How much will this cost? How many people do I need? How long is it going to take? Ideally somewhere you have to indicate that it is a long-term complex process." Another participant felt "the time to implement might be a weak point. It will take very long and a lot of effort."

5.6.5.2 Strong Points

All participants had a very positive view on the overall capability and value of the proposed CMF. The view of one participant is that: "It's quite detailed and well put together ..." Another strength that was identified is the potential of the CMF to create a foundation from which to build with one participant stating: "The initial strategy and planning is a strong point and key to developing a base from which to operate. Everything flows from this and would move everything and everyone in the same direction." In developing the foundation and creating organisational self-awareness one participant said that "The CMF is good at identifying gaps and understanding where the shortfalls are. It also has a good focus on continuous improvement to make sure the gaps are addressed." Strategy and planning, identifying gaps (understanding maturity) and continuous improvement are all themes which links to the overarching AM framework, with one participant commenting that a key strength is the "reference or mapping to ISO or GFMAM," and further noting that should there be expansion aspirations, "any investor that knows there is a ISO 55000-compliant CMF in place would see this as a very positive point." This links to comments from another participant who says that "what stands out is the fact that in bidding for new plants – the business development activities – there is a lot of things that you can take out of this framework. If you are aware of the framework you know this is the sort of ideal model of the operation requirements you can really make sure than the contract and business development process and the OEM contracts are fully aligned with the CMF requirements."

Two participants noted that a key strength was the how the framework was developed with one participant noting that: "There is a good agnostic view. The methodology and the CMF seems to be developed without any major preconceived idea around what such a framework or the processes should look like and developed organically – this is a major strength." A similar view is echoed by another participant who notes, "the strength of it is the comprehensiveness and the fact that it goes back to first principles by leaving all preconceived ideas at the door in terms of what systems and processes are appropriate to a REPP and built a framework from the ground up. That to me would be a strong point."

5.6.6 Framework Architecture and Success Criteria

All the previous responses of the face-to-face semi-structured interviews, including additional comments recorded during the interview process, were analysed according to the architectural aspects and success criteria defined in section 5.5. Participants were also asked to provide a rating of **Poor, Fair, Good or Excellent** for each of the twelve questions which attempted to describe the success criteria and the architectural aspects. Furthermore, some critical success factors identified by Jooste (2014) were modified in section 5.5 and incorporated in the questions to understand whether the framework adequately supports the critical success factors.

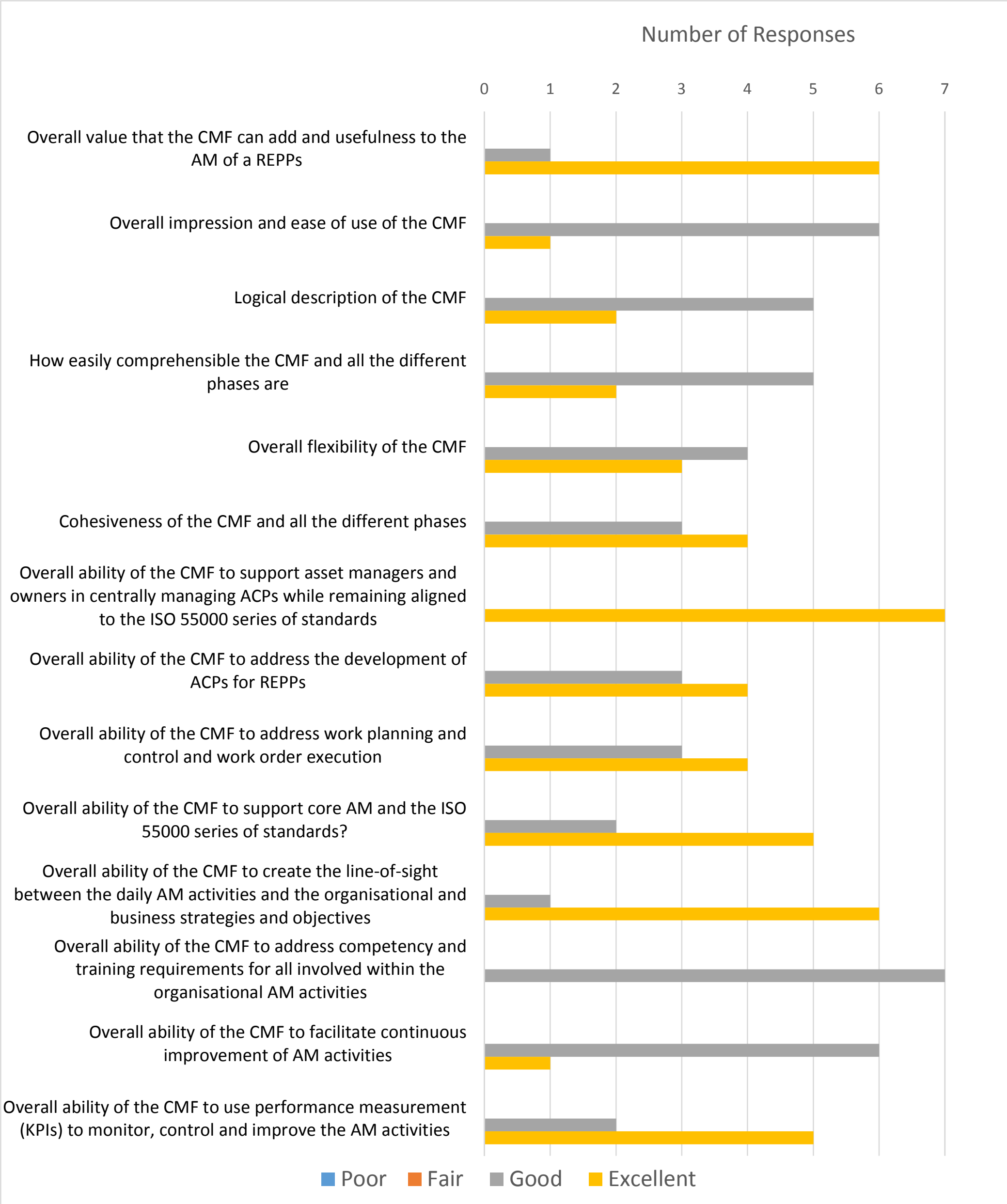


Figure 5.2: Participant feedback on the architectural and success criteria aspects of the CMF during validation

Assessing the architectural correctness of the proposed CMF and its respective phases, all the participants are also asked questions about the quality of its structural logic, cohesiveness of all the phases, flexibility, ability of each phase to address its objectives, the ease of understanding the CMF and the phases, its ability to facilitate continuous improvements and competency management, and the integration of AM requirements aligned with ISO 55000 series of standards. The results of these interview questions can be seen in figure 5.2 with none of the participants rating the CMF as *poor* or *fair* on any question. Furthermore, based on the participant responses and perceptions with the overall score for the questions related to the framework architecture and success criteria, where participants had to provide a rating of **Poor, Fair, Good, Excellent**, 49% thought that it was *good* and 51% thought it was *excellent*.

5.6.6.1 Overall value that the CMF can add to the RE industry and usefulness to the AM of a REPP

None of the participants rated the CMF as *poor* or *fair*, while 15% thought that it was *good* and 85% thought it was *excellent* in terms of the overall value that the CMF can add and usefulness to the AM of an REPPs.

The consensus among all participants was that the CMF could provide a guidance framework and could support Asset Managers and owners in centrally managing ACPs. One participant, who has managed a wind farm and a portfolio of solar PV farms thought that the CMF was "an excellent idea" and that "there is a lot of potential". He also noted that he would utilise the CMF in his particular environment by staying "I will effectively use some of the framework in my current organisation." A similar view is expressed by a second participant who also notes that the CMF can be applied within in industry and Asset Managers and owners can apply it to their organisations and all they need to do is "tweak it to their organisation and implement."

One participant expressed the usefulness of the CMF by commenting that it would assist someone who is setting up an organisation managing REPPs with an understanding of what some of the key requirements are in terms of people and process in order to be successful. Furthermore the participant stated that there is significant potential to use the CMF even during the development of REPPs and contracting stage with OEMs to build and deliver an overall better project.

The value of the CMF in a portfolio of REPPs to Asset Managers and owners is highlighted by numerous participants with one commenting that "there is great potential for it [the CMF] to be of benefit and an aid ... it [the CMF] also forces you to think of things that you take for granted."

Concerns were raised which impact the usefulness of the proposed CMF which relates to the amount of effort to implement such a detailed framework. One participant notes that Asset Managers and owners will need to apply their skills, experience and knowledge when applying the framework in their organisation.

All participants recognised the value of the use of such a CMF to aid Asset Owners and managers to centrally manage ACPs in a portfolio of REPPs. Based on the overall feedback, it is perceived that the proposed CMF can add value and has the potential to be useful in the RE industry in SA. Sufficient support for the CMF exists to conclude with confidence that the success criterion of perceived value and usefulness was met.

5.6.6.2 Overall impression and ease of use of the CMF

None of the participants rated the CMF as *poor* or *fair*, while 85% thought that it was *good* and 15% thought it was *excellent* in terms of the ease of use of the CMF.

A potential concern raised by one of the participants was the complexity introduced by all the ISO 55000 jargon and that it might be difficult for someone who does not have a very good background in AM. Another participant noted that should an Asset Manager not have a good understand of the basic concepts discussed throughout the CMF it could be challenging. The initial complexity of the CMF and all the associated process could be an initial shock which could impact the initial perception and ease of use. However after engaging with some of the details the perception of ease of use could improve with one participant mentioning that "once you get through the details it seems logical."

There were very positive comments from all participants regarding the ease of use of the CMF. One participant said: "Very well set out, it makes complete sense to me, especially as an engineer." The details contained in the CMF also assist in understanding the requirements set out in the ISO 55000 standard. Another participant notes that although the detail might be daunting, once a person takes the time to look at the detail the CMF is understandable and notes: "It's very clear if you take the time to look at it." A second participant states: "The flow is very clearly defined. It provides you will a clear process of how to potentially approach this."

All participants rated the impression of ease of use between *good* and *excellent*. Based on the overall feedback, it is perceived that the CMF could be regarded as complex, but once users understand the details the impression of ease of use improves. Sufficient support exists to conclude with confidence that the success criterion of ease of use was met.

5.6.6.3 How easily comprehensible the CMF and all the different phases are

None of the participants rated the CMF as *poor* or *fair*, while 79% thought that it was *good* and 29% thought it was *excellent* in terms of how easily comprehensible the CMF and all the different phases are.

This success criteria tie in very closely with the previous three success criteria discussions. The usefulness and ease of use provides a good indication of how comprehensible the CMF is. A few participants qualified their *good* rating by commenting on "the complexity and comprehensiveness". "It is a lot. People normally don't have the persistence to persevere through this processes." "Because it is very difficult to explain what is a complex process in simple terms. It is not something where you can just pick up the book and go and do it. So the clarity with which it is expressed is good."

Combined with previous comments from participants such as "very well set out, it makes complete sense to me, especially as an engineer". "It's quite detailed and well put together. It covers basically most of what I can think of." "It's very clear if you take the time to look at it," and "the flow is very clearly defined. It provides you will a clear process of how to potentially approach this." Sufficient support exists to conclude with confidence that the success criterion of whether the CMF is sufficiently clear and well defined to be implemented in practice without confusion was met.

5.6.6.4 Overall flexibility of the CMF

None of the participants rated the CMF as *poor* or *fair*, while 57% thought that it was *good* and 43% thought it was *excellent* in terms of the overall flexibility of the CMF.

The proposed CMF and the processes in each phase are developed as a guidance tool which Asset Owners and Asset Managers can use in their context altering the details of the CMF. The overall view of flexibility of the CMF is observed through the comments of participants who can relate to the overall flexibility.

The flexibility can be greatly assisted through ease of use and how comprehensive the CMF is, so both success criteria have been proven, and lay a good foundation for understanding the overall flexibility of the CMF. One participant mentioned that the processes are very clearly defined and offers the potential user a "clear process of how to potentially approach this."

The CMF can be used in any industry and asset type according to two participants while another participant states that: "This can be applied by any

RE AM organisation that has to do maintenance." One participant qualified their rating of *good* by stating that it is not possible to create a framework that is too flexible otherwise it cannot be effective while another participant qualified their rating of *excellent* by noting that the CMF "is applicable to all types of REPPs." There is a clear view that the CMF can be used for any type of REPP such as solar PV, wind, bio-gas and CSP and according to one participant states that you ... obviously would have to adapt it for a specific organisation."

The resounding confirmation of flexibility is captured by a comment of one of the participants: "There is a lot of potential and anyone can take this framework and start applying it to their organisation or tweak it to their organisation and implement." Sufficient support exists to conclude with confidence that the success criterion determining whether the overall flexibility of the CMF could be adapted to other environments, based on specific organisational needs, while maintaining its core functionality, was met.

5.6.6.5 Overall ability of the CMF to create the Line-of-Sight between the daily AM activities and the organisational and business strategies and objectives

None of the participants rated the CMF as *poor* or *fair*, while 14% thought that it was *good* and 86% thought it was *excellent* in terms of creating Line-of-Sight and alignment of AM activities with the overall organisational and business strategies.

There were very positive comments regarding the Line-of-Sight created by the CMF. All participants thought that in some way or another the Line-of-Sight was being created in the CMF. However, there were some reservations regarding the need to have the Line-of-Sight actively reinforced by people in combination with the CMF and not solely relying on the processes to create the Line-of-Sight. One participant stated "So does it provide sufficient Line-of-Sight? Perhaps not in itself [but] if it is brought up on a regular basis and people are reminded of that." Another participant stated: "As long as it is kept visible yes. The CMF gives you the possibility of creating the Line-of-Sight but then it is incumbent on the organisation that the vision is maintained throughout via communication and understanding and visibility of KPIs. The system is fine but then it is the management of the application that will keep the Line-of-Sight visible."

There exists the potential to create the Line-of-Sight and in many cases there is a clear understanding of the value that creating the Line-of-Sight can bring to an organisations and it "creates a nice link between things which seem unrelated." Other participants weighed in by stating: "It brings up the Line-of-Sight issue and you showed us in pretty much all of those phases where the Line-of-Sight-related activity is present even down to the WO level. So it will definitely enhance that visibility." "Yes it does and helps link them [OSP and AM activities] all together. The guys on the ground understand how their work translates to organisational KPIs and can understand the impact of their work." The Line-of-Sight aspect was highlighted by a participant as a specific strong point and noted: "I think that's actually one of the strong points – the whole follow through of the objectives from the top all the way to the bottom."

All participants recognised the that the CMF was laying the foundation and reinforcing the Line-of-Sight between the OSP and daily AM activities through its various phases. Sufficient support exists to conclude with confidence that the critical success factor of the overall ability of the CMF to create the Line-of-Sight between the daily AM activities and the organisational and business strategies and objectives was met.

5.6.6.6 Overall ability of the CMF to address competency and training requirements for all involved in the organisational AM activities

None of the participants rated the CMF as *poor* or *fair*, or *excellent*, while 100% thought that it was *good* in terms of the overall ability of the CMF to address competency and training requirements for all involved in the organisational AM activities.

Competency and skills have been a central theme throughout the study. The general consensus is that the CMF has the ability to address the competency requirements in the RE and assists in identifying gaps and addressing these gaps over time to ensure that all who are involved in the AM activities are adequately trained. Participants stated that: "It identifies gaps and then attempts to close those competency gaps." and "During the whole process the CMF looks at gaps and by looking at those gaps you identify skills gaps which can be addressed."

The overall ability of the CMF to address competency over time by using a competency framework and training was perceived to be possible by all participants. Addressing competency is a continuous improvement activity which is facilitated by the CMF. Asked whether the CMF can address competency requirements, one participant stated "Yes definitely – because where you lack the skills you will provide training." while another participant stated that "it's a framework that will definitely assist in managing skills and competency requirements." Lastly, one participant noted that the CMF "goes a long way in understanding the skills requirements and identify the skills gaps that you have in the organisation. Then it allows you to address these roles and scarce skills."

All participants recognised the that the CMF addresses the competency requirements. Sufficient support exists to conclude with confidence that the critical success factor of the overall ability of the CMF to address competency and training requirements for all involved in the organisational AM activities was being addressed.

5.6.6.7 Overall ability of the CMF to facilitate continuous/focused improvement of AM activities

None of the participants rated the CMF as *poor* or *fair*, while 86% thought that it was *good* and 14% thought it was *excellent* in terms of the overall ability of the CMF to facilitate continuous improvement of AM activities.

The CMF attempts to create the link between the strategic planning, the AMS , ACPs, work planning and control and competency management through a continuous improvement process. Phase 4 of the CMF specifically highlights the continuous and focused improvement process. There is a consensus from participants that the CMF facilitates an overall improvement process. However, there was one participant who was of the view that phase 4 needed to be split into two separate phases with one phase addressing competency management and the other continuous improvement as a separate aspect. There was also a concern regarding the clarity of the links to the continuous improvement process in the diagrams with one participant stating that "sometimes the continuous improvement links are not indicated clearly enough in the process".

One participant was very positive regarding the continuous improvement process offering a structured approach on how to improve a specific aspect once it has been identified as an improvement area. The participant stated: "I like the idea that the focused improvement process actually guides you in terms of how you will address the inefficiencies – as it is already explained. Sometimes people say there is a problem but they don't suggest how to fix it, This provides a potential process for how to fix it or address it at least makes it quite a good thing." Another key strength of the continuous improvement process is that the application does not make a clear distinction between a human asset and a physical asset with one participant stating "you apply the same logic to your competency as you do to your equipment. So you are treating it like an asset – it is essentially an asset – you get the cliché saying that people are our greatest asset but then it just gets forgotten about. Just having this will be a great step for most organisations." Furthermore, "the frequency at which reviews occur" was also highlighted as strong point of the improvement process.

All participants recognised the that the CMF addresses the continuous and focused improvement requirements. Sufficient support exists to conclude with confidence that the critical success factor of the overall ability of the CMF to facilitate improvement of AM activities was being addressed.

5.6.6.8 Overall ability of the CMF to use performance measurement (KPIs) to monitor, control and improve the AM activities

None of the participants rated the CMF as *poor* or *fair*, while 29% thought that it was *good* and 71% thought it was *excellent* in terms of the overall ability of the CMF to use performance measurement (KPIs) to monitor, control and improve the AM activities.

Throughout all the phases of the CMF KPIs are used to understand and measure performance, set targets for performance and facilitate creating the Line-of-Sight and alignment of AM activities with the overall organisational and business strategies. Evidence of the use of KPIs are observed in the process diagrams throughout each phase and through comments made by participants throughout the interview process.

Participants responded strongly to the use of KPIs prompts and numerous comments and suggestions regarding KPIs were made by participants. One participant suggested that asset-related financial KPIs be considered. Other suggestions were that the use of KPIs be expanded in the ACPD process to include target and contractual KPIs.

Two participants specifically noted how the use of KPIs help create the Line-of-Sight between the daily AM activities. One participant used a HSE example by stating that "you know why you are doing a risk assessment as it is linked to an organisational KPI of HSE", and another participant said that "the guys on the ground understand how their work translates to organisational KPIs and can understand the impact of their work".

Reference was also made by the participants regarding KPIs in terms of using KPIs which are specific to the SA RE industry, creating the Line-of-Sight. One participant also qualified their *excellent* rating for as being "due to stressing the Line-of-Sight application of the KPIs and improvement".

All participants recognised the that the CMF uses KPIs to address the continuous improvement activities. Sufficient support exists to conclude with confidence that the critical success factor of the overall ability of the CMF to use performance measurement (KPIs) to monitor, control and improve the AM activities was being addressed.

5.6.6.9 Achieved objectives

The first interview question in the framework synergy section G.3.5 was: "Considering the research methodology which was followed to develop the CMF, what is your opinion of the potential of the CMF to support Asset Managers and owners in centrally managing ACPs while remaining aligned to the ISO 55000 series of standards?"

There was a resounding consensus that the CMF would be able to deliver this objective with one participant stating: "Absolutely it will." The framework was regarded as having significant potential and one participant stated that they would use the framework in their organisation. One participant, who has extensive experience in the AM portfolio on a utility scale REPPs, stated that the CMF would provide guidance around the processes and people required to establish a RE asset management organisation and that "dependent on organisational context, if you are a greenfield organisation that have RE plants to run it should become your Bible".

There was complete consensus among all participants that the CMF covers the core strategic considerations of a RE AM organisation and furthermore also complies with the requirements of ISO 55001 in terms of strategy and planning. This view was discussed in section 5.6.1 with one of the participants, an experience AM practitioner, stating that in terms of the ISO 55000 framework the CMF "covers it excellently and you [the researcher] did a good job in terms of covering the ISO 55001 requirements".

The ability of the CMF to manage ACP through their development, execution and improvement is echoed through feedback from the various participants. All participants are of the opinion that the methodology for developing and managing ACPs is more sophisticated compared to that which they have seen in the general industry as well as in the RE industry. Evaluating the strengths of the ACPD process, words such as comprehensive, methodical, detailed, sophisticated and well structured were used. Some key strengths that were highlighted is the consideration for skills, obsolescence as part of the ALCA and the requirement to develop SJs while the experts are available.

The CMF has a dominant centralised view regarding the overall management of all the phases to leverage resources which can be shared across a portfolio of REPPs and optimise efficiency. Participants supported the centralised view, especially in SA where there are skills shortages and multiple REPPs are managed in a portfolio. However, there were some valid arguments from participants to decentralise functions which specifically relate to "soft" issues, such as people feeling valued.

Another key aspect addressed by the CMF is the lack of information sharing by OEMs and scarcity of critical skills, which are required to develop good ACPs and effectively manage REPPs over their LC. The CMF attempted to address these issues through a robust ACPD process with provision for the scarcity of skills and information and the competency management which address the skills from a medium-term to long-term continuous improvement perspective. All participants believed that the CMF could address the skills challenges by mitigating the skills risk through the consideration of skills requirements when developing ACPs and SJs. Furthermore, the use of a competency management framework to address competency and scarce skills over time also received positive feedback with participants noting that the competency framework will identify gaps where people and training are required and put the mechanism in place to continuously review progress in closing the competency gaps and assessing how well the competency framework is performing. The core requirements of a competency framework are thus being addressed that could mitigate the skills shortages provided the competency framework is implemented correctly.

The objectives of the CMF defined in section 5.5 are to provide an ISO 55000 series-aligned CMF, consisting of four phases with key features that are expressed using supporting business processes that can be used as a structured guide to centrally manage ACPs. Furthermore, key industry challenges such as the lack of information from OEMs, competency and skills shortages and inadequate maintenance plans for the RE technology are also addressed by the CMF which aims to add value to Asset Managers and Asset Owners in the RE industry in SA.

The potential of the CMF to add value to the AM of a portfolio of REPPs in SA has already been highlighted in section 5.6.6.1. Furthermore, based on the participant responses and perceptions with the overall score for the questions related to the framework architecture and success criteria, where participants had to provide a rating of **Poor, Fair, Good, Excellent**, 49% thought that it was *good* and 51% thought it was *excellent*.

The participant responses and perceptions engender confidence that the proposed CMF achieved its overall objectives and as such the success criterion discussed in section 5.5 is supported.

5.7 Improvement Suggestions

Based on the semi-structured interviews the deficiencies in the proposed CMF that required improvement or future research are identified. The improvement and future recommendations will be addressed per phase and then overall CMF.

5.7.1 Asset Management Framework – Phase 1

The effort in terms of resources such as time, cost and people to execute phase 1 has been identified as potential future research as it outside the scope of the study but was raised as a consideration by participants during the semi-structured interviews. This can be combined with developing an implementation plan for such an undertaking.

Secondly, improvements could be made regarding the high level overview of what each phase entails and what the outputs are. This could be achieved with an additional diagram highlighting these details. Furthermore, roles and responsibilities for aspects of each phase can be assigned, but this will differ from organisational to organisation and could potentially form part of future research to understand how responsibility would be allocated in a typical RE Asset Manager in SA.

Indicating feedback and feed-forward loops that facilitate continuous improvement and enable interaction with other parts of the business can be more clearly defined. Defining all the key role players or parts of the business which would benefit from feedback loops could also be a future area.

The KPI suggestions used in the diagrams are very focused on assets, performance and finances but do not address any of the softer issues which can be addressed in phase 1 which could relate to socio-economic development and economic development of communities or corporate social investment. KPIs which relate to these aspects could be included in the diagrams to prompt and remind people of the triple bottom line concept. Currently only physical assets are indicated in the diagrams and narrative of phase 1. Another improvement could be to clearly indicate the more intangible assets as being part of the AMS during the first phase 1 diagram set (step 1.1.1)(section 4.4.1) and narrative.

5.7.2 Asset Care Plan Development – Phase 2

The criticality ranking mechanism could be improved by shifting the component criticality ranking earlier in the ACPD process. The methodology for selecting components to include in the analysis process could be done with the subject matter experts in order to gain a more efficient analysis process by prioritising components as all components might not even be required to be part of the analysis process.

The COFCATs worksheet was developed in Microsoft Excel which might not be the most appropriate tool as it might seem overly complex when a large number of components have been analysed. The use of coded fields as opposed to free text could be introduced which will aid in consistent input of failure modes, assist in future failure analysis trends and also allow the data to be entered into a CMMS system.

The COFCATs worksheet and ACPD process can potentially be improved by adding an additional step and column whereby a specific review time for the maintenance approach will be specified. This can be especially important in the RE industry where there might be uncertainty of the maintenance approach and the frequency due to a lack of documentation, information, skills and experience with the technology. For example, a CBM approach has been selected for the gearbox oil of a wind turbine by installing a filter and particle detector with real-time measurements which need to be checked every six months. A column could be added whereby a different measure could be specified to check the suitability of the filter and particle detector to prevent a specific failure mode and whether the six-month interval is appropriate as part of the continuous improvement process of the ACPs. Therefore reviewing the maintenance approach could help mitigate the risk that the selected task is not adequate.

The ACPD process can be improved by ensuring that the ACPD team includes all the relevant team members. In this particular study the central planning and scheduling team should be a core part of the ACPD team as they will be performing the planning and scheduling based on the SJs that are develop as part of the ACPD process which will familiarise them with the details and raise any questions which they might have. Expanding the technician team which is part of the ACPD team would help them understand the importance of the maintenance tasks that they will be expected to perform as well as the importance of the feedback which they are required to provide after they have completed a WO. Technicians can also provide valuable input into the development of ACPs.

5.7.3 Work Planning and Control – Phase 3

One participant specifically noted the need to pay more attention to the requirement of an authorised person to perform lockout/tag out and switching. Work related to this authorised person could also be presented in a separate WO with special consideration during planning and scheduling. The processes could thus be enhanced by including a specific work flow for lockout/tag out and switching.

Reactive work initiation was highlighted by two participants as being a key improvement point. Although work orders related to reactive work is implied in the process and needs to be catered for by the planners, it would be beneficial to identify and suggest how reactive work would be dealt with in more detail. The planning and scheduling diagrams can be updated to more clearly indicate the process for dealing with incoming reactive or emergency work.

This also ties in with a comment by one of the participants who notes that there could be special consideration for whether it is beneficial to leave preventive work to go and attend to reactive work. The participant states: “So what happens in process breakdown? What happens if you are doing preventative maintenance on one wind turbine and the wind turbine next door stops? This is something that we dealt with frequently in Europe on wind farms. The question is whether it is really more effective to stop the current maintenance in progress – pack up and go to the turbine that has stopped. Or do you actually say no, the total downtime for my assets will be more if I pack up and go, considering travel time etc. So it might be better to complete the current maintenance and then go to the other wind turbine.” This aspect can be addressed in conjunction with the previous recommendation about reactive or emergency work. Should reactive or emergency work occur, the reactive work initiation process should clearly indicate that there should be consideration for current work in progress as it might not be beneficial to stop work on a preventative maintenance WO to attend to a stopped turbine, for example.

Other improvement opportunities focused on potentially improving feedback to the central team using mobile technology to get real-time WO status updates between the OSMT and the central planning and scheduling teams. The process could be improved to more clearly indicate or consider options for real-time updates from the OSMT in the field using mobile platforms.

5.7.4 Competency Management and Continuous Improvement – Phase 4

One participant notes the potential improvement of making the distinction between short-term and long-term competency requirements. Often in the RE industry skills might be needed for short periods of time while others will be required for the life of the REPPs. Clearly identifying which skills are short term, long term, the duration they are required. An example was given that when an RE AM is setting up operations for the first time or introduces a new plant to the portfolio there will be core skills requirements for a team who can set up the processes and systems, develop procedures and policies. However, once the initial work has been completed there is not a long-term requirement for the skills. The competency management process diagrams and narrative can be improved by specifically considering the need to analyse short-term skills requirements which can be linked to the LC of a RE project in SA.

The identification of which skills should be developed internally in the organisation and which could be outsourced should also be more clearly defined. Furthermore, even though skills are outsourced there needs to be a competency framework against which the outsourced competency is measured to ensure that suitable competency resources are supplied by contractors. The competency management process diagrams and narrative can be improved by specifically considering the need to analyse the core competency requirements and for the business to develop a framework for deciding which skills or competencies to develop in-house, re-engineer its organisational structure to accommodate the core competency and which skills it will outsource. This process can be expanded into future research where a decision framework can be developed to assist Asset Manager and owners with determining which skills should be part of the core in-house competency set and which skills should be outsourced combined with a outsource competency management framework.

Highlighting succession planning in the diagrams was identified by two participants as a potential weak point and the participant notes that “adding succession planning in the diagrams as it is a key item to consider”. “Succession planning in a new industry we know is going to be important. In all industries you have staff turnover and it is going to be quite violent in the RE space in SA for quite a few years to come as you have new projects coming and you want to poach experienced people.” The CMF can be enhanced through improving the competency management process diagrams and narrative to place more emphasis on succession planning.

One participant was very vocal on splitting the competency management and continuous improvement process into separate phases and not have them consolidated in phase 4 of the CMF. Furthermore, the participant also highlighted the importance of using phase 2, the ACPs, and phase 3 to identify the number of resources per competency as it will play an important role in the overall competency requirements. The view is expressed by the participant who stated that there should be a consideration of “using the ACP and CMMS to motivate the number and type of resources. I would still recommend moving competency management out of phase 4 and into a separate phase. There are a lot of things one can say about continuous improvement. You have a process there that I think covers the basics but that needs attention as a phase on its own.” The CMF can be enhanced by creating an additional phase in which to place competency management while continuous improvement remains within phase 4. Competency management touches on all the other phases and could be depicted as a phase which is adjacent to all the other phases. Furthermore, phase 4 of the CMF can be enhanced through creating a more pronounced link between the ACPD process and the skills requirements. The ACPD process will produce detailed maintenance plans which will indicate the number of maintenance hours and tasks which can be used to work out the total number of staff but also the skills breakdown of the staff complement to perform the maintenance work.

The need to review the effectiveness of the competency framework or competency management system was identified by one participant. It is thus not adequate to review whether your staff or the organisation meets the competency requirements but also whether the systems are able to close the gaps. The participant states: "The idea is not to assess whether someone is performing good or bad but to assess whether your competency framework itself is providing the training of and competency to people to do their work correctly ... You can consider it in your continuous improvement loop – you can have feedback where you [are] assessing the effectiveness of the competency framework to provide your staff with the required tools." The competency management process and narrative can be enhanced through adding a specific feedback loop to assess the competency framework to ensure that it is effective at managing the competency requirements. Checking the competency framework effectiveness can also be emphasised within the continuous improvement process as a management review task to ensure ongoing management of competency.

Participants spoke about training people for the greater good of the RE industry without a guarantee of employing people in the organisation they are trained. Two pertinent statements that reinforced this view are: "I think potentially you need to consider your recruitment strategy, like an internship programme to offset some risk and up-skill and identify talent. You should consider the turnover of people. It should be of real importance in SA as it is not like the US where you have a large pool of people you can pick from. SA has a general skill shortage and a very specific RE skill shortage." "Sometimes there are indirect benefits such as training people and building a pool of skilled people in SA that then means you have more options as an organisation – sometimes they [are] quite altruistic like environmental considerations – how is this captured in this process? Or even if you [are] training people you do it for the greater good. You cannot rely on that they will come back to your organisation but you are training for the industry. You need to think about a triple bottom line and make it clear that it is part of your organisational strategy." An improvement to highlight is the need to develop a local skills pool using strategies such as internship programs, for example. Such programmes will assist in enlarging the overall skills pool benefiting the people and potential employers which could also stabilise cost of skills. The CMF can be enhanced by including such a strategy in phase 1 as part of the organisational objectives but also in phase 4 as part of the competency management strategies.

5.7.5 Framework Synergy

All the participants were asked to provide suggestions regarding their view on potential ways the overall CMF can be improved in order to enhance the fulfilment of its intended purpose. No common improvement theme was observed through the feedback from participants. One participant notes that indicating the outcomes of each phase, with a very short description of what happens in each phase of the CMF on the high level diagram, might help to communicate the benefit to a management group or a non-technical audience. The participant states: "Potentially there is room for some kind of a broader overview that makes it easier for non engineers or non-technical people that do not understand." The CMF can be enhanced through adding an overview diagram such as figure 4.1 with clear purpose and outputs of each phase of the CMF.

One participant suggested during the phase 3 feedback that the competency management and continuous improvement elements be split into separate phases. This view was reiterated in the improvement suggestion for the overall CMF with the participant stating: "I would specifically split out competency management from continuous improvement from phase 4. The participant further qualified the reasoning by stating "but this might also be due to my own bias based on a similar framework that I have used in practice". This improvement point has been addressed.

The use of the prompts or example KPIs and example document contents was noted as a strong point, but one of the participants commented that it might not be clear enough that the text and diagrams only contain examples and should be used as a guidance mechanism or a prompt. The participant states: "Perhaps it would make sense to explain to people that these are just examples and that it is not all of the possibilities. You can note it in the diagrams." People strongly respond to the diagrams and prompts and the KPIs are only examples of potential KPI. The narrative and the diagrams can be improved to clearly remind users that the displayed KPIs are merely prompts and examples and should not be seen as exhaustive. Users should be reminded that each organisation will need to develop their own KPIs, strategies and document content based on their context and needs.

5.8 Discussion

Considering the semi-structured interview questions more focus could have been placed on the continuous improvement process in phase 4. Questions were very focused on competency management and the continuous improvement process was not prominent, which resulted in interview participants focusing on the competency management even when the interview questions would enable them to respond to the continuous improvement aspect. This observation is confirmed by the one participant who noted that the continuous improvement and competency management needed to be presented in separate phases.

The industry challenge regarding the complex ownership and management structures was confirmed by the participants who responded to a question whether the CMF contained sufficient RE elements and noted: "Yes, and also from the point of the view of the complex owner and management structures in the RE industry in terms of developers, EPC, O&M, Asset Owners and asset operators. That over a long term and someone who is currently in the business and wants to expand with other sites – I think having a CMF in place will assist with some of the business development aspects to bring that in line with what is currently in place." A second participant also alluded to the complexity when asked to comment on the weak points of phase 1 and noted: "I don't think that anything is missing, but it needs to be considered that there are different stakeholders involved with different agendas – you have different community groups, environmental organisations, Asset Owners, government and there is balancing act required. I think that where it could manifest is when you do a risk analysis that when you look at what you are doing as a company might meet the needs of other stakeholders or not. I think that it is important to understand from whose perspective you do this and that is not quite clear."

The industry challenge regarding skills was confirmed with insight into what the typical missing key skills are to develop good ACPs and that often specialists are brought in from abroad. Section 5.6.2 details the responses from participants regarding the skills challenges and key skills shortages noted as millwrights (electrical and mechanical combination); solar PV inverter and PV panel specialists; specialists regarding the wind turbine gearbox, bearings, structures, blades, control system and SCADA systems. One participant noted that there are no skills to interpret data coming from the wind turbines or RE systems/control systems/SCADA, which is compounded by the industry challenge of OEMs not sharing information or access to data as discussed in section 2.3.3. Wind turbines technicians were also highlighted as a skills concern and this confirms reports in section 2.3.2. Managerial skills regarding REPPs, such as site managers and Asset Managers, are also highlighted as a local skills challenge. The poaching of staff is also a major challenge faced by the RE industry in South Africa.

The issue of centralisation is also addressed. The discussion on centralisation and decentralisation in section 2.2.8 notes that most organisations follow a hybrid or semi-centralised approach. Furthermore, the decision whether to centralise or decentralise functions was made intuitively. These sentiments are also reflected in the responses of the participants.

There was complete consensus regarding the value of centralisation of all aspects with some qualification made regarding the organisational design that needs to enable centralisation; that the organisation has to be sensible regarding some of the aspects which might need to be decentralised; technology that needs to enable it; and involvement of technicians and other departments in developing ACPs (refer to section 5.6.3). The view on whether competency management should be managed in a centralised mode is slightly mixed and generally qualified by some participants. There were participants who had no reservations on its centralisation while others thought that some the management should be centralised with team input and that execution regarding training should be decentralised (refer to section 5.6.4).

The view on the overall CMF regarding centralisation was also varied with a strong view that the centralisation in such a specialised field is good and especially in a multi-technology portfolio where resources can be leveraged. However, there is a clear need to have strong collaboration with decentralised sites. A very interesting soft issue raised was that it would be difficult to keep scarce skills engaged in remote sites should everything be centralised and they have no decision making power. These people should feel empowered and accountable (refer to section 5.7.5).

The view on centralisation for the four phases of the CMF can be summarised as:

- *Asset Management Framework – Phase 1*: Management centralised with input from decentralised sites. SAMP/AMPs can be developed in a centrally but should be executed on a day-to-day basis on the decentralised sites to keep scarce skills/managers engaged and accountable.
- *Asset Care Plan Development – Phase 2*: Management centralised with input from decentralised sites.
- *Work Planning and Control – Phase 3*: Management centralised with strong collaboration with decentralised sites and partial decentralisation of work.
- *Competency Management and Continuous Improvement – Phase 4*: Management centralised but responsibility to ensure that training is attended should be the responsibility of the local decentralised teams.

Although all the CMF phases are managed centrally, the overall CMF has a hybrid or semi-centralised approach which will be dictated by the organisational design and context.

5.9 Chapter Summary

This chapter discusses the validation of the proposed CMF using face and user validation. The methodology followed for the validation is described which includes a discussion of the expert panel interviewed for the validation, the success criteria against which the success of the framework is judged and the method of data collection. The findings obtained through the semi-structured interview process are then documented and judged against a set of architectural and success criteria to assess the success of the proposed CMF.

The critical findings of the validation are that the proposed CMF meets all the success criteria and based on the analysis of the semi-structured interview process the perception of the expert review panel would indicate that there is an overall consensus that the proposed CMF would add value to Asset Managers in the RE industry in SA by providing them with an ISO 55000 series-aligned guidance framework supported by business processes that can be used to centrally manage ACPs in a multi-technology portfolio of REPPs. Furthermore, the CMF also successfully addresses key industry challenges such as the lack of information from OEMs, competency and skills shortages and inadequate maintenance plans for the RE technology. The CMF, thus, shows potential to address the identified problem.

The expert participant panel consisted of seven individuals, which is a significant number of participants and led to a degree of diversity and resounding expert consensus among responses concerning strong points, weak points, and improvement suggestions. It was observed that the participants were generally satisfied that the framework follows a logical structure and is well-defined with architectural aspects and success criteria rated as *good* by 49%, and *excellent* by 51% of the expert participants. The research objective to validate the proposed framework by the method of face and user validation and subsequently drawing conclusions regarding the validity of the framework, as discussed in section 1.3, was achieved in this chapter.

This chapter contributes towards the eight and ninth research objectives stated in section 1.3:

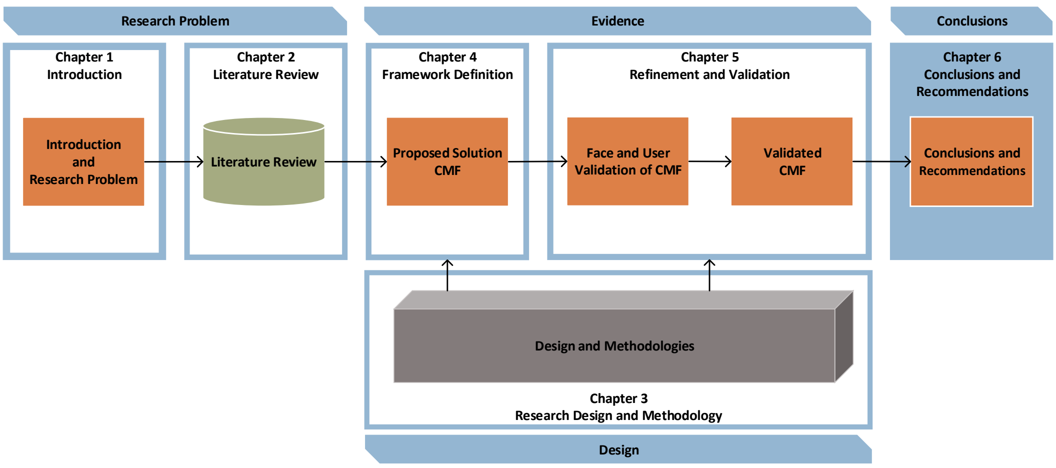
8. Determine the skills required to develop and manage ACPs for REPPs and the extent to which functions can be centralised or decentralised.
9. Validate the CMF via face and user validation in line with the required framework features and success criteria.

The next chapter will summarise the findings of this research, draw conclusions, discuss contributions and make recommendations for future research.

Chapter 6

Conclusions and Recommendations

Science is simply common sense at its best, that is, rigidly accurate in observation, and merciless to fallacy in logic. – Thomas Huxley (1825-1895)



The purpose of this chapter is to consolidate and summarise the findings, reflect on the research process by evaluating the outcome of the study against the initial research objectives/questions and to draw conclusions. A brief overview of previous chapters is provided. Thereafter, theoretical and practical contributions are discussed followed by the limitations of the study and recommendations for future research.

6.1 Overview

The study is presented in six chapters including an introduction, research methodology, literature review, research methodology, proposed solution, validation and conclusion. This is a brief overview of the content of the study.

Chapter 1 broadly outlines the study, the RE industry in SA and establishes the research domain and context within which the problem was identified and defined. Key challenges are identified such as the need to use more sophisticated maintenance philosophies, lack of access to information and data, the dearth of competency and the complexity of management and ownership structures in the SA RE sector. Management and maintenance frameworks exist which could be used as guidance to develop and improve the AM function related to REPPs in SA. However, challenges such as the novelty of the ISO 55000 and the formalised AM discipline, combined with the non-prescriptive requirements of ISO 55001 create a daunting challenge of developing operational or maintenance frameworks which are aligned with ISO 55000. In order to address this, the purpose of this study was to investigate potential solutions to provide an ISO 55000-aligned framework with key features which are expressed using supporting business processes that can be used to centrally manage ACPs in a multi-technology portfolio of REPPs. Research questions, objectives and methodology of the study are also defined in Chapter 1.

Chapter 2 entails a comprehensive review of literature on the scholarship that is relevant to the research, which is the discipline of AM and the essential AM landscape elements, the field of maintenance management and key aspects of the SA RE sector. The strategy and planning elements of the ISO 55000 series are explored, as well as exploring philosophies that can be used to develop ACPs and a review of typical maintenance management frameworks. Some of the key challenges in the SA RE industry are examined, such as skills challenges, inadequacy of existing maintenance approaches, the lack of information from OEMs and the complex nature of REIPPPP projects' ownership and management structures. The literature review further contextualises the study and lays the foundation for synergising all the AM, maintenance management and RE elements as part of the base framework development.

Chapter 3 presents the research design and methodologies used to formulate a methodical approach to undertake the research. The research approach is presented through explaining the philosophical world-view, research design and methods which are used to study the problem. The chapter concludes with the scientific reasoning used in the thesis.

Chapter 4 uses the analysis of the literature to develop a CMF, which consists of four phases, and is supported by business processes for the management of ACPs in the SA RE sector. Each phase of the CMF is described in detail regarding its specific objectives and how it relates to the overarching AM framework and general framework features. Furthermore, the relevant 39 AM subjects are associated in the CMF to demonstrate alignment with the ISO 55000 series of standards.

Chapter 5 validates the proposed CMF. Numerous validation methods are reviewed to identify the appropriate validation technique for this study. The combination of face and user validation is selected as the most suitable validation process. Face-to-face semi-structured interviews with an expert panel of SA RE Asset Owners and Asset Managers is selected as the data collection method. Responses and findings from the interviews are analysed and presented. The CMF is assessed against the success criteria and critical success factors which support the framework structure and its applicability to industry. Lastly, potential CMF improvement suggestions are highlighted after the validation process.

Shared participant views engender confidence in the ability of the proposed CMF to aid RE Asset Owners and managers to centrally manage ACPs for a portfolio of REPPs while remaining aligned with the ISO 55000 series of standards.

The last chapter presents the closing of the research study by providing the conclusion of the research, discussing limitations and recommendations for future research and contributes towards the tenth research objectives stated in section 1.3:

10. Draw conclusions and make recommendations regarding the CMF.

6.2 Summary of Research Results

The results of the research are summarised in support of the five research questions as outlined in section 1.2.

What philosophies, techniques and models within the maintenance field can be adopted to develop ACP for a portfolio of multi-technology REPPs?

The first research question investigated in this study is to understand the philosophies, techniques and models in the maintenance field which can be adopted to develop ACP for a portfolio of multi-technology REPPs. Through a structured process of studying literature, analysing content and conducting interviews with experts the answer is obtained (refer to chapters 2 and 5). In response to the research question RCM is identified as a maintenance philosophy that can be used to develop ACPs. Using key challenges identified in the RE sector and practical experience, identified RCM models were modified and enhanced to develop a customised RCM process which will address some of the challenges faced by the RE industry and develop ACPs for a portfolio of multi-technology REPPs. Together with the development of the RCM process the COFCATs worksheet was developed to assist in the ACPD process.

What elements or characteristics should the proposed framework and supporting business processes have to ensure that they are aligned with an overarching AM framework and maintain the Line-of-Sight?

The second research question which is set out for investigation is what elements or characteristics should the proposed framework and supporting business processes have to ensure that they are aligned with an overarching AM framework and maintain the Line-of-Sight. Through a structured process of studying literature and analysing content in response to the second research question, the CMF was structured with phase 1 (refer to section 4.4), which sets the underlying AM framework, and is based on the planning and strategy requirements of ISO 55001. Phase 1 of the CMF develops the foundation on which core Line-of-Sight elements such as stakeholder requirements; the OSP containing organisational strategies and objectives; and AM policy, SAMP and AMPs that are mapped back to the OSP. The use of KPIs, SMART objectives and strategies strengthen the framework on which the Line-of-Sight can further be expanded. The CMF continues the Line-of-Sight by mapping KPIs and strategies in phases 2, 3 and 4 back to the OSP and ultimately the stakeholder requirements. Based on feedback of the expert interviews the need to have the Line-of-Sight reinforced by management or key people in the organisation or processes is key to strengthening the Line-of-Sight irrespective of whether the process lays the foundation.

What characteristics of the proposed theoretical framework can be centralised and which need to remain decentralised?

The third research question which is set out for investigation in this research is to understand what characteristics of the proposed theoretical framework can be centralised and which need to remain decentralised. In response to the research question the discussion in section 5.8 identifies the following:

- *Asset Management Framework – Phase 1*: Management centralised with input from decentralised sites. SAMP/AMPs can be developed centrally but should be executed on a daily basis on the decentralised sites to keep scarce skills/managers engaged and accountable.
- *Asset Care Plan Development – Phase 2*: Management centralised with

input from decentralised sites and OSMT.

- *Work Planning and Control – Phase 3*: Management centralised with strong collaboration with decentralised sites and partial decentralisation of work. RMC responsible for planning and scheduling in collaboration with the OSMT with work execution decentralised.
- *Competency Management and Continuous Improvement – Phase 4*: Management centralised but responsibility to ensure that training is attended to should be the responsibility of the local decentralised teams.

What are the scarce competencies required to assist in managing ACPs for REPPs and what can be done to address the competency issue?

The fourth research question which is set out for investigation in this research is to understand what scarce competencies are required to manage ACPs and what can be done to address the competency issue. Through a structured process of studying the literature and analysing the feedback of interviews with experts the answer is obtained (refer to Chapter 2 and 5). The complexity in the SA RE industry regarding ownership and management of REPPs requires a key understanding of technical, regulatory, contractual and commercial aspects of these projects to effectively manage all stakeholder requirements. The management of ACPs is thus not limited to technical skills. There is also a dearth of managerial skills from a strategic AM perspective which has a direct impact on all phases of the CMF. The technical skills challenges are a shortage of qualified and experienced wind turbine technicians and staff who have a key understanding of wind turbine performance and who can use data from the wind farm to perform detailed analysis. Furthermore, other specialised components of wind turbines such as the gearbox, blades, SCADA and control systems also face a major challenge regarding local competency. The solar PV technology faces challenges with PV panels and inverter technology. On technician level there are also challenges as REPPs require technicians who have knowledge of electrical and mechanical aspects of these plants. The dearth of cross-skilled technicians is a challenge in wind and solar PV technologies. All these competencies are required to holistically manage ACPs. These skills challenges can be addressed through understanding the maintenance requirements of REPPs, how they impact staff skills and numbers, the AM objectives, OSP and stakeholder requirements. These competency requirements will be a long-term challenge that can be addressed through developing a robust competency framework as presented by the CMF.

What could a theoretical management framework look like that can be used to manage ACPs for a multi-technology portfolio of REPPs?

The last research question in this study is to understand what a theoretical management framework would look like to manage ACPs for a multi-technology portfolio of REPPs. Through an iterative process, and influenced by the literature in the fields of AM and maintenance management, the proposed solution to the problem is an ISO 55000-aligned guidance CMF supported by business processes that can be used to manage ACPs in a multi-technology portfolio of REPPs. The CMF, described in Chapter 4, has four key phases which are represented by business processes and their associated steps. The following four phases are included in the CMF:

- Asset Management Framework – Phase 1
- Asset Care Plan Development – Phase 2
- Work Planning and Control – Phase 3
- Competency Management and Continuous Improvement – Phase 4

6.3 Contributions of the Research

This research contributes to the existing maintenance management, AM and RE scholarship in theory and in practice.

6.3.1 Theoretical Contributions

The study leads to the following theoretical contributions:

- An ISO 55000 and GFMAM 39 AM subject aligned CMF for a portfolio of multi-technology REPPs in SA.
- A customised RCM-based ACPD process which addresses some of the key challenges in the RE industry.
- A contribution to the body of knowledge regarding the application of the ISO 55000 series and GFMAM 39 AM subjects to the RE industry.
- A confirmation that there are competency challenges in SA and what these skills challenges are; that OEMs do not share information and data; and maintenance philosophies used by OEMs in the RE industry are not adequate to optimise performance (no alignment between OEM and Asset Owner).
- A confirmation that there are complexities in the SA RE industry regarding the ownership and management structures (no alignment between OEM and Asset Owner).
- The current body of AM scholarship is expanded and a contribution is made to the scholarship in the emerging field of RE in SA with prudent AM affecting the success of services in the industry.

6.3.2 Practical Contributions

The practical contribution of this study are defined below. These contributions are substantiated by selective feedback from industry experts, indicated in italics, during the validation process.

- A practical, comprehensive, objective and overall cohesive CMF that was developed from theory and experience.
  - *"I think that my overall picture is that the strength of it is the comprehensiveness and the fact that it goes back to first principles by leaving all preconceived ideas at the door in terms of what systems and processes are appropriate to a REPP and built a framework from the ground up. That to me would be a strong point ..."*
  - *"There is a good agnostic view. The methodology and the CMF seems to be developed without any major preconceived idea around what such a framework or the processes should look like and developed organically – this is a major strength."*

- Provides a comprehensive, methodological, and sophisticated process and approach of developing ACPs for REPPs which can be applied to any RE technology and addresses some of the key challenges in the SA RE industry.
  - *"This is more sophisticated than what I have seen within my extensive experience in the RE industry in Europe and in the few years in the SA RE industry. Even within my current organisation we are very advanced compared to most other Asset Managers of REPPs – yet we are not close to this sort of level of sophistication but it is ideally where we would like to be."*
  - *"This can be applied by any RE AM organisation that has to do maintenance."*
  - *"It seems very comprehensive, sequential and methodical."*
  - *"The obsolescence is a very critical point and really a strong point. Also the process is detailed and broad enough to cover all your bases."*
  - *"Much more detailed and sophisticated that what I have seen thus far. Sometimes people would touch on some of the areas but not cover all the key aspects such as in this case. It is very well structured."*
  - *"There are some very specific characteristics that we don't normally see related to ensuring the correct skills and very relevant the question related to obsolescence of components ... I think there is evidence that there is specific attention paid to the specific industry."*
  - *"I do believe it [the CMF] is more sophisticated as what we see mostly is the use of TBM and if something fails they [the OEM] would go and change it. The type of maintenance we see [in the SA*

RE industry] is more reactive or elective maintenance and not too much CBM."

- A practical, comprehensive, adaptable CMF that adds value and can support Asset Managers and owners in centrally managing ACPs while remaining aligned to the ISO 55000 series of standards.
  - *"There is a lot of potential [within the CMF] and anyone can take this framework and start applying it to their organisation or tweak it to their organisation and implement."*
  - *"I think there is great potential for it [the CMF] to be of benefit and an aid. I think that what you have to bear in mind with any system like this is to use discretion as to when and where to apply it. Because it is extremely detailed and the application of it is where you need to apply your skills, experience and knowledge of the organisation. I guess it goes without saying you are putting in place a framework and one has to go through the framework and adjust throughout and it also forces you to think of things that you take for granted."*
  - *"It touches on everything. It tells you of all the things that you need to look at ... You can take it and apply it to almost any aspect of the business and it will help to pull things together."*
  - *"I think it is excellent, I think there is a lot of potential in here. I will effectively use some of the framework in my current organisation."*
  - *"If someone had to set up an RE company from the start it would give them an idea of some of the key processes and people that [are] required to be successful. It also adds a lot of potential to the details related to the contractual agreements with the OEMs."*
  - *"There is definitely an upside. Especially where there are multiple sites and multiple technologies on the generation side."*

The final conclusions to the research are drawn against the background of the research results and contributions.

6.4 Limitations

The acknowledgement of unavoidable limitations is an important part of the scientific research process. The outcomes of the research effort can be restricted or influenced by the unique characteristics and context of the imposed limitations.

The development and the validation of the proposed CMF are influenced by the following limitations.

- Resource availability and time did not allow for an extensive validation process through the implementation and application of the CMF in practice. The most suitable and practical identified method of validation for the given research context is the test for face and user validity with industry experts. The results indicate face and user validity, and thus that the views of the researcher and the potential users are aligned and that the CMF provides a credible solution that can be applied by potential users. However, this does not remove all doubt of validity of the proposed CMF when applied in practice. Furthermore, field testing would require applying the CMF in practice and observing the results over a period of time. Validation by expert review is widely used in research, but the exclusion of field testing can be considered as a limitation to the validation of the framework.

- The study used an expert sample size that is deemed to be sufficient and most of the expert participants were very experienced engineers and Asset Managers. Although the study did include some representative junior level operations and central planning based staff, interviews were not conducted with technicians who actually perform maintenance in their day-to-day work. This limitation was due to time constraints and access to such staff on RE power plants. Including some additional interviews might have added significant differentiating views.
- The ACPD process is aimed at developing ACPs for RE assets. However, the COFCATs worksheet and example are based on a transformer in an REPP. Performing the ACPD process on an RE technology-specific component was challenging as there were no experts available within the resource constraints to facilitate the development of a an ACP for a wind turbine component, for example.
- The CMF is intended to be applicable to any RE technology type. Although participants confirmed that it could be used for any RE technology type, the participants represent RE technologies such as wind, solar PV and CSP, and other technologies such as bio-fuels, wave technology and geothermal are not represented through participant experience.

6.5 Recommendations and Future Research

Observed limitations of this study, feedback received during the face and user validation process combined with insight acquired into the field of study lead to considerations that may be valuable to address in future research.

- The effort in terms of resources such as time, cost and people to execute phase 1 has been identified as potential future research, as was raised as a consideration by expert participants.
- Future research could attempt to understand whether there is a break-even point regarding the number of REPPs that are managed by the

CMF or whether there is a maximum point where the CMF will no longer be effective.
- During the day-to-day operations of an REPP emergency reactive work could occur. An example could be that a wind turbine has a breakdown while PM is being performed on a different wind turbine in the vicinity. Future research could be to develop the reactive work initiation process that considers work in progress, as it might not be beneficial to stop work on a PM WO to attend to a stopped turbine. A model can be developed which could accept input parameters such as distance to failed wind turbine from the current location, demobilisation time, travel time, technician hourly rates, measured wind speed, wind forecast data with turbine power curves to determine whether it will be beneficial to leave PM work in progress to attend to reactive work.
- Mobile technology, the internet of things and industry 4.0 are changing the AM landscape. The real-time updates of maintenance work planning and execution can be streamlined using mobile technology. Future research can consider the development of a work planning and control process which is optimised through the use of modern central CMMS and mobile workforce technology.
- The SA RE competency challenges will remain in the industry for many years and Asset Managers of REPPs need to understand what skills are core to their business. Future research could be to develop an RE skills matrix, informed by the ACPD process, and decision framework that can assist Asset Managers with determining which skills should be part of the core in-house competency and which skills should be outsourced.
- The CMF could have an impact on the organisational design. Future research could consider what the typical roles would be from an AM and technical perspective and how this would translate into an organisation design to support the CMF.
- Future research could be conducted to develop a comprehensive OSP, SAMP, stakeholder requirements, level of service and performance KPIs which are applicable to the RE industry in SA which could be used to enhance the CMF.

6.6 Conclusions

For the management of ACPs to be beneficial to all stakeholders, Asset Owners, managers, technical staff and contractors need to work in partnership to effectively and holistically manage ACPs for REPPs during each LC stage.

The study aims to address some of the challenges in the RE O&M context by attempting to develop a framework to manage ACPs for a portfolio of mixed technologies such as solar PV and wind. There is a need to understand and develop sophisticated ACPs and frameworks for maintaining REPPs. This is especially important in the next five to 10 years after which many REPPs could have their foreign-managed O&M contracts renewed or terminated. Should these contracts be terminated, it could be in the interest of stakeholders to take responsibility for O&M activities as it could prove more cost effective and deliver improved technical and financial performance. However, should contracts be renewed or end of warranty periods reached, it would be beneficial if Asset Owners are capable of understanding maintenance requirements and cost drivers to strengthen their negotiating positions. If Asset Managers do not develop internal maintenance and AM capabilities for RE assets it will result in sustained high O&M costs and dependence on international contractors and delay the development of local technical and managerial skills for these assets.

Based on the discussion in section 2.3, SA could potentially have 115 wind farms (average 72 MW per project) and 130 solar PV farms (average 65 MW per project) by 2030. The number of onshore wind and solar PV facilities in SA could double over the next decade. Market consolidation and owners taking responsibility (refer to section 2.3), due to reduced margins and increased competition, could potentially increase the number of REPPs under management by a single Asset Manager/owner, introducing additional complexity. Pricing pressure and consolidation could also drive vertical integration of supply chains, increasing the need for optimised feedback and continuous improvement loops between various business functions.

Asset Managers of REPPs in SA require structured guidance on how to apply ISO 55000 when developing an overarching AM framework. The proposed solution to the problem is an ISO 55000-aligned guidance CMF supported by business processes that can be used to centrally manage ACPs in a multi-technology portfolio of REPPs. The CMF provides a mechanism to align the requirements of all stakeholders, provides a way of managing the complex ownership and management environment in the SA RE industry and improving overall asset performance through an effective AMS. The CMF provides Asset Managers with an opportunity to consider how to exploit central management platforms in terms of developing central systems, processes, best practice and resources in order to optimise the cost of delivering AM services across a multi-technology portfolio of RE assets. Delivering optimised and sustainable AM services will be key to remain competitive in the RE market where costs and tariffs are continuously declining. The proposed CMF contributes an ISO 55000-aligned guideline on improving the management of ACPs in a multi-technology portfolio of REPPs. Therefore, the research objectives stated in section 1.3 are achieved in chapters 1 to 5.

Appendix A

GFMAM - 39 Asset Management Subjects

A.1 Asset Management Subjects

The following section will review the 39 AM subjects in order to identify relevant topics within the subject than can assist in managing and developing a robust AM system.

A.1.1 Strategy and Planning

A.1.1.1 1: Asset Management Policy (Clause 5.2 of ISO 55001)

Definition (GFMAM, 2014, 13):

> *The principle and mandated requirements derived from and consistent with the organisational corporate plan, providing a framework for the development and implementation of the asset management strategic plan and the setting of the asset management objectives.*

The AM policy, which can be a single page or a few well crafted pages, needs to provide the high level principles as well as the framework required to create and implement the approach that an organisation takes regarding AM. Top management expresses the intentions and direction of an organisation through the AM policy and it needs to be signed off by an appropriate executive officer in order to demonstrate commitment towards AM (IAM 2014*a*, 20; GFMAM 2014, 13).

The AM policy needs to be the start of the golden thread that provides the proverbial "Line-of-Sight" and offers the rationale for the justification of all AM activities in the organisation and indicates that the OSP is being converted into effective AMPs (IAM, 2014*a*, 20).

The PAS 55 document lists 11 requirements for an AM policy, however, an AMS needs to consider more than these requirements. The requirements of an AM policy can be grouped into five broad categories which are briefly discussed (IAM 2014*a*, 20; GFMAM 2014, 13; British Standards Institution 2008*a*, 6).

Consistency: There needs to be coherence between the AM policy, other organisational policies, organisational objectives, stakeholder requirements and other constraints. Furthermore, risk management practices needs to be reviewed regularly.

Appropriateness: The AM policy needs to be suited to the type of business (nature and scale).

Compliance: Does a commitment exist in the AM policy where the organisation is required to comply with mandatory regulations and laws, whether voluntarily or not?

Principles and framework: Can an effective AMS be created within the framework and principles set out by the AM policy.

Continual improvement: The AM policy needs to be fully supported by top management, communicated effectively to the organisation, reviewed on a regular basis and be committed to continuously improve the AMS.

A.1.1.2 2: Asset Management Strategy and Objectives (Clause 4.4 and 6.2.1 of ISO 55001)

Definition (GFMAM, 2014, 14):

> *The strategic plan for the management of the assets of an organisation that be used to achieve the organisational and corporate objectives.*

Initiated by the AM policy, the second phase of the "Line-of-Sight" is the AM strategy and associated objectives which are defined by the ISO 55000 standard as the SAMP (IAM, 2014*a*, 21).

The AM strategy and objectives need to define the objectives and associated time lines that the organisation intends to achieve from the undertaken AM activities. An AM strategy is regarded as being effective if it includes AM objectives that are SMART (IAM, 2014*a*, 21).

An AM strategy can be represented as a single document or as smaller separate documents. In many cases organisations select to develop an AM strategy for each class of asset that sets out the strategy and objectives of each asset class. These separately defined AM strategies need to remain aligned within the overall AM strategy and objectives. In order for an organisation to be an effective Asset Manager there needs to be coherency between in the set of AM strategy and objectives documents (IAM, 2014*a*, 21).

Twelve requirements of an AM strategy as defined by PAS 55 can be converted into 7 broad categories (IAM 2014*a*, 21; GFMAM 2014, 14; British Standards Institution 2008*a*, 7):

Consistency: Is there consistency between the AM strategy, OSP and the AM policy?

Risk-Based: Does the AM strategy subscribe to a risk-based approach and prioritising activities bases on criticality and the associated risk?

Life-Cycle Approach: Is there consideration of the LC of assets and the interaction between each stage of the LC in the AM strategy?

Framework: Is there a clear framework being created by the AM strategy that enables the development of AM objectives and plans that is inclusive of the correct level of prioritisation, optimisation as well as the management of information?

Stakeholders: Is there a clear framework that defines how the AM strategy will be assess regarding its engagement and communication with stakeholders?

Functional, performance and condition requirements Is there consideration for how the AM strategy will identify current and future functional and performance requirements of the assets as well as how the organisations plans intend to meet these?

Continual improvement Does top management support the AM strategy and is the AM strategy effectively communicated and frequently reviewed in order to make sure that it still meets the requirements of the AM policy and the OSP?

Furthermore the GFMAM (2014, 14) also states that the AM strategy should detail:

- the methodology to determine asset criticality;
- a description of how the AM strategy fits into the AM system;
- a description of the overall management system;
- accountabilities for the activities set out by the AM strategy and the

maintenance of the AM strategy;
- outline the decision making criteria used during life-cycle and risk analysis; and
- details on how the asset information will be managed to enable or support LC and risk analysis.

A.1.1.3 3: Demand Analysis - excluded

A.1.1.4 4: Strategic Planning (Clause 4.4 of ISO 55001)

Definition (GFMAM, 2014, 16):

> *The process and organisation uses to undertake strategic asset management planning.*

Strategic planning includes the processes for determining long term renewal, enhancements and maintenance work volumes, associated risk and costs to meet the AM objectives. Strategic planning is a framework that is used to facilitate consistency in the development of work load and cost estimation spanning across different asset groups. The strategic planning framework needs to (IAM 2014*a*, 22; GFMAM 2014, 16):

- ensure that the asset criticality is considered when budgeting across asset types are undertaken and are aligned with the overall business goals;
- outline how maintenance policies, asset information and asset renewal influence the development of the AM strategy and objectives;
- offer a guideline on the methodology used to develop work load, costs schedules and output measures for various asset types as well as an indication of which decision support tools should be used;
- outline how Demand Analysis is utilised during the development of workload related to maintenance, renewal and enhancement of assets;
- enable the development of scenario based work volume modelling to facilitate the analysis of the impact on funding, performance, risk and costs during different scenarios;
- outline how asset information and costs will be assigned a confidence level and how the confidence level will impact the work load and costs indicated in the AM strategy and objectives; and
- the strategic planning processes need to outline how the organisation is planning to ensure that the AM strategy and objectives are going to be realised through the day-to-day plans.

A.1.1.5 5: Asset Management Planning (Clause 6.2.2 of ISO 55001)

Definition (GFMAM, 2014, 17):

> *The activities to develop the asset management plans that specify the detailed activities, resources and responsibilities, time-scales and risks for the achievement of the asset management objectives.*

The purpose of ***Asset Management Planning*** is to ascertain the management approach, over specific time horizon, which will aspire to achieve AM objectives aligned with the AM strategy. This process will deliver AMPs which are explained in section 2.1.3.7 and is "documented information that specifies the activities, resources and time-scales required for an individual asset, or a grouping of assets, to achieve the organisation's AM objectives" (IAM 2014*a*, 22; International Standards Organisation 2014*a*, 14). An output of the process are AMPs that detail the activities to engaged in to deliver AM objectives. The specified activities, as an example, could include an operational maintenance regime or capital investment to build new assets.

The AM planning process is performed to ascertain the manner in which asset will be managed, over a specific time horizon, in order to determine how the AM objectives will be achieved in accordance with the AM strategy. Using an example, an AM objective could be to - reduce sewer flooding of properties. In order to achieve this objective, a range of activities could be combined such as, installing flood gates, capital investment to replace sewers, maintenance to remove tree roots and a customer education campaign to reduce unwanted items in sewers that could cause blockages. The combination of activities that will be used needs to be selected based on approaches that are described in the subject group AM Decision-Making (IAM, 2014*a*, 22).

Additional information to be included is the responsibilities, resources (human, financial, knowledge), the preferred suppliers, how decisions are made and who carries the responsibility for the AM Decision-Making as well as how plans will be funded. AMPs should (IAM, 2014*a*, 23):

- clearly define the time-scales and benefits of each specified activity;
- describe its justification and how optimisation of resources and activities have been achieved to provide the best LCC;
- explain the cost benefit related to obtaining the AM objective;
- provide information regarding the performance of current assets;
- provide information on stakeholder engagement; and
- specify how the AM plan will be approved, monitored, reviewed and updated.

A.1.2 Asset Management Decision-Making

A.1.2.1 6: Capital Investment Decision-Making (ISO 15686)

Definition (GFMAM, 2014, 18):

The processes and decisions to evaluate and analyse scenarios for decisions related to capital investments of an organisation. These processes and decisions may relate to new assets for the organisation (greenfields) and/or replacement of assets at end of life (Capital Expenditure (CAPEX) sustaining projects).

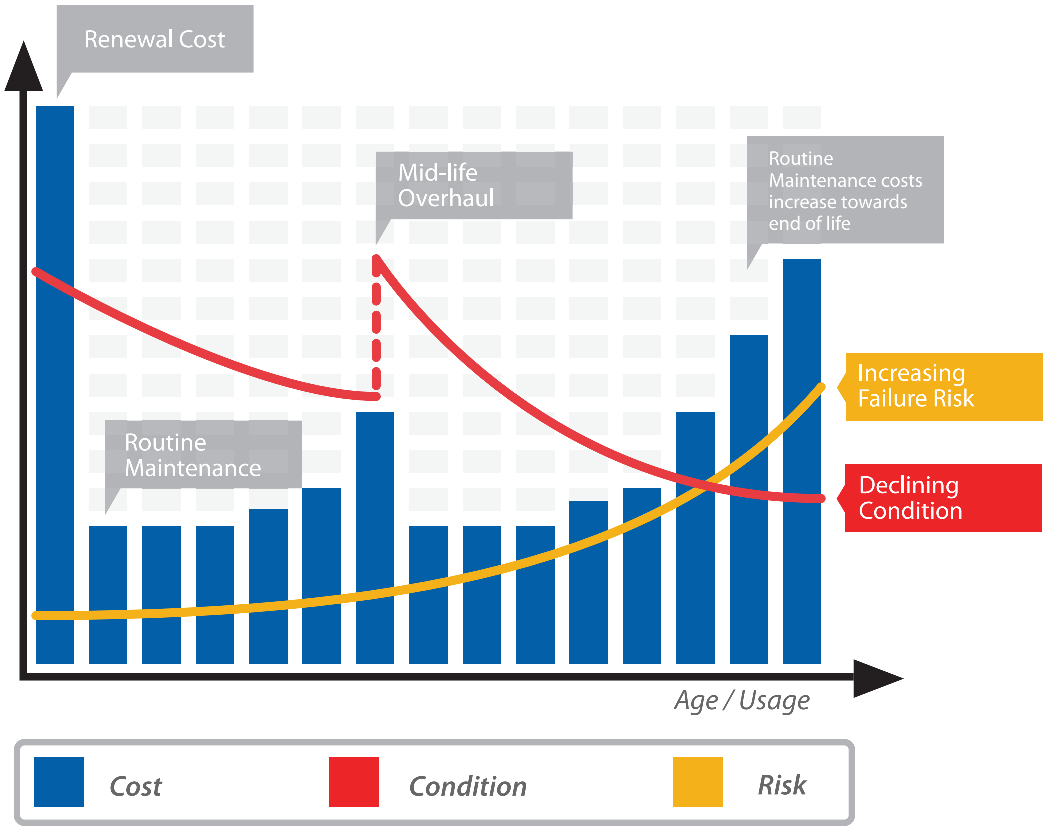


Figure A.1: Life-cycle analysis (Adopted from IAM (2014*a*, 27))

Business success is often hinged on sensitivity to timing on capital programmes. The timing of these programmes are often based on basic assumptions, but there is an increasing demand for more sophisticated methods in justifying CAPEX ***Capital Investment Decision-Making*** analyses the trade-off between CAPEX, OPEX and risk in order to optimise capital investment decision. A tool that can be used for such an analysis is LCC analysis and can assist in determining which intervention(s) will deliver the lowest LCC. This is linked to ***Life-Cycle Value Realisation*** that in practice means combining the processes of ***Capital Investment Decision-Making*** and ***Operations and Maintenance Decision-Making*** in support of decision making to maximise the value obtained from assets over the asset life. The example in figure

A.1 shows the fluctuation in annual costs for a specific asset system (IAM, 2014*a*, 26).

A.1.2.2 7: Operations and Maintenance Decision-Making (Clause 6.1 of ISO 55001)

Definition (GFMAM, 2014, 19):

> *The management activities and processes involved in determining the operations and maintenance requirements in support of the asset management objectives and goals.*

It is common for Asset Owners to adopt the maintenance regime specified by equipment suppliers. The adopted maintenance regimes often do not account for the operational context and my not be optimal. Increasing pressure to reduce operational expenditure combined with ***Capital Investment Decision-Making***, requires that maintenance regimes clearly show the value to the organisation. Decision making around O&M needs to be supported by techniques such as FMEA, RCM, TPM and Risk Based Inspections. The mentioned tools or philosophies are some of the methods available to design maintenance frameworks and plans which are appropriate for the specific assets and context. However, Asset Owners should understand the limitations of these tools before applying them (IAM, 2014*a*, 29).

A.1.2.3 8: Life-Cycle Value Realisation (Clause 6.1 and 6.2 of ISO 55001)

Definition (GFMAM, 2014, 19):

> *The activities undertaken by an organisation to balance the costs and benefits of different renewal, maintenance, overhaul and disposable interventions.*

In practice, the maximisation of value obtained from assets is achieved through the synergy between the ***Capital Investment Decision-Making*** and ***Operations and Maintenance Decision-Making*** processes. Techniques such as ALCA and value optimisation can be used to calculable the benefits in terms of costs, risks and asset performance and suitability considerations over the life of the asset (IAM 2014*a*, 29; GFMAM 2014, 20).

Key aspects that would typically be considered as part of the ***Life-Cycle Value Realisation*** is (GFMAM, 2014, 20):

- system modelling to determine whether proposed solutions will meet the required level of service;
- a multidisciplinary approach and related to the quantification of O&M, risk and performance; and
- consideration for complexity and criticality in order to establish criteria for the use of tools such as ALCA and value optimisation.

Using these **Life-Cycle Value Realisation** techniques can mitigate short-term thinking by making the considerations for aspects such as reliability, maintainability and sustainability mandatory. ***Asset Management Strategy and Objectives*** can greatly benefit from ALC costing and value optimisation as well as optimise the value delivered through the AMPs of all critical assets (IAM, 2014*a*, 29).

A.1.2.4 9: Resourcing Strategy (Clause 7.1 of ISO 55001)

Definition (GFMAM, 2014, 21):

> *Determining the activities and processes to be undertaken by an organisation in order to procure and use people, plant, tools and materials to deliver the asset management objectives and asset management plan(s).*

The ***Resourcing Strategy*** is required to reflect the change in requirements over the planning horizon of the activities in the AMPs. It needs to consider aspects such as skills and resources in order to optimise their use. However, the ***Resourcing Strategy*** does not only include skills but considers the availability of critical spares and raw materials. Existing analytical tools / methods can be used for spares optimisation and considers the cost of keeping spares compared to the risk of not having them available.

A.1.2.5 10: Shutdowns and Outage Strategy - excluded

A.1.3 Life-Cycle Delivery

A.1.3.1 11: Technical Standards and Legislation Decision-Making (Clause 7.6.1 of ISO 55001)

Definition (GFMAM, 2014, 23):

> *The processes used by an organisation to ensure its asset management activities are compliant with the relevant technical standards and legislation.*

The ISO 55001 requires that the AMS of an organisation should document all legal and regulatory requirements. According to the IAM (2014*a*, 36) there is a shift in many sectors to develop technical standards / legislation that follow a risk-based approach that is more aligned to the AM decision process endorsed by the IAM and enable organisations to define the appropriate way of meeting these requirements. In practice there are scenarios where legislative requirements drive sub-optimal organisational activities. An example to illustrate this is when inspections are required every month but an analysis of costs and risks indicate that inspections are only required every 12 months. In the scenario where the cost of complying is significant, it may be worth challenging the technical standard or legislation. Organisations should thus periodically assess compliance to any technical standards or legislation (IAM, 2014*a*, 36).

A.1.3.2 12: Asset Creation and Acquisition - excluded

A.1.3.3 13: Systems Engineering - excluded

A.1.3.4 14: Configuration Management (AS/ISO 10007:2003, EIA-649-A 2004, MIL-STD 973)

Definition (GFMAM, 2014, 26):

> *A management process for establishing and maintaining consistency of a product's physical and functional attributes with its design and operational information throughout its life.*

Configuration Management addresses the need to manage the functional and physical attributes of components/software through the ALC. The ***Configuration Management*** process is often part of a greater management of change process and a key element of prudent project management. The military standard MIL-HDBK- 61A, Configuration Management Guidance provides a framework that guides configuration management and covers the following (IAM, 2014*a*, 37):

- Configuration Management and Planning
- Configuration Identification
- Configuration Change Control
- Configuration Status Accounting
- Configuration Verification & Audits

A.1.3.5 15: Maintenance Delivery

Definition (GFMAM, 2014, 27):

> *The management of maintenance activities including both preventative and corrective maintenance management methodologies.*

The objective of maintenance is to enable assets to meet their performance, safety, environmental and output requirements. The ***Operations and Maintenance Decision-Making*** outlined the requirements for appropriate maintenance regimes. However, ***Maintenance Delivery*** is related to optimised coordination of resources in order to deliver the selected maintenance regime. The O&M phase of the LC often significantly contributes to the LCC and it is therefore important that the planning and delivery of maintenance will be optimised. In the context of AM, the chosen asset maintenance strategy and plans need to be in-line with the AM strategy and objectives as well as AM planning activities. Maintenance activities should at least be split intoCM, PM and PdM (IAM, 2014*a*, 41).

Maintenance Delivery is informed by ***Data and Information*** and emphasises the requirement of keeping record of maintenance activities such as measurements and inspections in order to analyse asset performance and plan in accordance (IAM 2014*a*, 41; GFMAM 2014, 27). Maintenance activities are often resource intensive in terms of logistics, planning scheduling, spare parts and needs a maintenance management system tool to manage the process. Maintenance management within an organisation is broad and includes aspects such as supply chain management, consideration for warranties, inventory management, resource competency, specialist support services, management and legal, as well as commercial considerations. Maintenance management includes the need to keep the arrangements under review and deliver the optimal maintenance strategy at the time. Maintenance is itself a broad term with many specialist disciplines and professional bodies (IAM, 2014*a*, 41).

A.1.3.6 16: Reliability Engineering (Clause 6.2 of ISO 55001)

Definition (GFMAM, 2014, 28):

> *The processes for ensuring that an item shall operate to a defined standard for a defined period of time in a defined environment.*

The IAM (IAM, 2014*a*, 41) defines ***Reliability Engineering*** as "the systematic application of engineering principles and techniques throughout a product LC to ensure that a system or device has the ability to perform a required function under given conditions for a given time interval."

Reliability Engineering also ties in with ***Operations and Maintenance Decision-Making*** and is a continuous process throughout the LC of an asset.

Reliability considers potential events and failure is viewed as a probabilistic phenomenon and can be indicated by a probability density function and concerned keeping equipment functional with a probability of not failing, at a specified statistical confidence level. Reliability is also measured over a specified time period and under specific conditions (equipment cannot function for an indefinite time period or under all conditions). The ***Reliability Engineering*** body of knowledge is well established and some of the key activities performed by reliability professional is to develop and manage reliability programmes, calculate system failure allowances, perform a FMECA, offer advice and information on maintenance requirements, investigate field failures and ensure processes are in place to analyse information (GFMAM 2014, 28; IAM 2014*a*, 42).

Reliability Engineering is very reliant on statistical techniques that develop reliability (times-to-failure) models of a systems based on probability density function of the system components as seen in figure A.2.

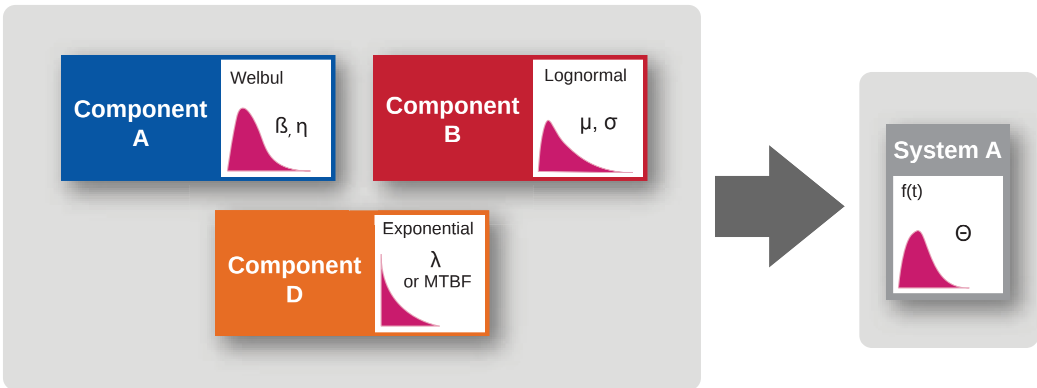


Figure A.2: System reliability model based on component probability density functions (Adopted from IAM (2014*a*, 42))

Reliability models are refined through the feedback of actual failure rate data once assets are operational. A Failure Recording and Corrective Action System (FRACAS) is required to accurately capture failure information and should be consistent with the FMECA to address the failure rates of all the identified failure modes and facilitate the selection of maintenance or inspection interventions (GFMAM 2014, 28; IAM 2014*a*, 42). Some of the key artefacts noted by the GFMAM (2014, 28) is the RCM analysis outputs, completed RCAs, and Weibull plots and analysis.

A.1.3.7 17: Asset Operations (Clause 6.2 of ISO 55001)

Definition (GFMAM, 2014, 29):

> *The processes used by an organisation to operate its assets to achieve the business objectives.*

Asset Operations deliver the product or service to the customer and is therefore a critical part of achieving the ability of an item to perform a required function under given conditions for a given time interval organisational objectives. Asset Managers thus need to provide operators with the sufficient information in order to operate assets in the design and O&M specifications (IAM, 2014*a*, 42)).

Asset Operations can include the development of an Asset Operations strategy and Operations plan that would lay the foundation for the approach, activities and resources required to manage and implement operations (IAM, 2014*a*, 42).

A.1.3.8 18: Resource Management

Definition (GFMAM, 2014, 28):

> *Implementing the Resourcing Strategy to manage the use of funds, people, plant, tools and materials in delivering asset management activities.*

Resource Management considers how the AM activities that enable the AMPs are resourced and endeavours to manage and deliver competent human resources, spares and inventory, plant and equipment, tools, vehicles and special equipment. ***Resource Management*** also considers risks involved with insufficient resources (IAM, 2014*a*, 44).

A.1.3.9 19: Shutdowns and Outage Management - excluded

A.1.3.10 20: Fault and Incident Response - excluded

A.1.3.11 21: Asset Decommissioning and Disposal - excluded

A.1.4 Asset Information

A.1.4.1 22: Asset Information Strategy (Clause 7.5 of ISO 55001, ISO 27000/1/2)

Definition (GFMAM, 2014, 34):

> *The strategic approach to the definition, collection, management, reporting and overall governance of asset information necessary to support the implementation of an organisation's asset management strategy and objectives.*

Asset information is how data relevant to assets are used to manage these assets. Reliable asset information related to asset costs, consequence of failure, and resource availability enables informed decision making. An ***Asset Information Strategy*** should dictate how asset information will be collected, maintained and utilised to support the strategic planning and LC activities. The LC related to collecting and maintaining asset information including the decision making support value generated by asset information would be considered in the ***Asset Information Strategy***. There should be a clear alignment between the AM strategy and objectives and the ***Asset Information Strategy*** which should also consider (GFMAM 2014, 34; IAM 2014*a*, 49):

- information flow and data models;
- how to define and approach information requirements while considering the cost of acquiring the data and the value it can offer;
- the management and governance of data;
- the requirements, functionality, integration and purpose of asset information systems;
- the transfer of data between parties responsible for the management of assets;
- asset policy; and
- information gap analysis.

The ***Asset Information Strategy*** objectives should be SMART with a key consideration for internal and external stakeholder requirements. ***Asset Information Strategy*** also needs to be approved by the appropriate stakeholders in the organisation (GFMAM 2014, 34; IAM 2014*a*, 49).

A.1.4.2 23: Asset Information Standards (Clause 7.5 of ISO 55001, ISO 27000/1/2)

Definition (GFMAM, 2014, 35):

> *The specification of a consistent structure and format for collecting and storing asset information and for reporting on the quality and accuracy of asset information.*

Asset Information Standards facilitate the collection, categorisation, and provision of asset information and considers (GFMAM 2014, 35; IAM 2014*a*, 50):

- the classification of assets based on an agreed topology that enables the management of the asset inventory;
- defining the attributes that should be managed for each asset type;
- defined methods for categorising and recording asset failure and performance information that can be used in future to improve maintenance planning, long-term planning and reliability measures;
- the requirements, functionality, integration and purpose of asset information systems; and
- defined methods for the assessment and record keeping of asset use in order to estimate asset-life and maintenance intervals.

Furthermore, *Asset Information Standards* need to consider the criticality of assets in order to determining the level of quality and accuracy of the information collected from all the asset types (GFMAM 2014, 35; IAM 2014*a*, 50).

A.1.4.3 24: Asset Information Systems (Clause 7.5 of ISO 55001, ISO 27000/1/2)

Definition (GFMAM, 2014, 36):

> *The asset information systems an organisation has in place to support the asset management and decision-making processes in accordance with the Asset Information Strategy.*

Applications, software and other system that collect, save and analyse asset information used to manage assets over their LC are regarded as ***Asset Information Systems***. These systems facilitate effective integrated planning and operational activities and can vary from complex Enterprise Asset Management suites to integrated environments of "Best of Breed" solutions, custom developed applications and spreadsheet based analytical tools. ***Asset Information Systems*** consider (GFMAM 2014, 36; IAM 2014*a*, 51):

- an asset register outlining all the assets;
- Geographical Information System (GIS) to record spatial information related to assets;
- systems to manage work planning and contro;l
- spares and material management;
- SCADA and process control systems to record performance data;
- CdM systems to measure asset indicators that could include temperatures and vibration in order to assist in predicting potential failures; and
- mobile work devices such as tablet computers and other hand held file devices.

A robust reporting system is required to provide information to different stakeholders and in different formats over the AM LC. The line between ***Asset Information Systems*** and other systems being used in the organisation is not always that clear as information in other corporate systems could support AM objectives. An example would be that training and competency information stored in the corporate HR systems could be used to determine who is best skilled to attend to a defect (GFMAM 2014, 36; IAM 2014*a*, 51).

A.1.4.4 25: Data and Information Management (Clause 7.5 of ISO 55001, ISO 27000/1/2)

Definition (GFMAM, 2014, 37):

> *The data and information held in an organisation's information systems and the processes for the management and governance of that data and information.*

Organisations that are asset intensive often rely on data and information in order to perform operational and strategic AM activities. Asset Data quality covers aspects such as accuracy, completeness, consistency, validity, timeliness and uniqueness. The quality of data should be assessed and a plan needs to be developed to acquire all missing or sub-standard data in a time-frame that is acceptable. Furthermore, it is acceptable not to gather missing data if the data will not add any benefit to the organisation and the decision has been approved by top management (GFMAM 2014, 37; IAM 2014*a*, 51).

Asset Knowledge is often subjective and can be influenced in numerous ways. Knowledge is developed from the amalgamation of values, experience, context specific information and insight embedded in key individuals. The quality of knowledge has an impact on the reliability and calibre of decision-making. An organisation thus has to ensure that personal knowledge and insights are captured and made available in the organisation as a measure to counteract losing such knowledge due to staff leaving or change of organisational ownership and management. Attempts at preventing loss of knowledge and information include the use of concepts such as BIM (Building Information Modelling) during various stages of the ALC (GFMAM 2014, 37; IAM 2014*a*, 51).

A.1.5 Organisation and People

A.1.5.1 26: Asset Management Leadership (Clause 5.1 of ISO 55001)

Definition (GFMAM, 2014, 38):

> *The leadership of an organisation required to promote a whole life asset management approach to deliver the organisational and Asset Management objectives of the organisation.*

Comprehending ***Asset Management Leadership*** requires an understanding of what it means to be an effective leader. Successful leaders have varying personalities, styles and approached to leadership and yet remain effective leaders. Regardless of the leadership style all leaders should be able to (GFMAM 2014, 38; IAM 2014*a*, 54):

- provide the organisation with direction by having a clearly articulated vision of how the use of assets can be optimised and communicate this in manner which is persuasive and practical;
- be able to make difficult decisions, while remaining decisive as often problems with the AM context are hard to define and solving these problems require decision to be take that can affect individuals and the entire organisation;
- inspire staff to pursue and achieve the organisational objectives; and
- provide all stakeholders with the confidence that the most appropriate direction is being taken that will deliver the required results.

Effective leaders need to be able to motive all members of the organisation and this can be achieved through various ways. Leaders could act as a role models, offering the required organisational support, regard people as individuals with clear psychological and tangible incentives. Good leaders have a range of techniques which they combine in the most appropriate manner and need to be trusted by the people they lead. Trust is gained through consistent fair, and just while willing to take responsibility when key challenges arise. Leadership should not be confused with managing or supervising as managers and supervisors plan, organise and control work that has already been defined and has set procedures. However, leaders are involved in defining, developing and implementing procedures and systems required to perform the work (GFMAM 2014, 38; IAM 2014*a*, 54).

A.1.5.2 27: Organisational Structure (Clause 5.3 of ISO 55001)

Definition (GFMAM, 2014, 39):

> *The structure of an organisation in terms of its ability to deliver the organisational and Asset Management objectives.*

The question around where AM should be placed in an organisation does not have a clear answer and should be based on the ***Organisational Structure***, the perception of AM by senior staff and the AM maturity of the organisation. Conventional hierarchical organisations often have departments working in silos and are only integrated at the top structures of an organisation. Senior management should take accountability for AM in these hierarchical organisations, however if AM is regarded as an engineering function it might be challenging convince senior management to take responsibility. The responsibility of AM should be clearly defined and adopted by senior management across all organisational functions in order to gain the most benefit for the organisation otherwise only incremental benefits may be achieved (GFMAM 2014, 39; IAM 2014*a*, 55).

Senior management often regards AM as a tactical issue if the people responsible for AM do not have the authority to act more strategically, creating a stalemate situation. The situation will differ in organisations making ***Organisational Structure*** a key consideration in the AM context. The risk is that if AM is positioned incorrectly in the organisation during the introductory stages it could be years before the true potential benefits might be realised. Key factors that would contribute to the success of AM is having organisational structures (and cultures) that support obtaining organisation objectives and goals, has well defined and communicated top management support, is consistently applied and promoted within the organisation, are viable with a clear Line-of-Sight between starting at top management all the way down to the people on the ground (GFMAM 2014, 39; IAM 2014*a*, 55).

A.1.5.3 28: Organisational Culture (Clause 5.3 of ISO 55001)

Definition (GFMAM, 2014, 40):

> *The culture of an organisation in terms of its ability to deliver the organisational and Asset Management objectives.*

The entire manner in which an organisation operates and performs is defined by its culture. Performance areas which are affected by ***Organisational Culture*** include safety, finance, security, customer service and AM. It is important to proactively manage the culture in an organisation that seeks to benefit from AM. Culture dictates the way that things are done and a organisation needs to create and nurture a culture which will drive success. In the case where the culture of an organisation is short-term, risk averse, output driven and not open to new ideas a change needs to be affected in order to benefit from AM thinking and practices and be open to long-term planning, value processes and outputs, promote innovation and benchmarking itself against industry best practice. A culture which is conducive to AM practices can be established by top management having a clearly defined idea of what they are trying to achieve as well as why the proposed approach is likely to succeed. The view taken by top management should include both the organisational objectives and the AM strategies and objectives while considering the organisational constraints (GFMAM 2014, 40; IAM 2014*a*, 56).

Top management can draw on numerous best practice principles when considering the best organisational structure and culture to address AM activities such as to (GFMAM 2014, 40; IAM 2014*a*, 56):

- provide a clear purpose for the organisation;
- consistently apply practices throughout the entire organisation;
- provide clear roles and responsibilities while keeping people motivated;
- establishing a clear chain of command, channels of communication, information flow and that communication is acted upon;
- ensure that everyone in the organisation understands who is responsible for making decisions; and
- established visible support from top management for AM initiatives.

A.1.5.4 29: Procurement and Supply Chain Management - excluded

A.1.5.5 30: Competence Management (Clause 7.2 of ISO 55001)

Definition (GFMAM, 2014, 41):

> *The processes used by an organisation to systematically develop and maintain an adequate supply of competent and motivated people to fulfil its asset management objectives including arrangements for managing competence in the boardroom and the workplace.*

Competency management addresses the ability of employees to perform their duties at the required standard. An organisation needs to ensure that it has the required competent people in order to sustain a successful organisation. Competency needs to be practised and can be difficult to maintain if the related activities are not performed often (IAM, 2014*a*, 56).

Senior management needs to be aware of what the implication would be on the competency of their workforce when implementing AM strategy and objectives. The practical implication of this is that there should be a clear understanding of what the competency requirements are at all levels of the organisation with clearly defined roles and responsibilities as well as the relationship between roles (IAM 2014*a*, 56; GFMAM 2014, 41).

As an example the IAM has developed competences framework that can be used by organisations to determine their competence requirements and develop their competence management systems around these requirements. Competency management should include the assessment of people against a competence framework on an ongoing basis in order to identify training needs. Research indicates that organisation need to take strategic approach regarding the management of competence and behaviour and should consider individual and business competence (IAM 2014*a*, 56; GFMAM 2014, 41).

The team of people that become involved in AM in an organisation normally comes from a diverse background ranging from technical, operations and management. Ensuring that these diverse teams have a common understanding of AM is key element of AM strategy and planning. The multidisciplinary and cross-functional nature of AM require members of such teams to be open to methodologies and approaches from other disciplines and able to integrate these into decision-making (IAM 2014*a*, 56; GFMAM 2014, 41).

A.1.6 Risk and Review

A.1.6.1 31: Risk Assessment and Management (ISO 31000:2009 - Risk Management - Principles and guidelines IEC/ISO 31010 - 2009 Risk management - Risk assessment techniques HB 327:2010 - Communicating and consulting about risk)

Definition (GFMAM, 2014, 43):

> *The policies and processes for identifying, quantifying and mitigating risk and exploiting opportunities.*

Risk Assessment and Management is key element that assists an organisation to derive the most benefit from optimised AM Decision-Making. ***Risk Assessment and Management*** also enables an organisation to deliver its OSP and deliver as much value as possible from its assets. The importance of establishing a view on the criticality of assets is to inform the AM strategy and decision-making tools and processes followed by the organisation. The process of assessing the critically of an asset requires the organisation to assess the potential impact a failure would have, and is influenced by the vision, mission, values as well as other business policies, key stakeholder requirements, goals and risk management criteria. Assets inherently do not carry any risk or criticality, only once a consequence of failure against an organisational objective has been quantified its criticality can be defined. After the consequence of failure has been determined the organisation needs to document the information in a usable format that will enable easy analysis. The criteria an organisation used to assess risk needs to reflect key considerations, issues or metrics that the organisation is responsible for managing. The risk assessment also provides the organisation with a consistent methodology for assessing and managing uncertainty and thereby optimising AM decision-making. The organisation needs to understand how risk related to assets and AM can be combined in a corporate governance framework (IAM 2014*a*, 59; GFMAM 2014, 43).

The SAMP and AMPs should consider risks to business continuity and performance and then account for any associated costs that would need to be incurred to adapt procedures, informations systems or infrastructure that could mitigate the impact of events. The ISO 31000, Risk Management Principles and Guidance, provides guidance on good practice approaches to ***Risk Assessment and Management*** (IAM 2014*a*, 59; GFMAM 2014, 43).

A.1.6.2 32: Contingency Planning and Resilience Analysis - excluded

A.1.6.3 33: Sustainable Development - excluded

A.1.6.4 34: Management of Change - excluded

A.1.6.5 35: Asset Performance and Health Monitoring

Definition (GFMAM, 2014, 47):

> *The processes and measures used by an organisation to assess the performance and health of its assets using performance indicators.*

Assets Performance and Health Monitoring is a key requirement to practice good AM. A measurement framework needs to consider asset performance and the performance of the AMS in order to be robust. The Line-of-Sight remains a key element as performance measures and targets need to be aligned with organisational objectives, stakeholder requirements which are expressed in the OSP and the AM objectives and strategies. The AM decision-making processes is informed through feedback from appropriate performance measures that assist in understanding physical assets and is an important part of business and risk management (IAM 2014*a*, 62; GFMAM 2014, 47).

The measures of the desired functional performance, level of service and condition of assets are defined in the AM policy and SAMP. Asset systems (rail track, a process plant, whole plants, etc.) typically have specific performance criteria. Monitoring at the asset and AMS level is required to understand and manage performance in support of strategic and tactical decisions. Lagging performance measures considers part performance of assets while leading performance measures are intended to predict the future performance. These two indicator types are generally combined to see how the processes are performing and how outcomes are being achieved. Proactive, reactive, leading, lagging, qualitative and quantitative measures, which are explained well, and is a required consideration by PAS 55 while ISO 55001 specifies performance evaluation requirements which are aligned to other management standards. The efficiency of processes is monitored through internal efficiency measures while actual delivery of the business is determined via output measures (IAM 2014*a*, 62; GFMAM 2014, 47).

The discussed principles are depicted in figure 2.22. The term asset health is increasingly being used to indicate measures that monitor current and the predicted capability of an asset to perform its intended function (IAM 2014*a*, 62; GFMAM 2014, 47).

A.1.6.6 36: Asset Management System Monitoring (Clause 9.1, 9.2, 9.3 of ISO 55001)

Definition (GFMAM, 2014, 63):

> *The processes and measures used by an organisation to assess the performance and health of its Asset Management System.*

Measuring the performance of the AMS is just as important as measuring the performance of the assets and involved understanding how effective and efficient the organisation's AM processes and activities are. Adopting a "Plan-Do-Check-Act" approach to all aspects of the AMS is embodied in the ISO 55001 standard. Measurement at varying levels of granularity is required to provide insight on the AMS performance. The top management level information is summarised while the detail increases in the rest of the organisation based on the decisions and issues that are being managed. Having accountabilities for reporting of measures, acting on them and managing individual performance are clear requirements for good practice. Performance measures and the management thereof is integrated in business processes and the documented AMS. Organisations that practise AM often include asset performance measures as part of individual targets. Performance measurement is also linked to data and information management and will require information systems that can monitor, predict and trend performance on an ongoing basis. The monitoring of the AMS considers feedback mechanisms from all areas of business such as asset health, HSE, audits, etc. and compares this with anticipated performance in order to effect changes in objectives, risk control and the AMS to optimise the direction of the organisation (IAM 2014*a*, 63; GFMAM 2014, 48).

A.1.6.7 37: Management Review, Audit and Assurance

Definition (GFMAM, 2014, 49):

> *An organisations processes for reviewing and auditing the effectiveness of its asset management processes and asset management system.*

The "Plan-Do-Check-Act" cycle, which is part of the management system design and plays a key role in closing the loop in the collection of business process which is part of the ***Management Review, Audit and Assurance*** process. Audits, the system performance monitoring, asset health monitoring and incident investigation processes offer the assurance that the organisation is performing its functions as intended (IAM, 2014*a*, 64).

The ***Management Review, Audit and Assurance*** process is a means of understanding whether the organisation is following processes and standards to ensure that these aspects are in place and in use. These processes are all part of managing risk (IAM, 2014*a*, 64).

The audit process is inherently part of the "Check" in "Plan-Do-Check-Act" and needs to be conducted in various departments in the organisation. An internal audit team would normally be assembled and report on various functions of the business. This would also include technical and HSE audit teams responsible for evaluating the technical, legislative and regulatory compliance (IAM, 2014*a*, 64).

Another assurance activity could include the continued monitoring of AM activities performed my managers and supervisors with the purpose of understanding where external expertise might be required for critical activities. Furthermore, the organisation can take stock of its activities through the review of (IAM, 2014*a*, 64):

- organisational performance compared to the SAMP;
- performance of employees against their performance contracts;
- feedback from customer or stakeholders;
- how effective the organisational business processes are; and
- the risk profile of the organisation and whether there have been any major changes.

A.1.6.8 38: Asset Costing and Valuation - excluded

A.1.6.9 39: Stakeholder Engagement

Definition (GFMAM, 2014, 51):

> *The methods an organisation uses to engage with stakeholders.*

The formalisation of stakeholder engagement is increasingly becoming a requirement, especially for utilities which are bound by regulations. Organisations are expected to consult stakeholder groups. ***Stakeholder Engagement*** also relates to articulating the methods that are used to engage and interact with the identified stakeholders in various scenarios which are set out in the organisation's AMPs.

The costs and outputs of each engagement scenario needs to be understood and documented, and clear priorities of stakeholders identified in these scenarios. Furthermore, identifying stakeholders who have an interest in the physical assets of the organisation are critical and would include stakeholders such as regulators, government, owners, landowners, communities, stakeholders and customers as examples. Each of the identified stakeholders have an impact on the overall performance of an organisations and can play a role in strike actions, withholding a license to operate, imposing penalties or influencing parts suppliers are just a few examples of negative impact that could be experienced by an asset-centric organisation due to stakeholder mismanagement (IAM, 2014*a*, 66).

The relationship with each external stakeholder is a reflection of their interaction with the specific organisation. The overall health of the relationship between the organisation and the stakeholders will determine how well they interact and also how well the stakeholders will support and the SAMP. Furthermore, the interaction with stakeholders can be measured and KPIs can be used to monitor performance. External ***Stakeholder Engagement*** will play a critical role in supporting the overall ability of the organisation to manage asset in a manner which is effective, efficient and reliable (IAM, 2014*a*, 66).

In reality, stakeholders will generally not be in the direct control of the organisation and ***Stakeholder Engagement*** is influenced through the way the internal management of ***Stakeholder Engagement*** aligns the outcomes of these interactions with the OSP. Internal management of ***Stakeholder Engagement*** geared towards improving external stakeholder relationships can be done trough various means (IAM, 2014*a*, 66).

The organisation can alter or develop business processes, establish policies to enforce procedures, create incentive programmes that will align the behaviour of employees towards the vision of how the organisation would like internal and external stakeholder to perceive the organisation (IAM, 2014*a*, 66).

Appendix B

Consequence of Failure, Cause analysis and Task Selection (COFCATs)

A	B	C	D	E	F
Scope and Preparation 2.1					
Criticality Analysis of Asset Type - 2.2.1	**Document Reliability Measures - 2.1.2**	**Select Systems and Components for Analysis and estimating effort - 2.2.3**	**Assign alphanumeric code - 2.2.4**	**Understand the required skill set and expertise - 2.2.5**	**Gather History, Drawings, OEMS and Procedures - 2.2.6**
HV TRANSFORMER (5)	OSP: Plant availability, target 98%, AM OBJ 1 = 98%, level of service	3.5.2 Oil insulation The transformer oil is a highly refined product from mineral crude oil and consists of hydrocarbon composition of which the most common are paraffin, naphthene and aromatic oils. The oil serves as both cooling medium and part of the insulation system. The quality of the oil greatly affects the insulation and cooling properties of the transformer. The major causes of oil deterioration are due to moisture and oxygen coupled with heat. Another function of the oil is to impregnate the cellulose and isolate between the different parts in the transformer. If the isolation fails there is a short circuit. A short circuit can appear if there is conducted particles present in the oil. Conducted particles are for example water, that appears in the oil as a result of the aging process of cellulose, and other particles, for example metal, these particles are also a result of aging.	HV TRAN-OIL	Transformer specialist required, will need to procure the skills externally	Transformer manual, oil specifications, oil test history
			HV TRAN-OIL	Transformer specialist required, will need to procure the skills externally	Transformer manual, oil specifications, oil test history

Figure B.1: COFCATs worksheet columns A to F

G	H	I	J	K	L
COFCATs 2.2					
Describe all the functions of the component or system - 2.3.1	Describe the way each component/ system function can fail - 2.3.2	Describe the dominant component failure modes for each functional failure - 2.3.3	Describe the causes and potential causes of the failure mode - 2.3.4	Potential Causes (FT) - 2.3.4	Potential Causes (FT) - 2.3.4
insulate active parts of transformer	fails to insulate active parts of transformer	The HV transformer insulation oil fails due to change in its physical chemistry	[1] Particles in the oil, [2] water in oil	[1a] overheating, [1b, 2a]ageing	
cool active parts of transformer	fails to cool active parts of transformer	The HV transformer cooling oil fails due to change in its physical chemistry	[1] To hot air/water, [2] Oil circulation out of function	[1a] Air/water circulation out of function, [2a] Dirt, particles in the oil, [2b] pump failure	[1a] Fan/pump failure, [2a] Ageing, [2a] overheating

Figure B.2: COFCATs worksheet columns G to L

M	N	O	P	Q
COFCATs 2.2				
Is the occurrence of failure evident - 2.3.5	Describe the system effect for each failure mode - 2.3.6	Describe the consequence of the failure based on the asset reliability criteria - 2.3.7	Classify the component Critical, Potentially Critical, Economic, Commitment, RTF - 2.3.8	Probability and consequences ranking of each failure mode - 2.3.9
yes	Short circuit in transfer due to - Reduction in the electrical strength & Breakdown voltage; increase the dielectric loss of oil	Transformer will fail resulting in the inability to export power to the grid and complete revenue loss for 14 day business until interruption insurance activates	Critical	3
yes	Overheating of transfer due to - Reduction in the electrical strength & Breakdown voltage; increase the dielectric loss of oil	Transformer will fail/trip resulting in the inability to export power to the grid. If the failure only resulted in a trip the revenue loss will be limited. A major failure will result in complete revenue loss for 14 day business until interruption insurance activates	Critical	3

Figure B.3: COFCATs worksheet columns M to Q

R	S	T	U	V	W
COFCATs 2.2					
RCM task selection using task selection logic and classifying as PM, CM, DOM) - 2.3.10	**Review history/supplier recommendations/use the DTMM for task frequency selection - 2.3.11 (Comments from findings)**	**Review history/supplier recommendations/ use the DTMM for task frequency selection - 2.3.11 (Task Frequency)**	**Spare parts considerations - 2.3.12**	**Component life-cycle task consideration using ALCC - 2.3.13**	**Operator asset care - 2.3.14**
Hotspot Temperature monitoring, Dissolved Gas Analysis (DGA), Oil Quality Test, Furan Analysis, Partial Discharge measurement, Winding Tan Delta and Capacitance **[DGA test review by RMC]**	no prior major issues	3M	Spare transformer to be kept in stock	LLC analysis - more cost effective to have online DGA overe 20 years compared to manual oil sampeling	Yes, cleaning staff could check the temp gauge and for any leaks during routine cleaning of area. Check sheet supplied. The RMC could also monitor on on-line temp.
Visual Inspection on Fan and Radiator fins, Fan Contactor voltage measurement	Issues with transformers overheating and have constant trips. Transformers might be running at high core temp.	2M		Obsolescence not a concern with the oil, but the fan will be obsolete and needs a alternative	Yes - onsite bird and bat monitoring team can perform basic inspection to ensure there are no obstructions to the vent

Figure B.4: COFCATs worksheet columns R to W

X	Y	Z	AA	AB	AC
Standard Jobs - 2.4					
Assemble minifile - 2.4.1	Review existing or develop maintenance procedures - 2.4.2	Review existing or develop operating procedures for system - 2.4.3	Review existing or develop risk Assessments - 2.4.4	Planning: craft, no of persons, work hrs, job duration, spare parts, special tools, estimated cost - 2.4.5	Build the standard job within the CMMS system - 2.4.6
SharePoint file with all relevant information	P005A_R00 - 22kV-370V Inverter transformer, document not complete	Needs to be created	Needs to be created	Job requires one electrician and one solar tech. The solar tech needs to be trained in using the portable DGA and the electrician needs to know how to switch the RMU. The job will require 3 hours from both crafts and should take 3 hours to complete. The solar tech needs to be HV/MV certified. The estimated cost will be R500 for the solar tech and R450 for the electrician labour. No consumables are expected to be used.	Completed standard job
Existing maintenance plan has no consideration for specific consideration of the oil and the specific failure mode	needs to be created	needs to be created	Needs to be created	Job requires one electrician and one solar tech. The solar tech needs to be trained in using the portable DGA and the electrician needs to know how to switch the RMU. The job will require 3 hours from both crafts and should take 3 hours to complete. The solar tech needs to be HV/MV certified. The estimated cost will be R500 for the solar tech and R450 for the electrician labour. No consumables are expected to be used.	needs to be created

Figure B.5: COFCATs worksheet columns X to AC

AD	AE	AF	AG	AH	AI	AJ
Follow Up Tasks - 2.5						
Checking for Completion - 2.5.1	Spell check and proof read - 2.5.2	Prioritise analysis tasks - 2.5.3	Implement plan - 2.5.4	Analysis report - 2.5.5	Review meeting - 2.5.6	Tracking results - 2.5.6
Done	Done	3	Done	Done	Notes	Completed
Done	Done	3	Done	Done	Notes	Completed

Figure B.6: COFCATs worksheet columns AD to AJ

Appendix C

Complete Business Process

C.1 Asset Management Framework - Phase 1

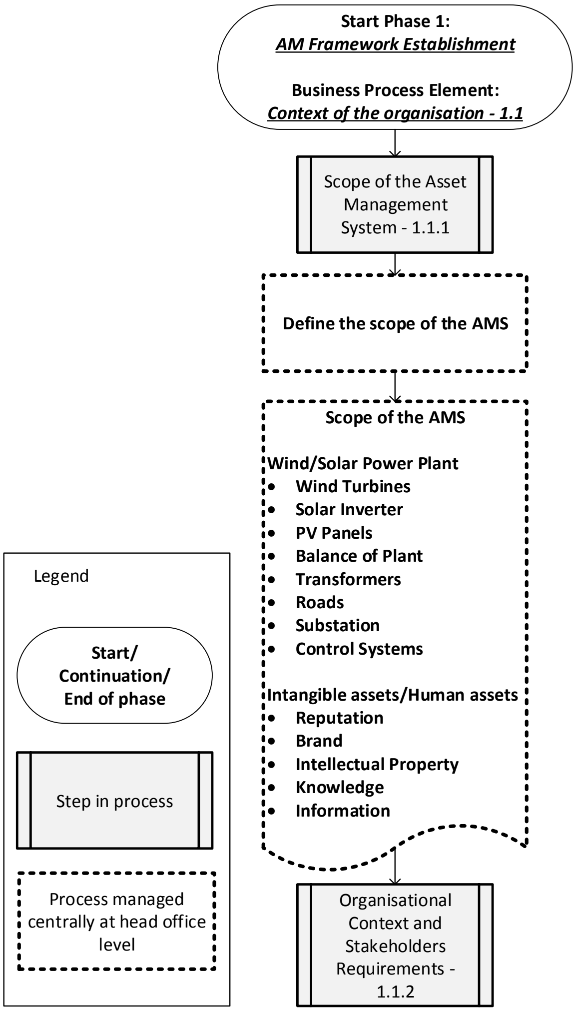


Figure C.1: Scope of the asset management system – 1.1.1

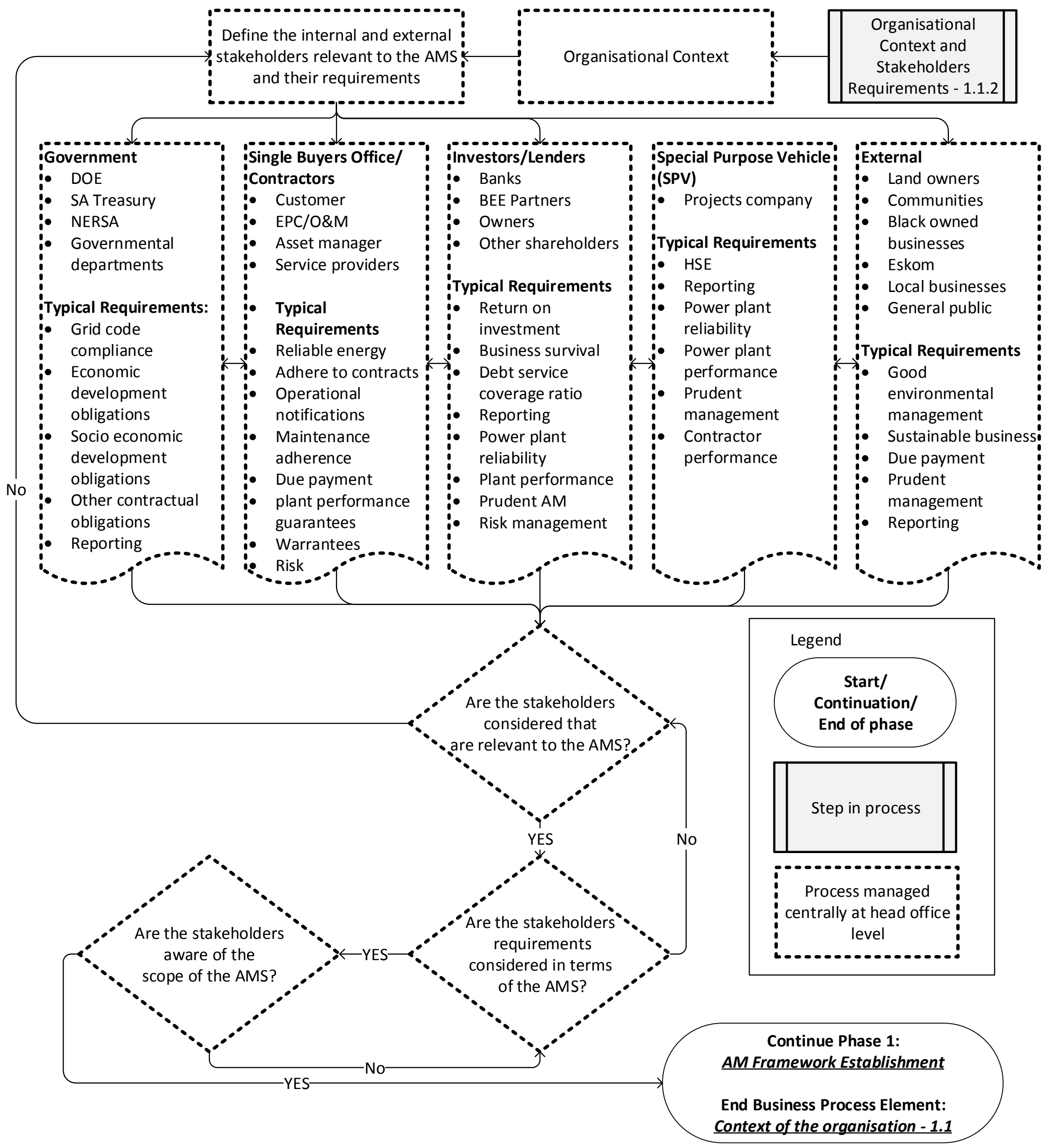


Figure C.2: Organisational context and stakeholders requirements – 1.1.2

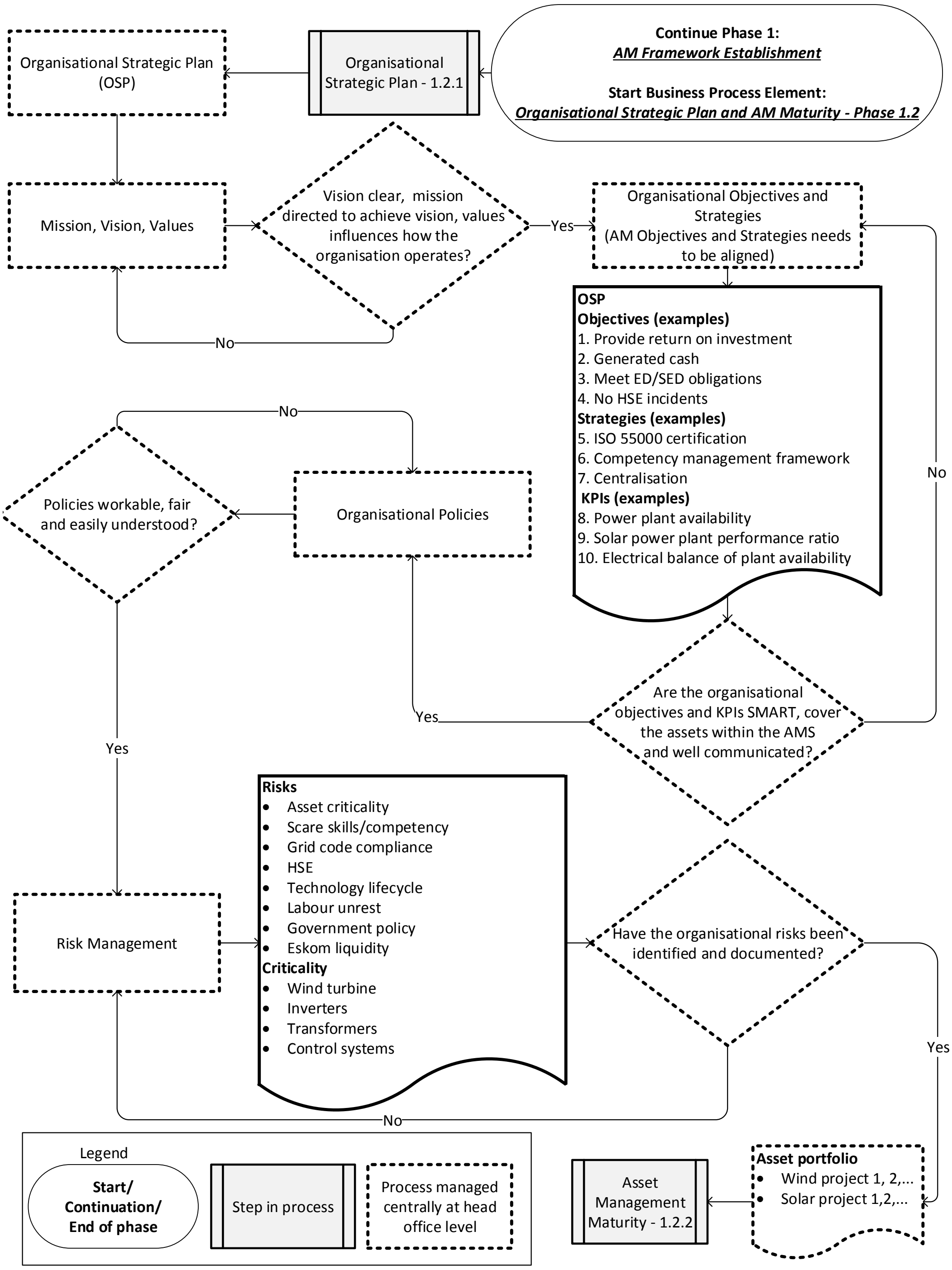


Figure C.3: Organisational strategic plan – 1.2.1

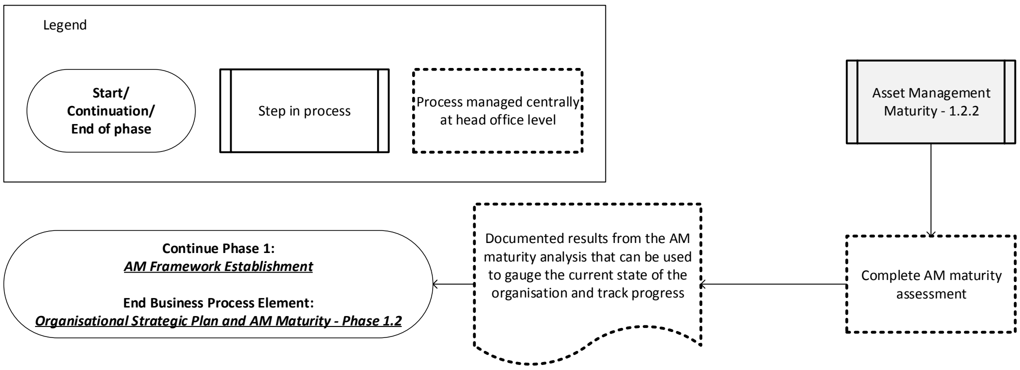


Figure C.4: Asset management maturity – 1.2.2

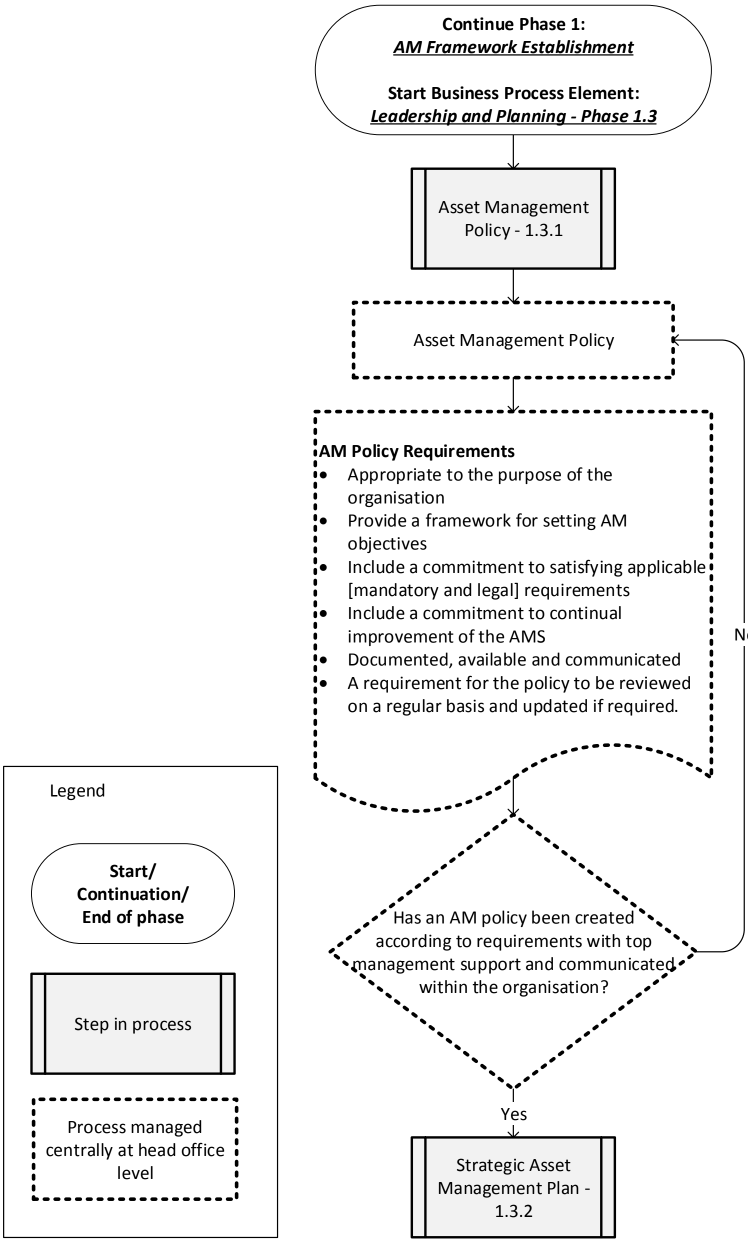


Figure C.5: Asset management policy – 1.3.1

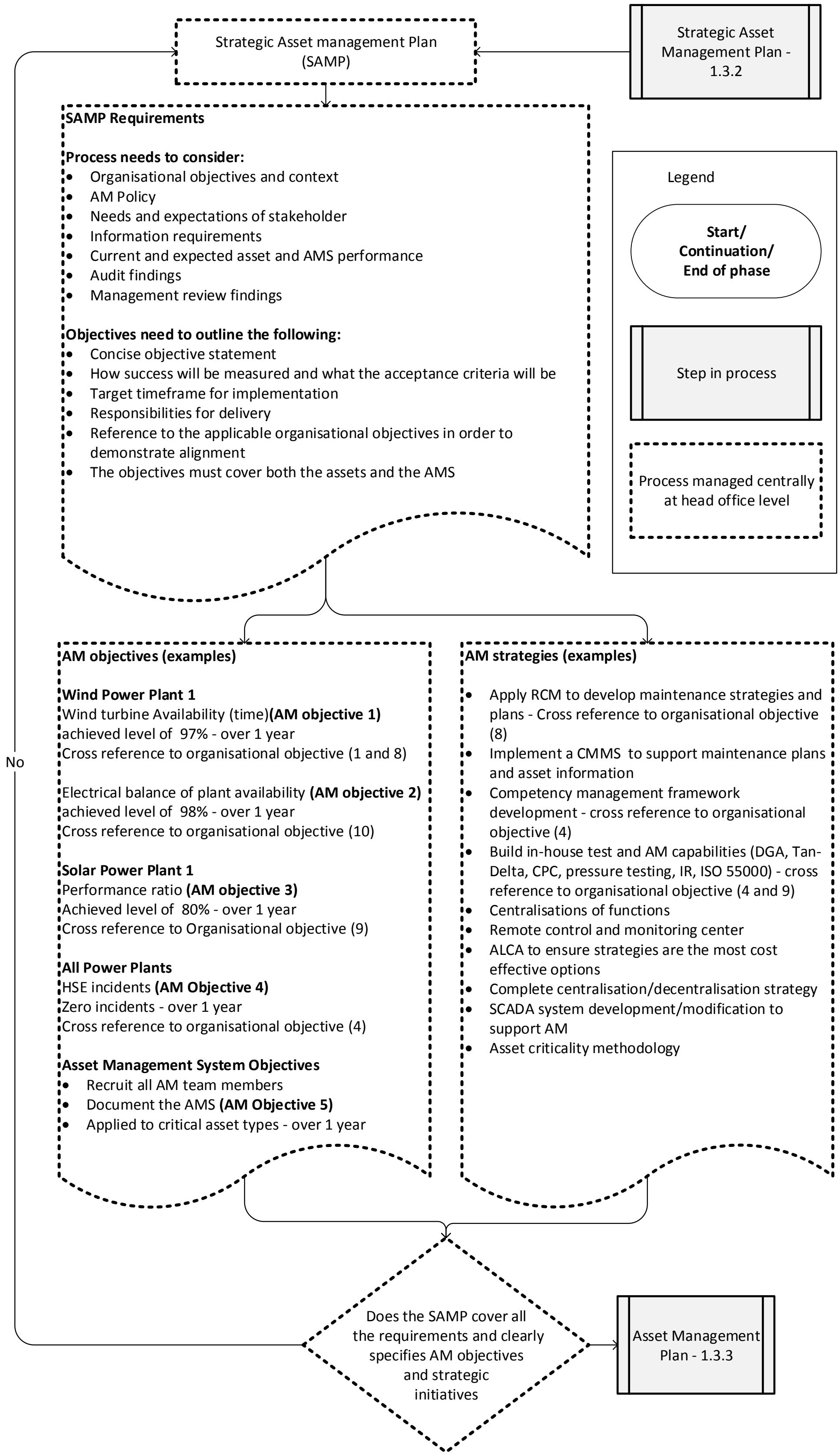


Figure C.6: Strategic asset management plan – 1.3.2

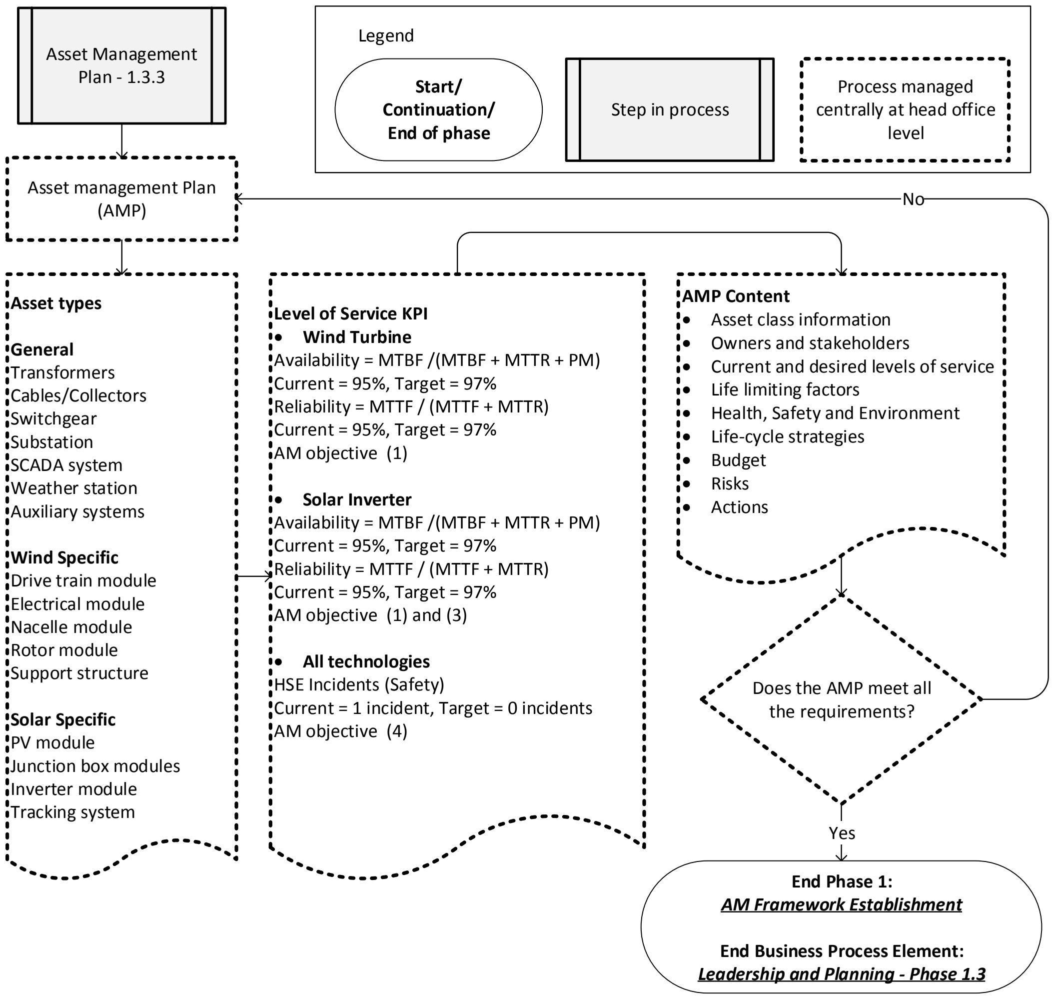


Figure C.7: Asset management plan – 1.3.3

C.2 Asset Care Plan Development - Phase 2

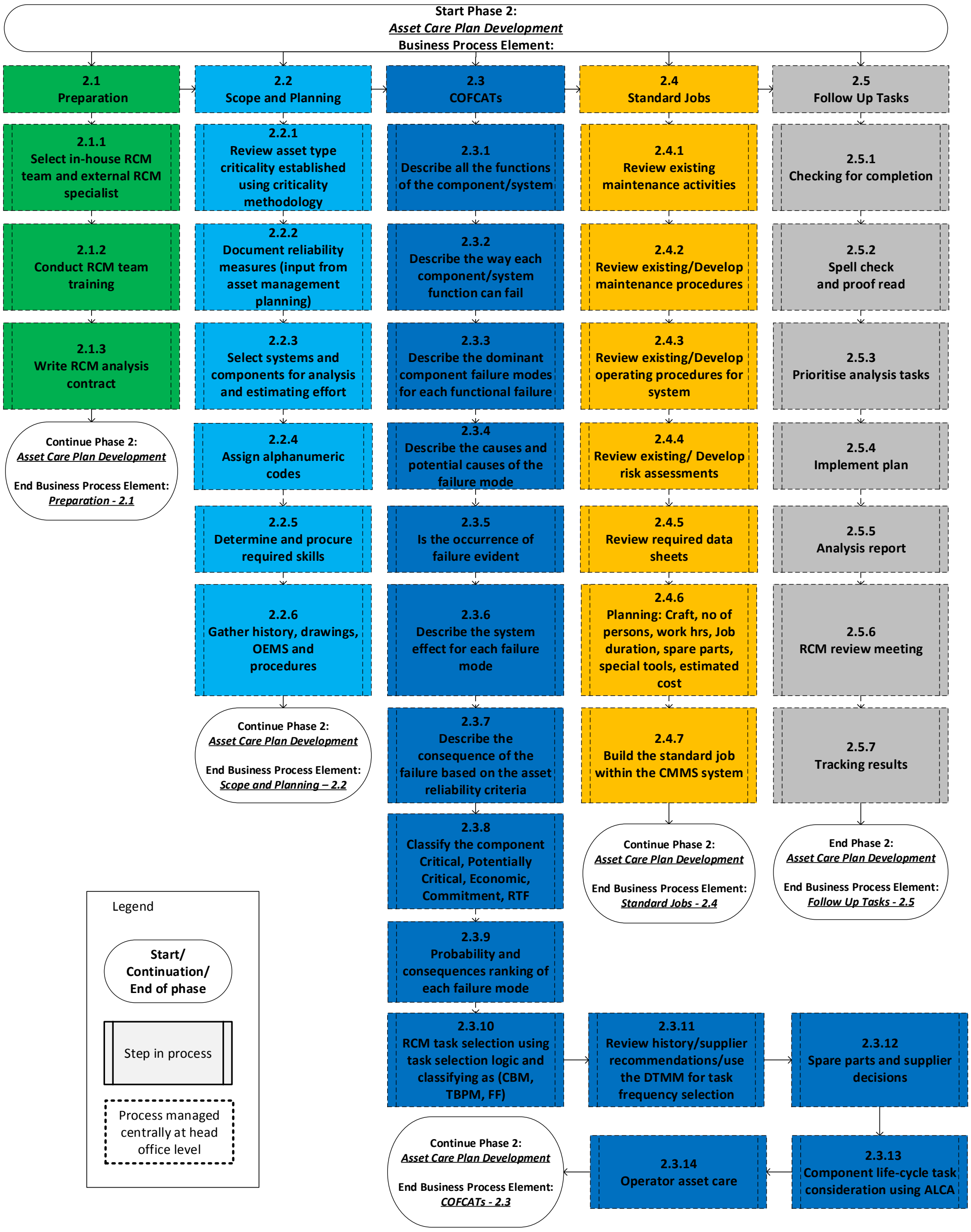


Figure C.8: Asset care plan development process (including COFCATs) - 2.3)

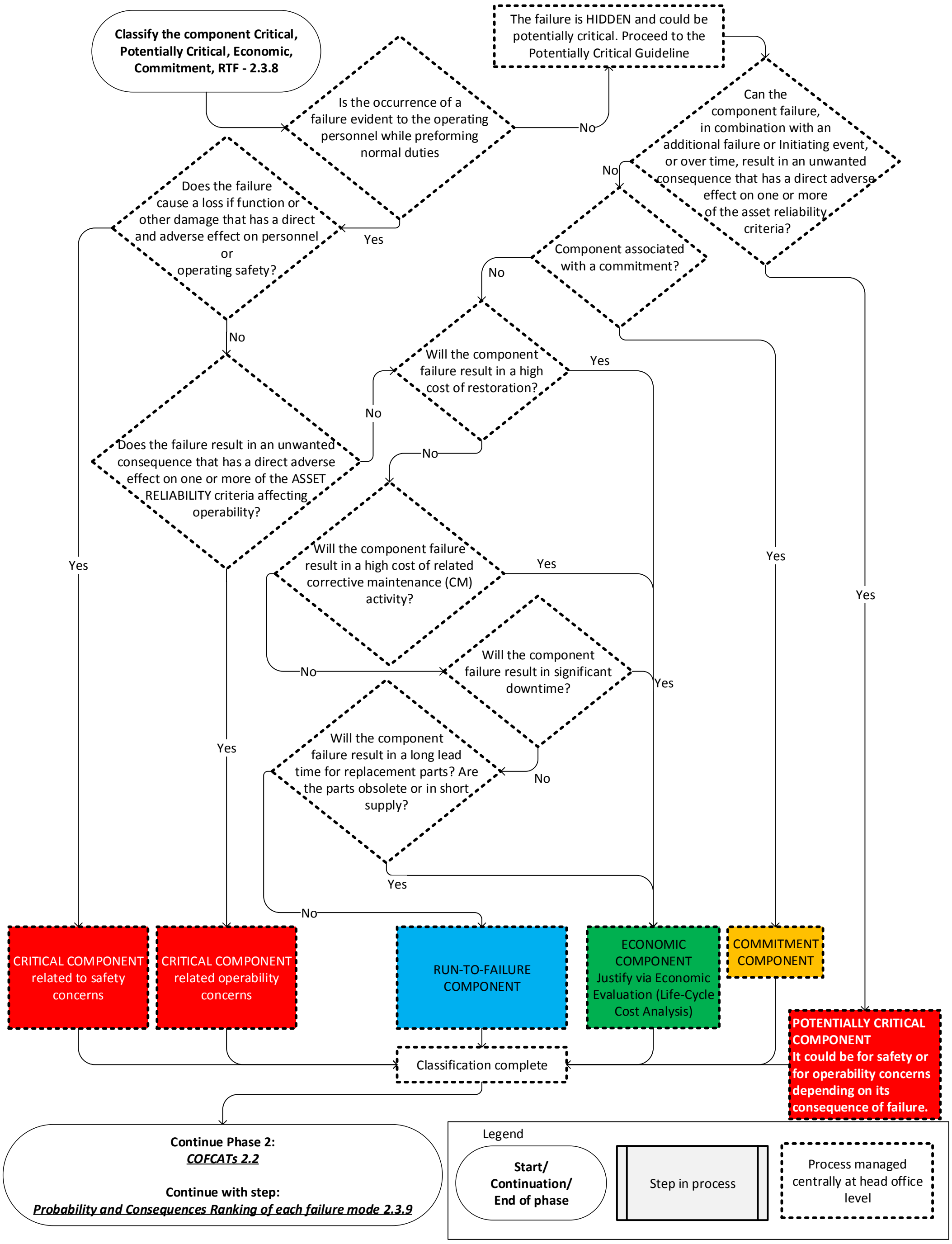


Figure C.9: Identification of component as critical, potentially critical, commitment, economic or run-to-failure – 2.3.8

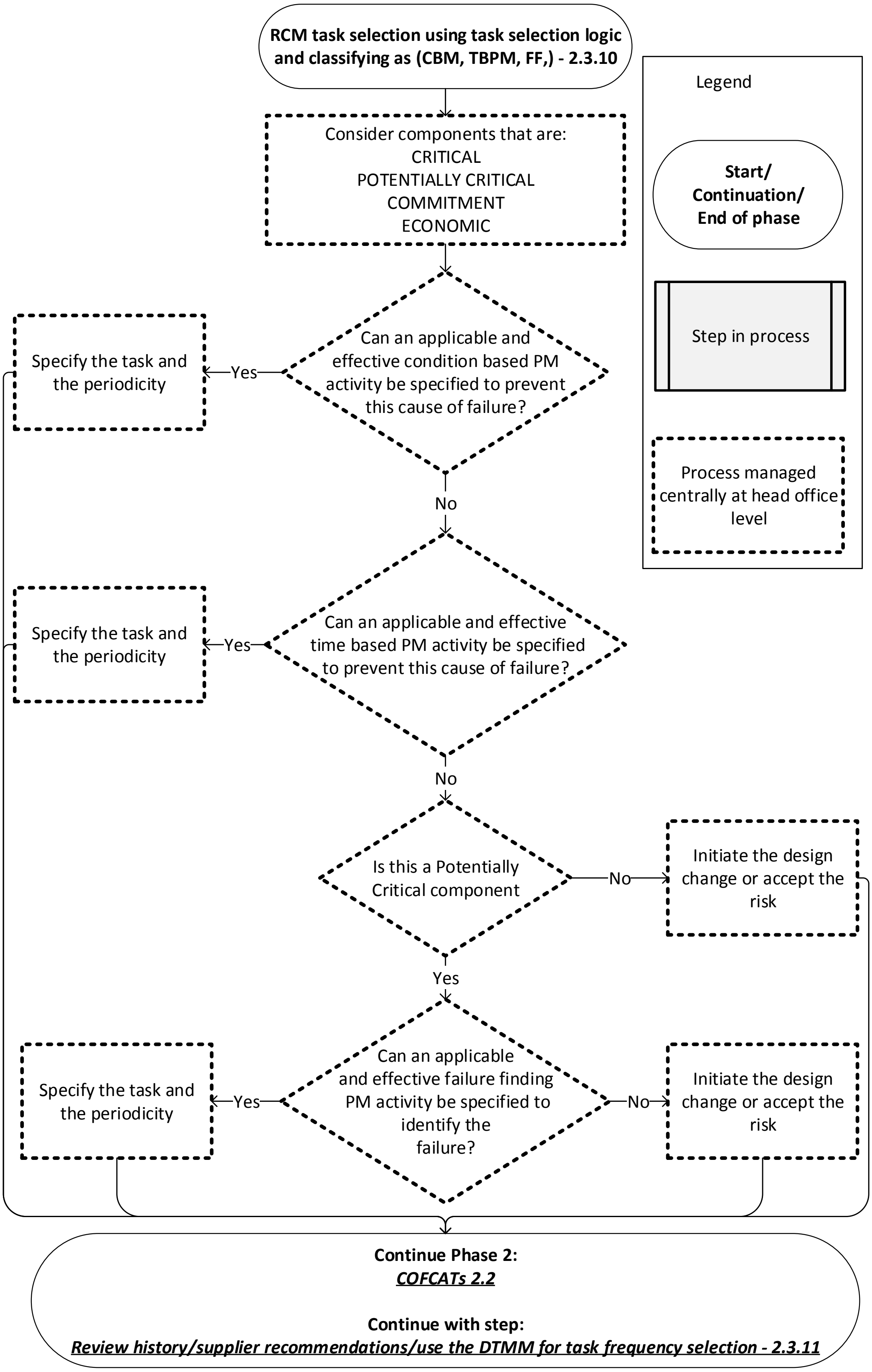


Figure C.10: PM task selection logic tree – 2.3.10

C.3 Work Planning and Control - Phase 3

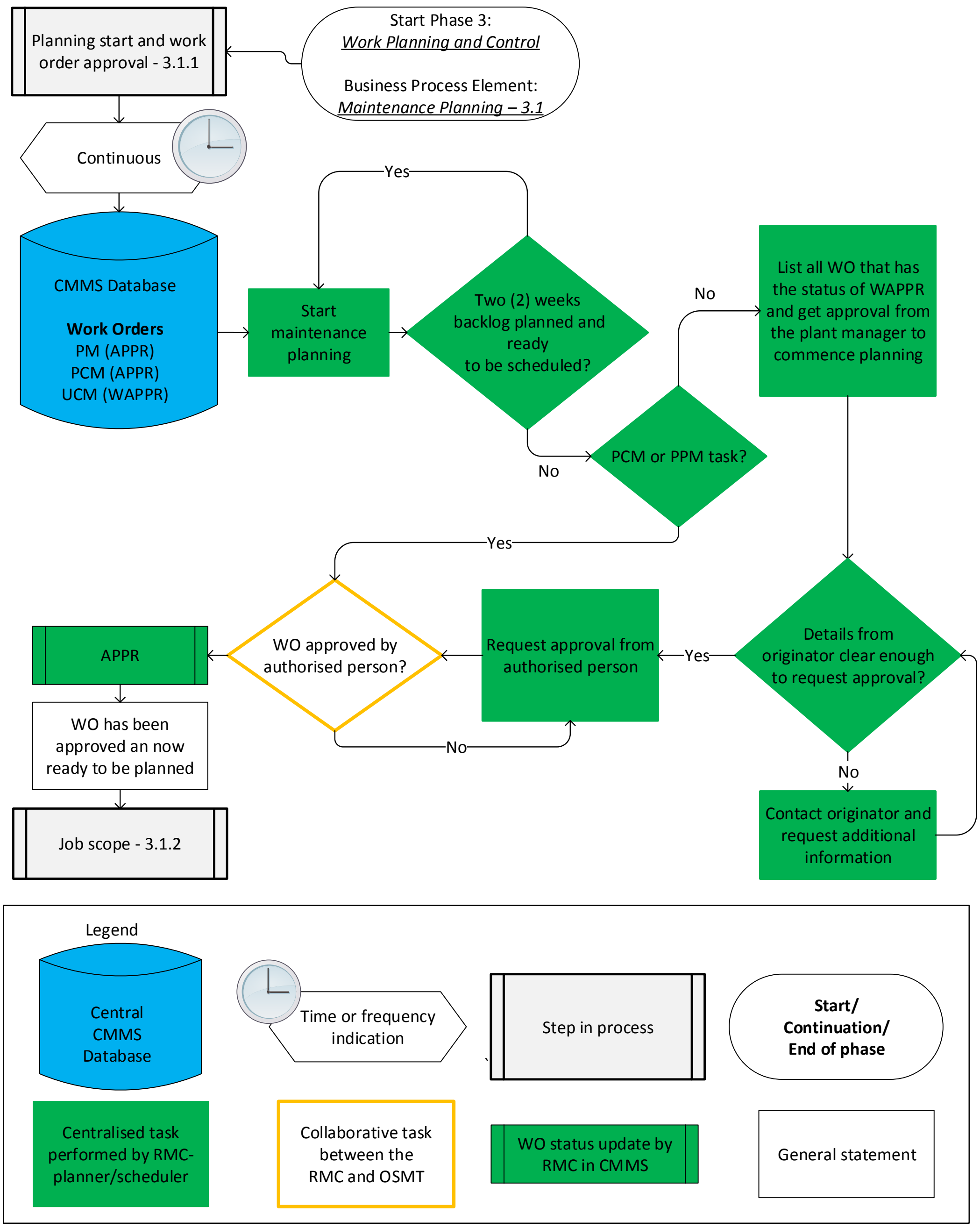


Figure C.11: Planning start and work order approval – 3.1.1

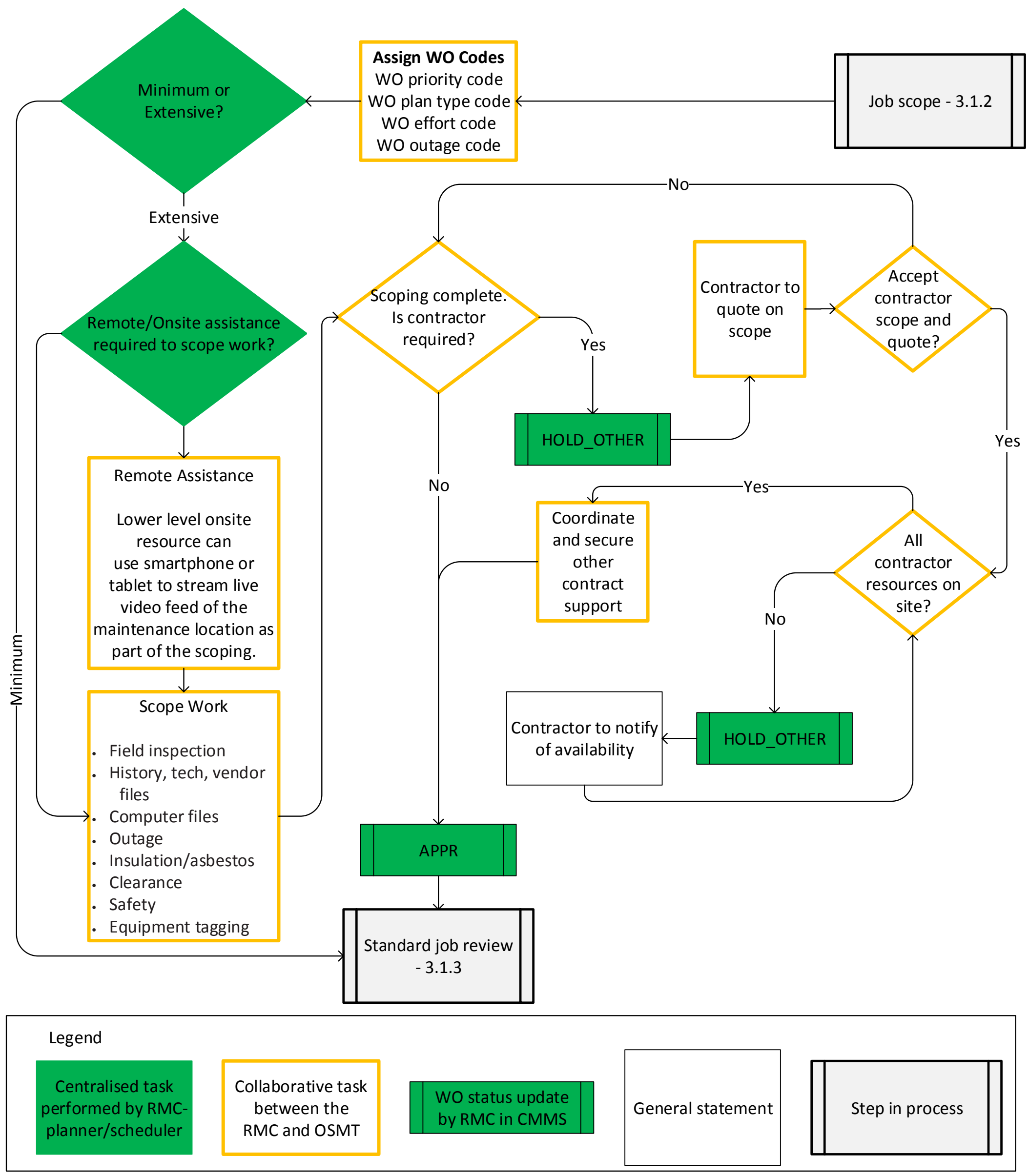


Figure C.12: Job scope – 3.1.2

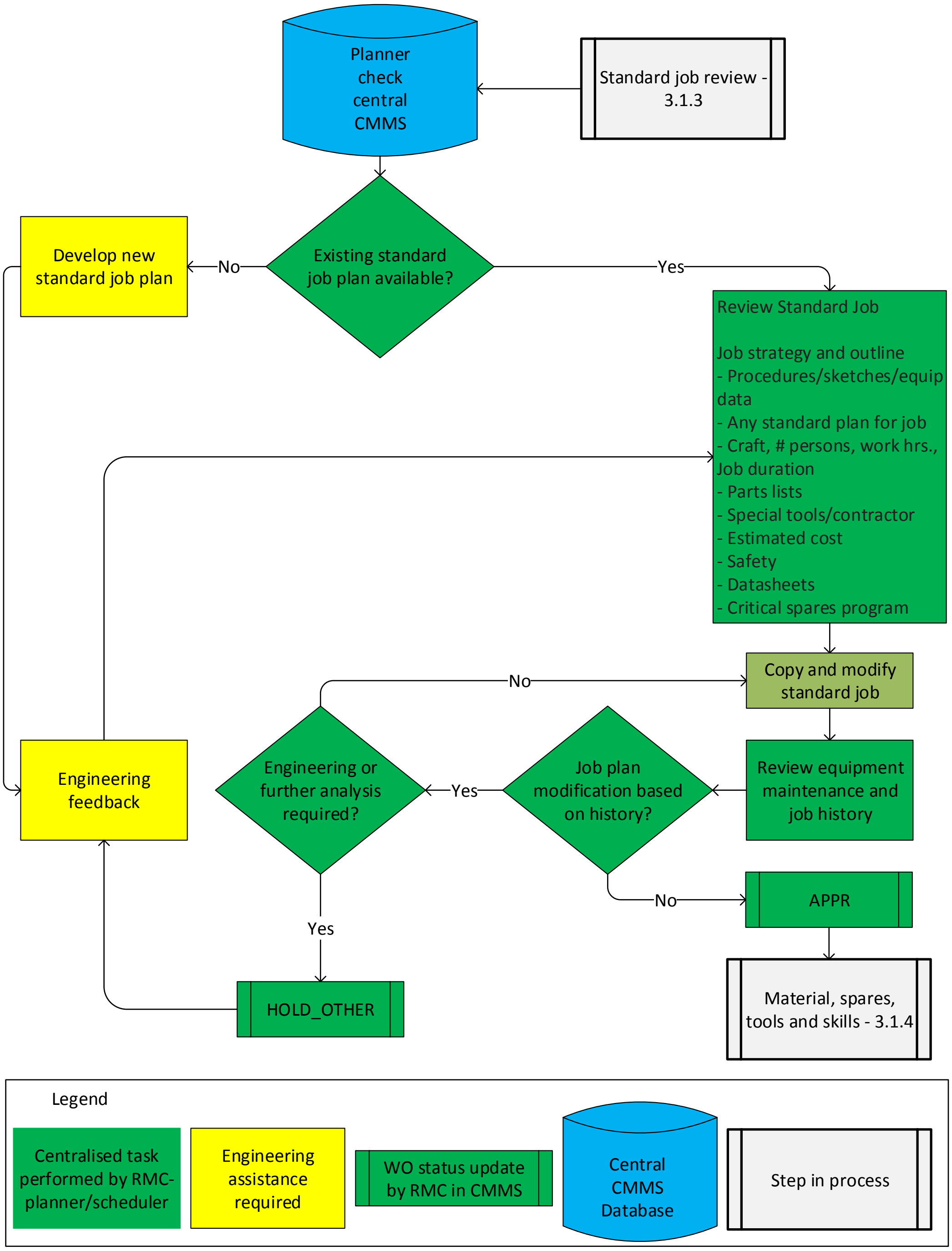


Figure C.13: Standard job review – 3.1.3

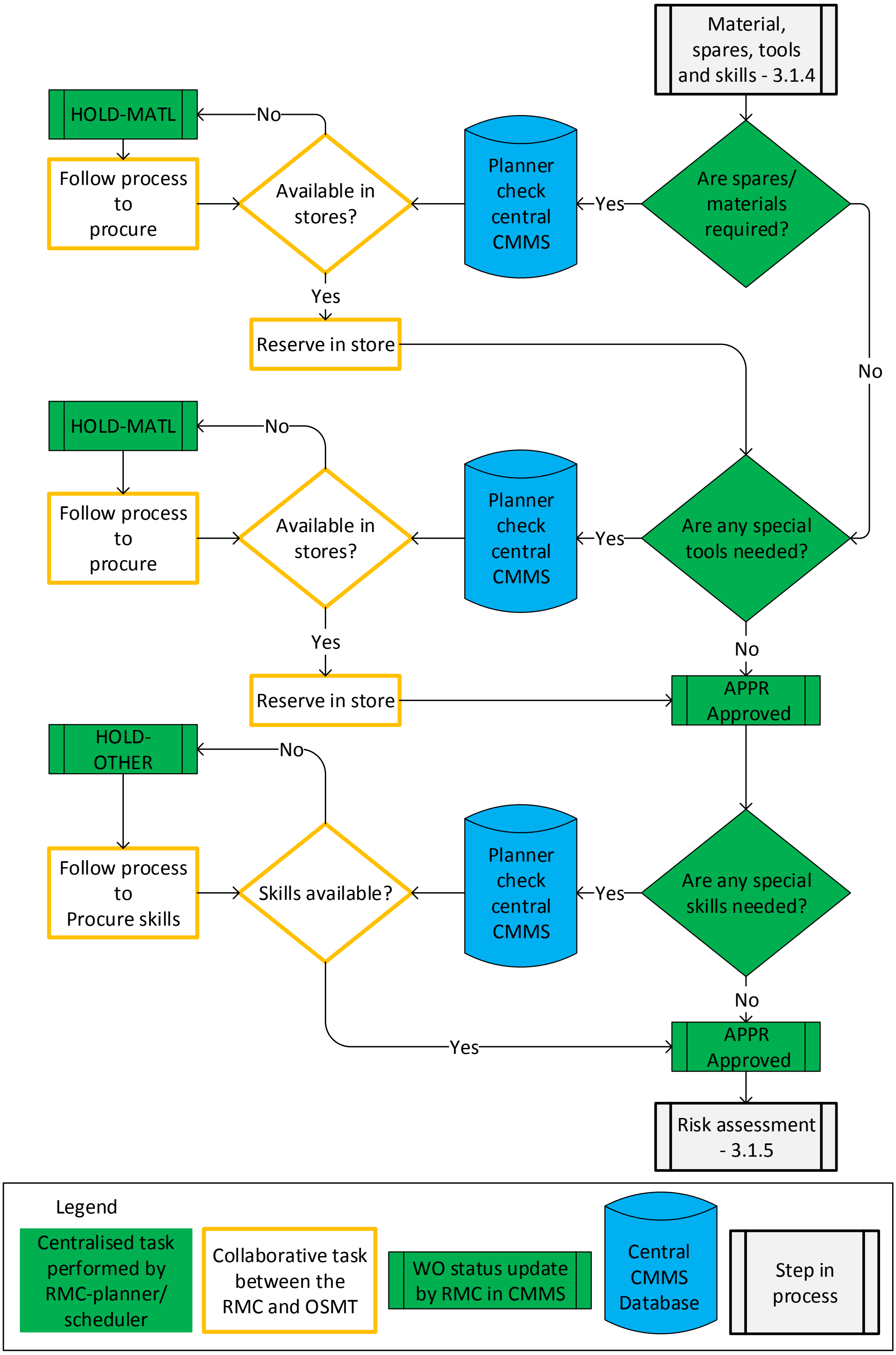


Figure C.14: Material, spares, tools and skills – 3.1.4

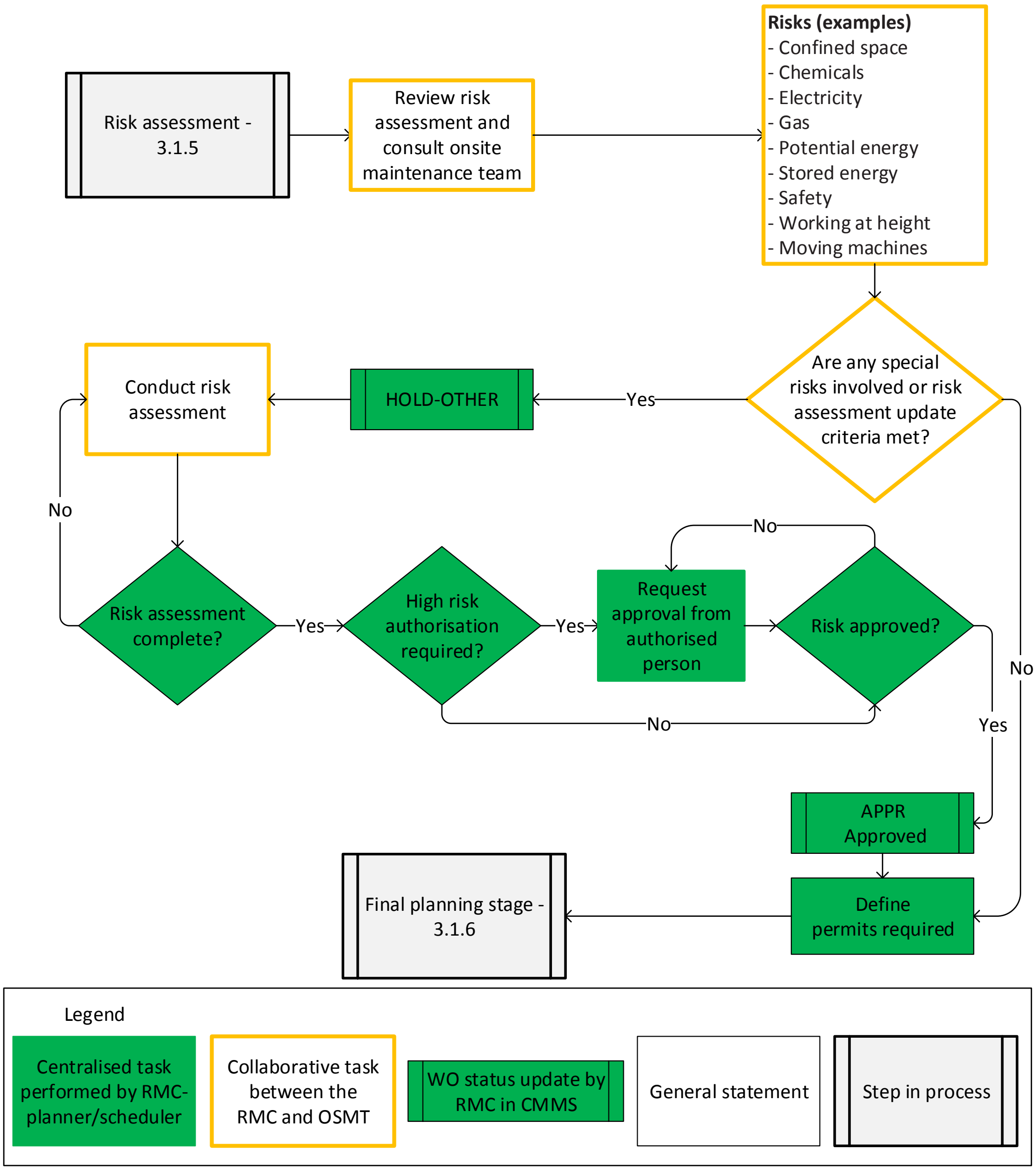


Figure C.15: Risk assessment – 3.1.5

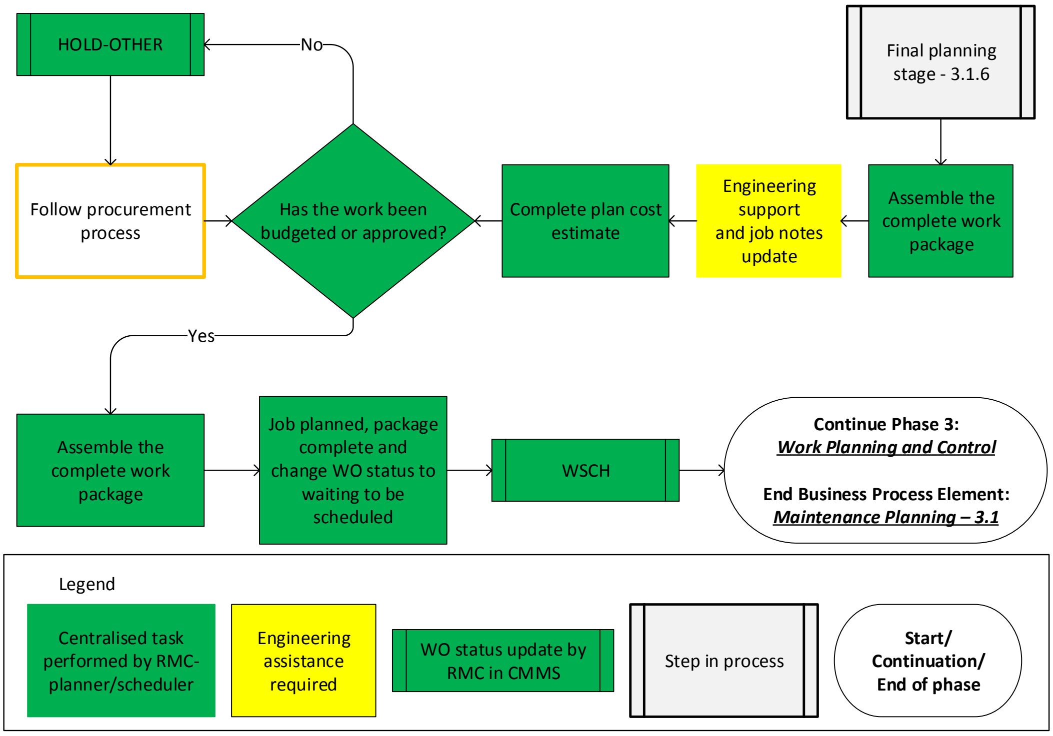


Figure C.16: Final planning stage – 3.1.6

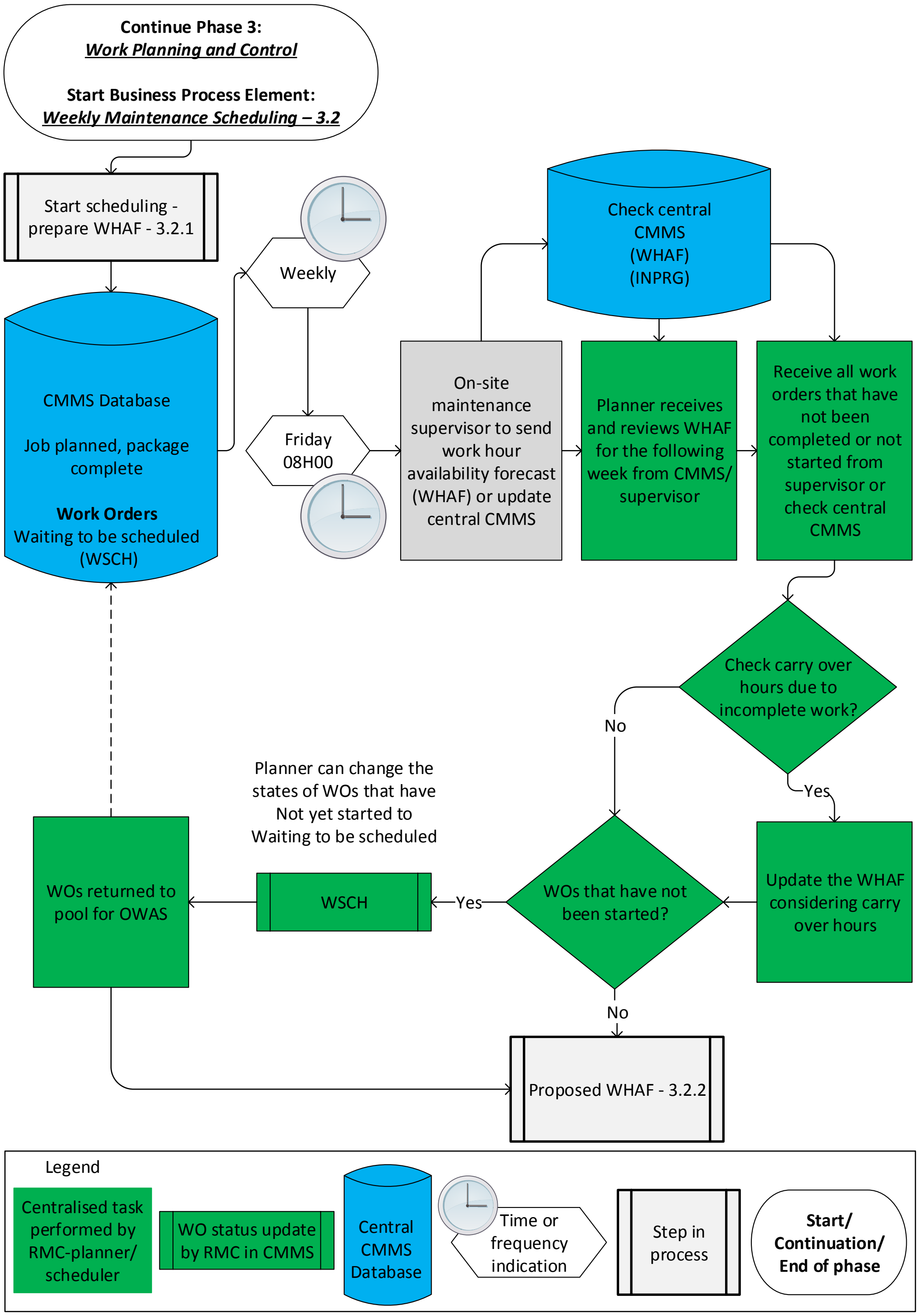


Figure C.17: Start scheduling - prepare WHAF – 3.2.1

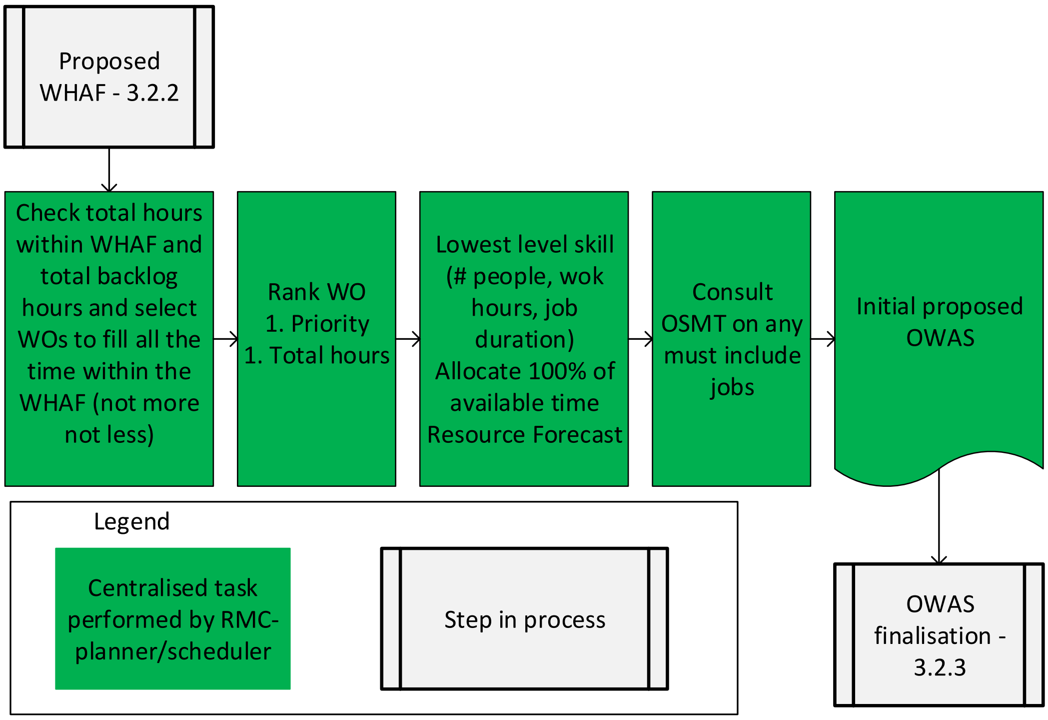


Figure C.18: Proposed WHAF – 3.2.2

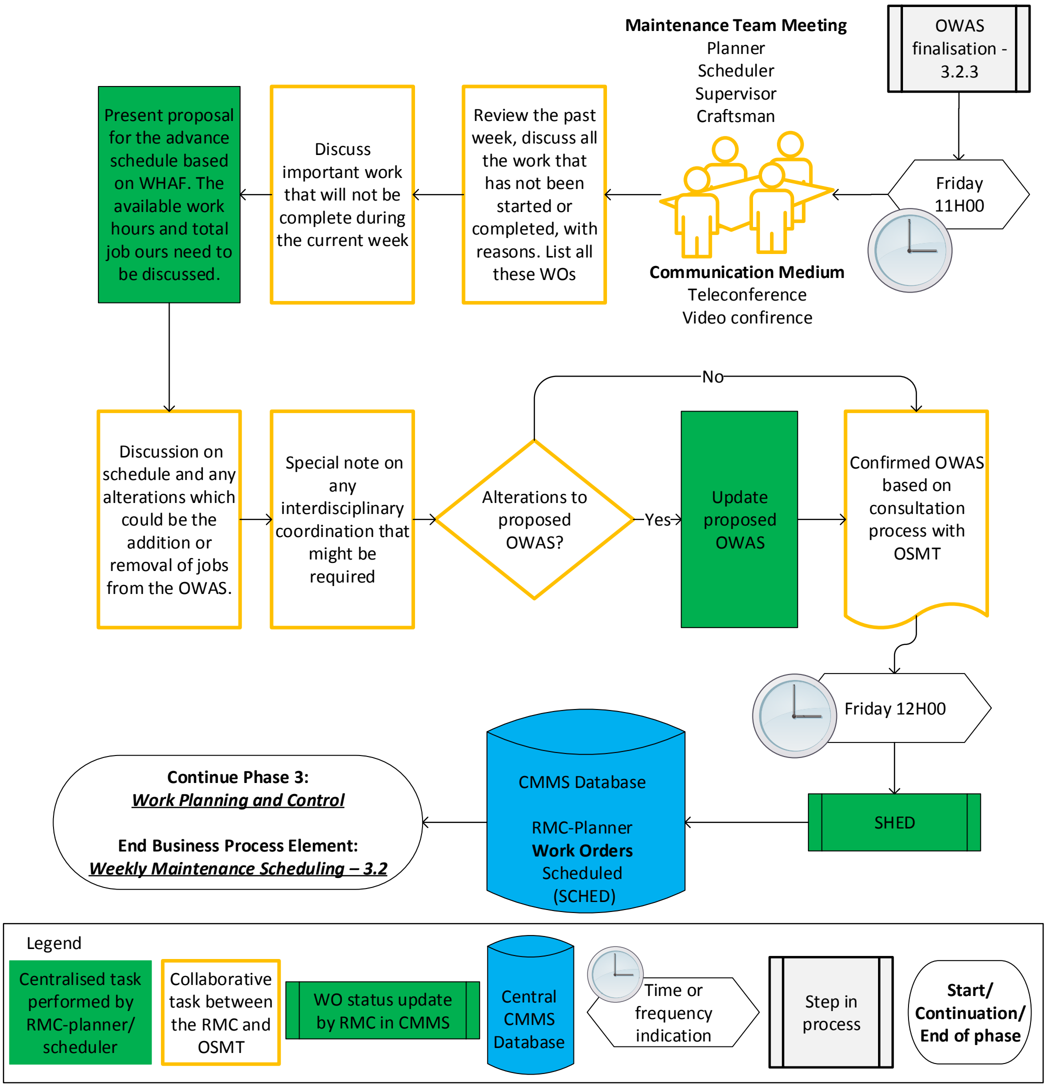


Figure C.19: OWAS finalisation – 3.2.3

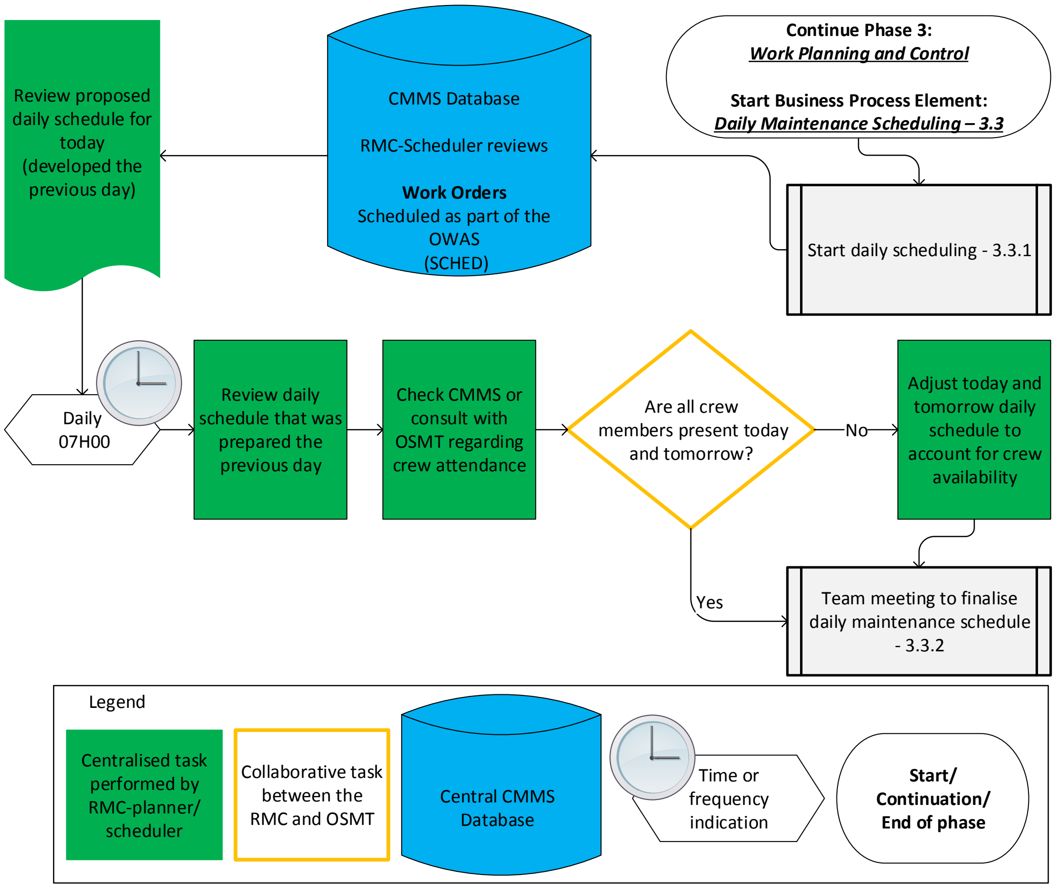


Figure C.20: Start daily scheduling – 3.3.1

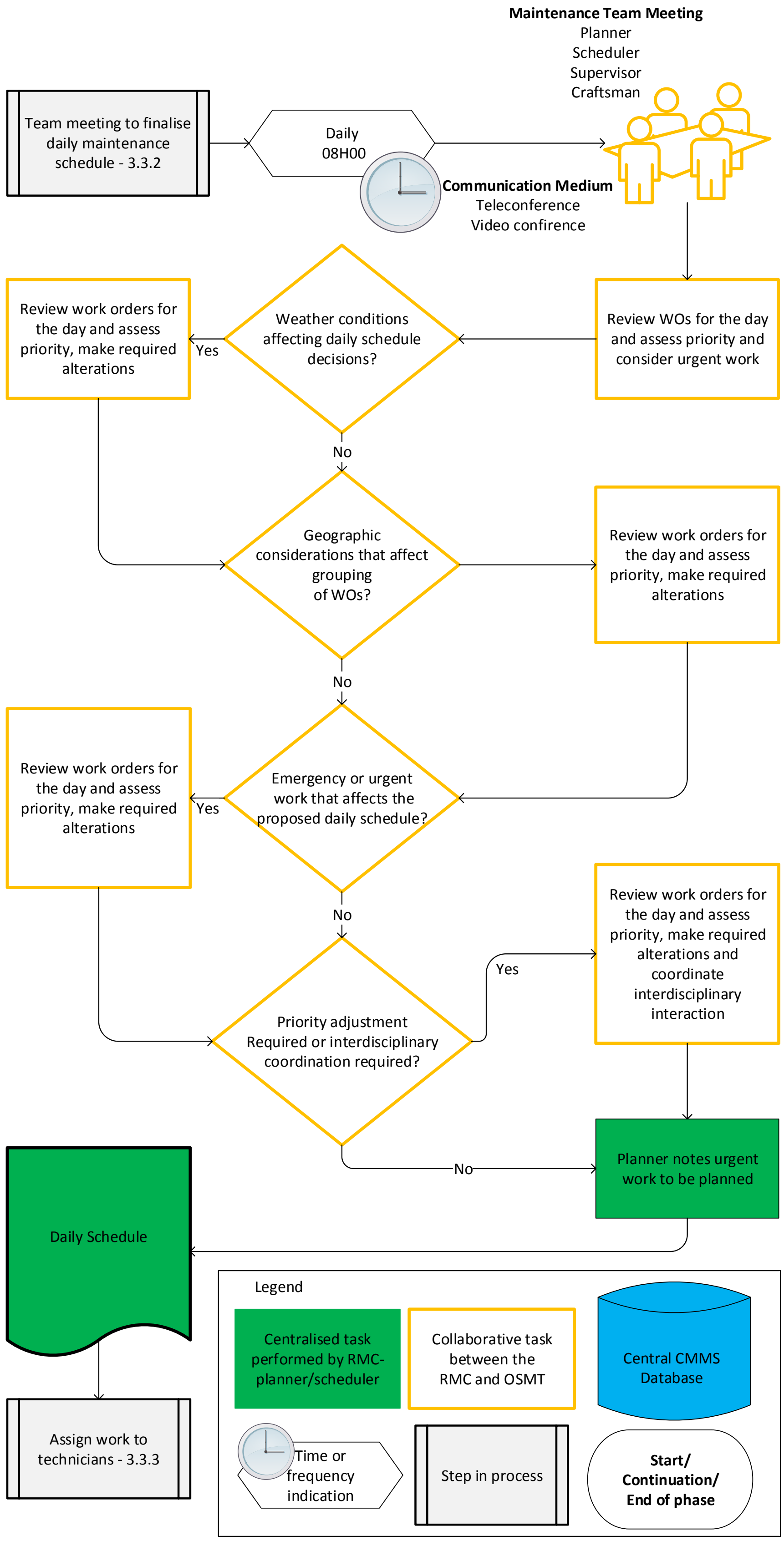


Figure C.21: Team meeting to finalise daily maintenance schedule - 3.3.2

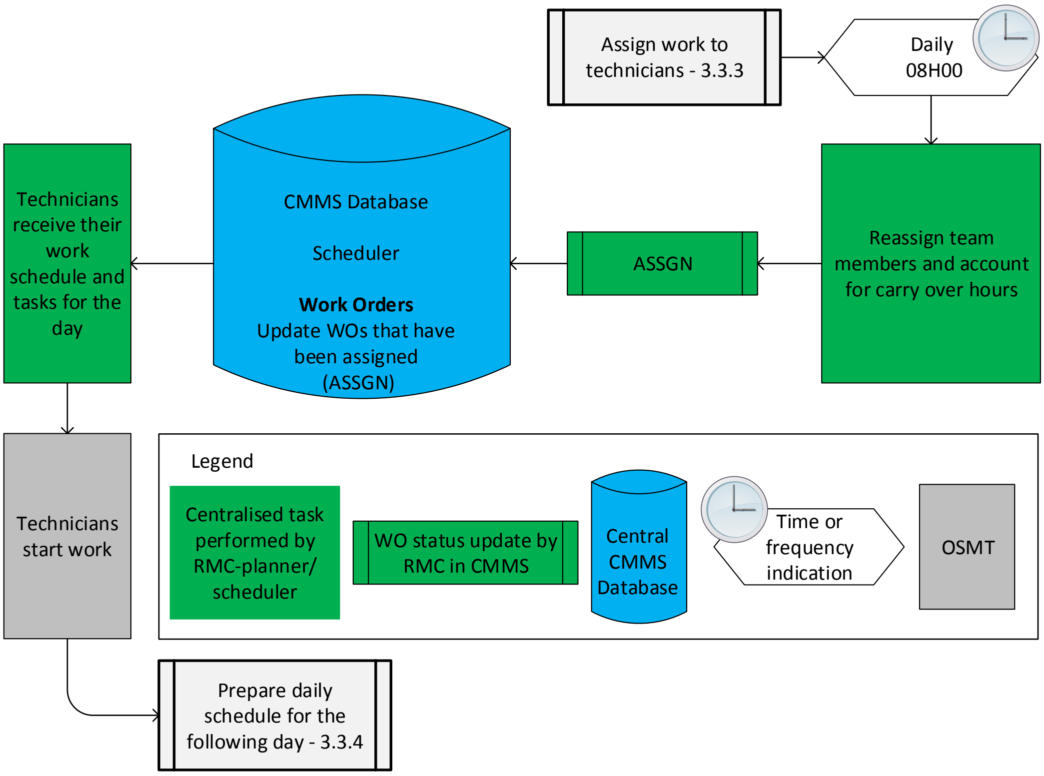


Figure C.22: Assign work to technicians – 3.3.3

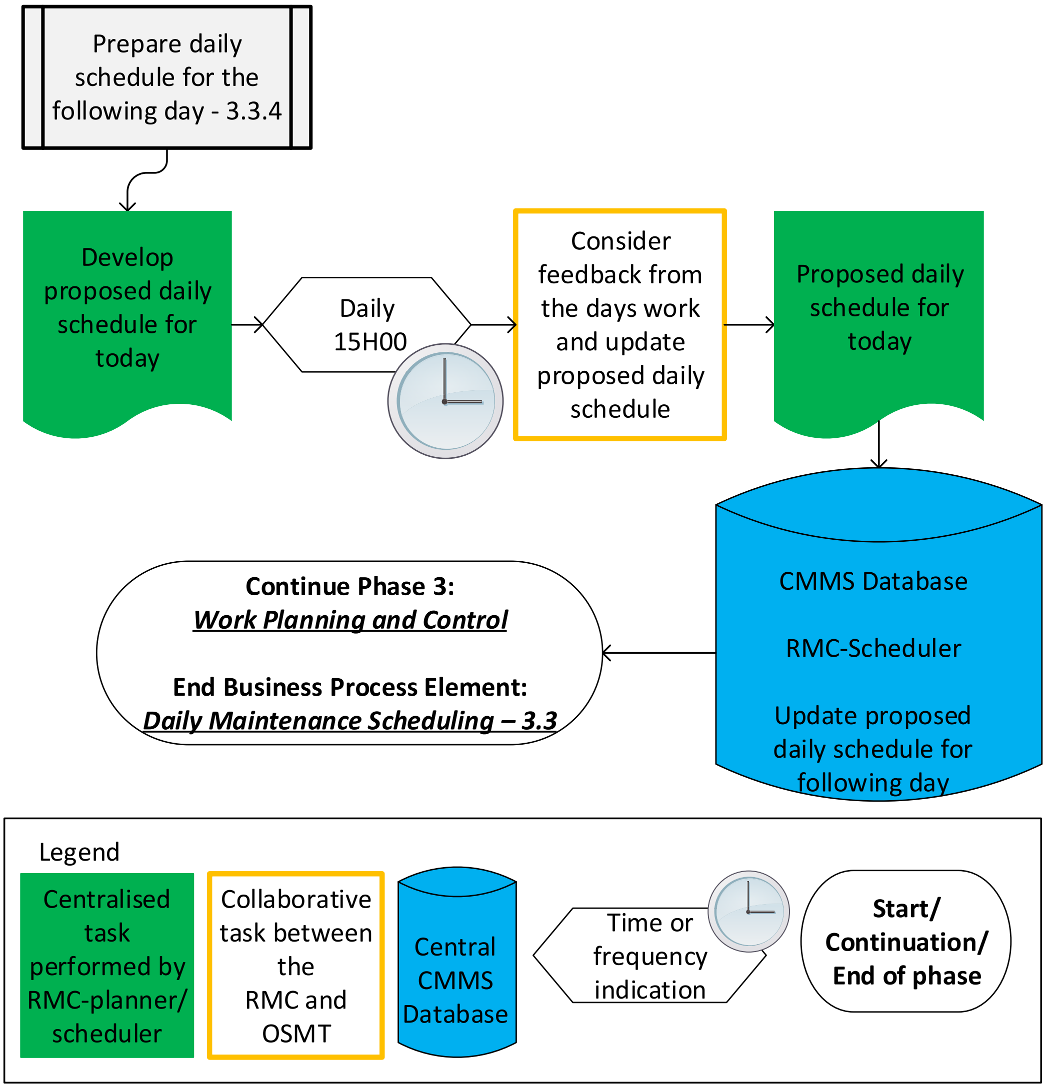


Figure C.23: Prepare daily schedule for the following day – 3.3.4

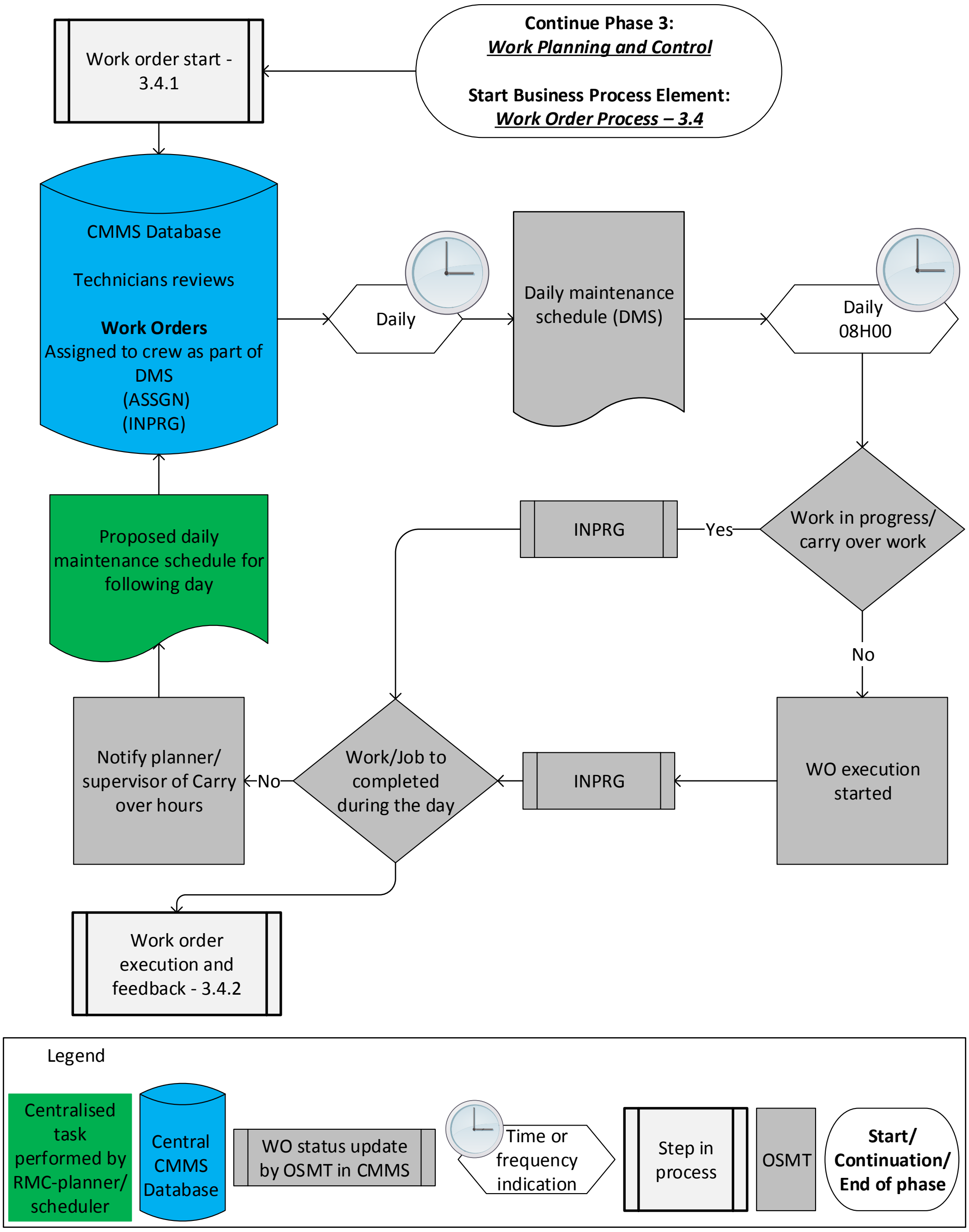


Figure C.24: Work order start – 3.4.1

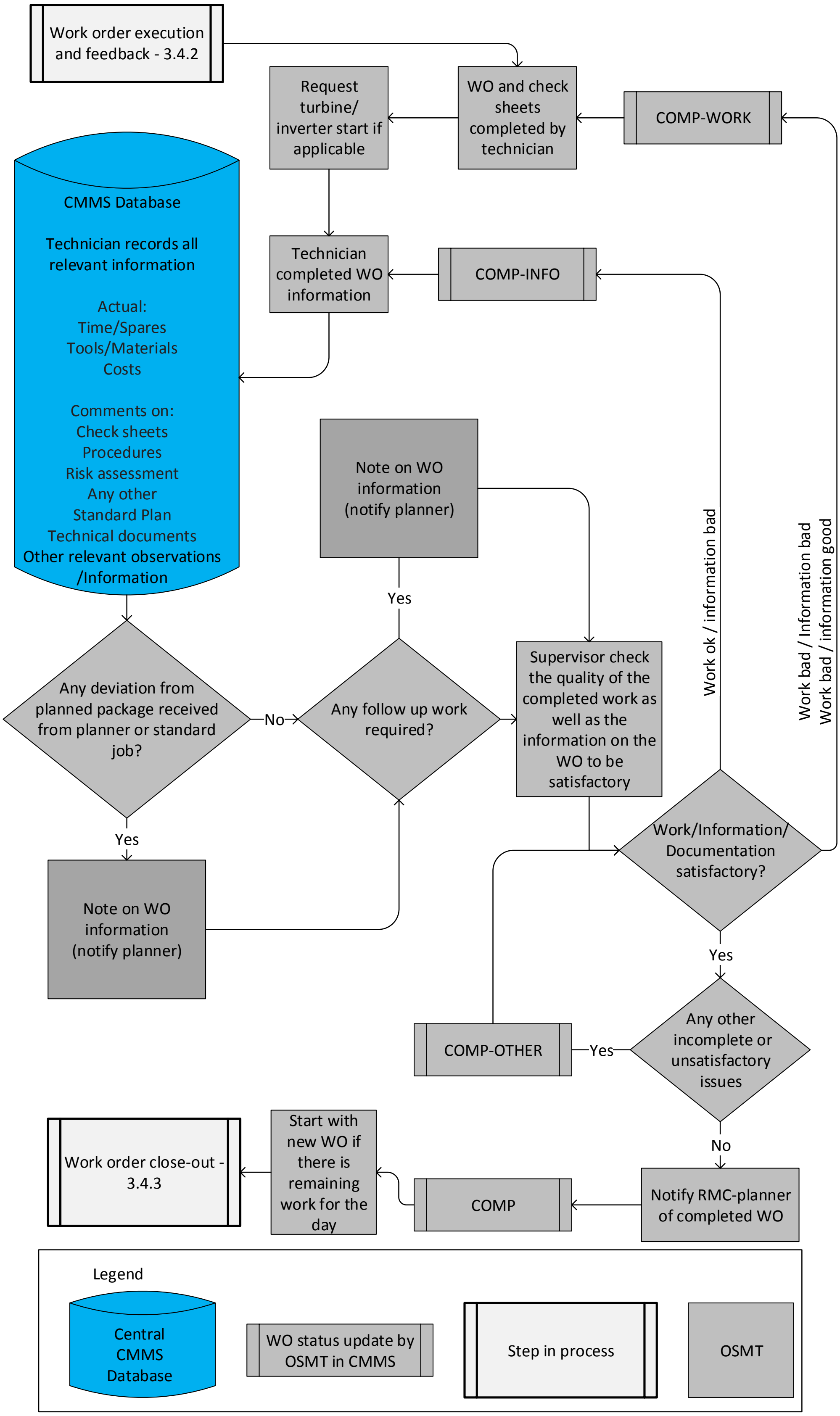


Figure C.25: Work order execution and feedback – 3.4.2

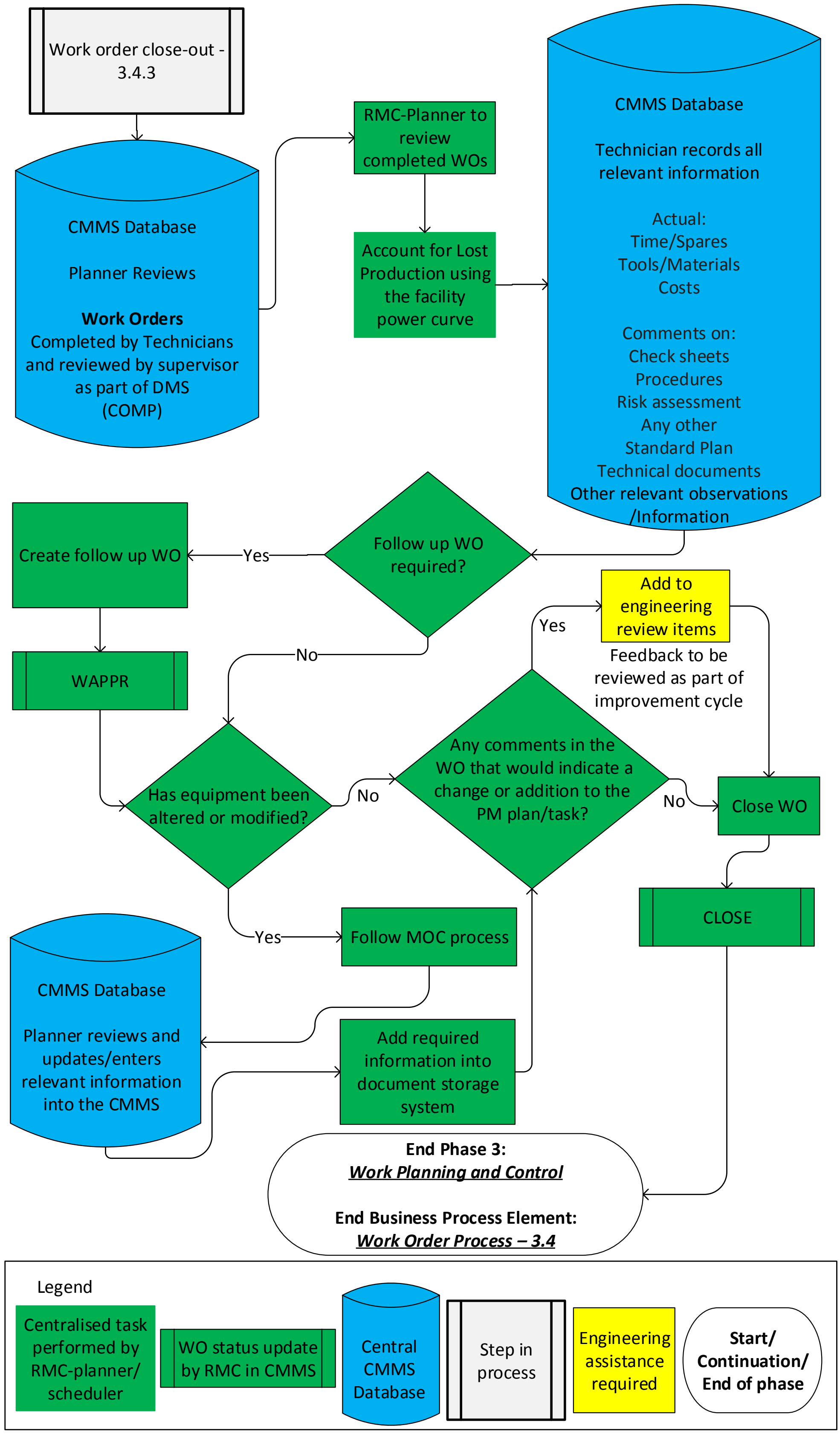


Figure C.26: Work order close-out – 3.4.3

C.4 Competency Management and Continuous Improvement - Phase 4

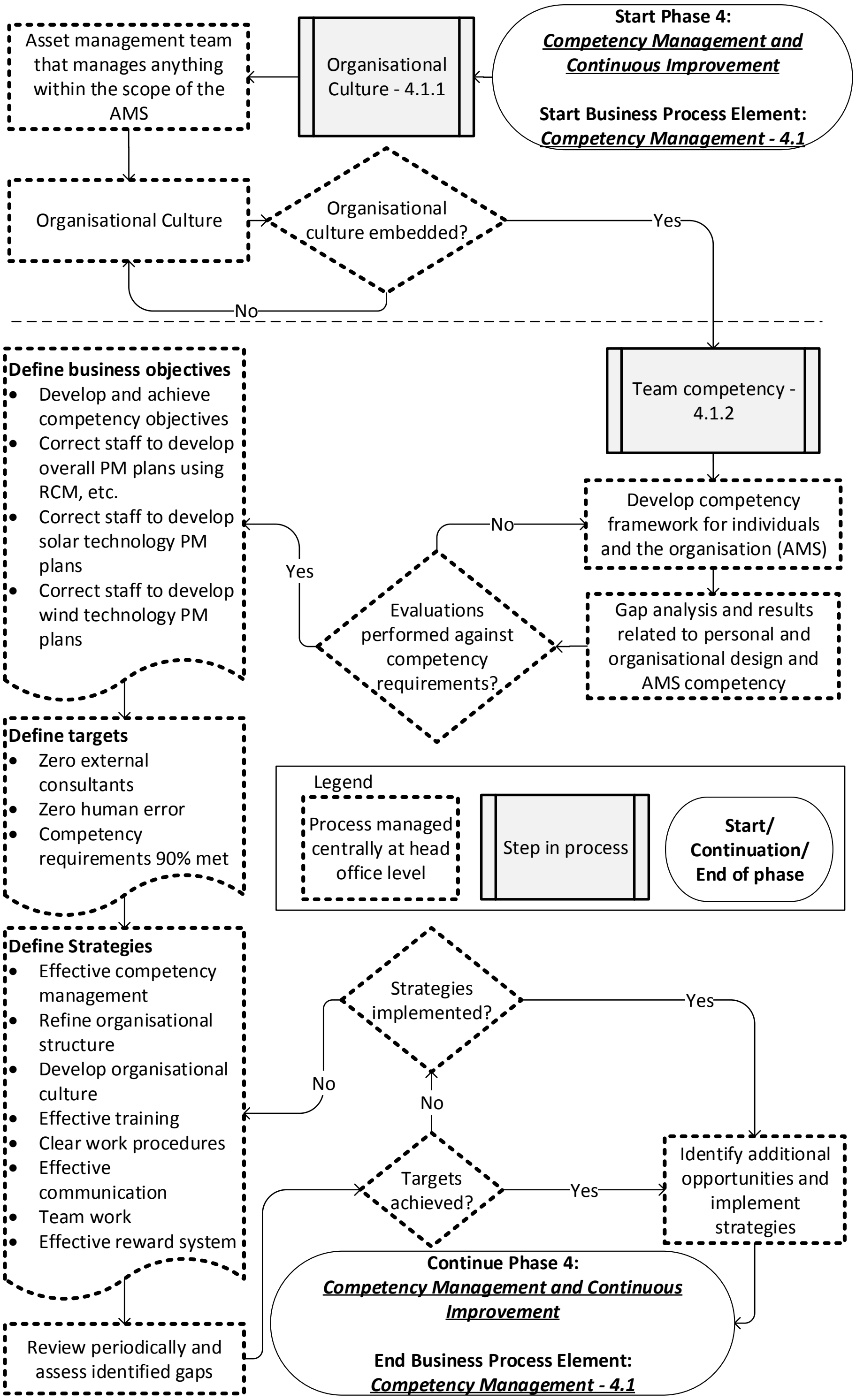


Figure C.27: Competency framework – 4.1.1

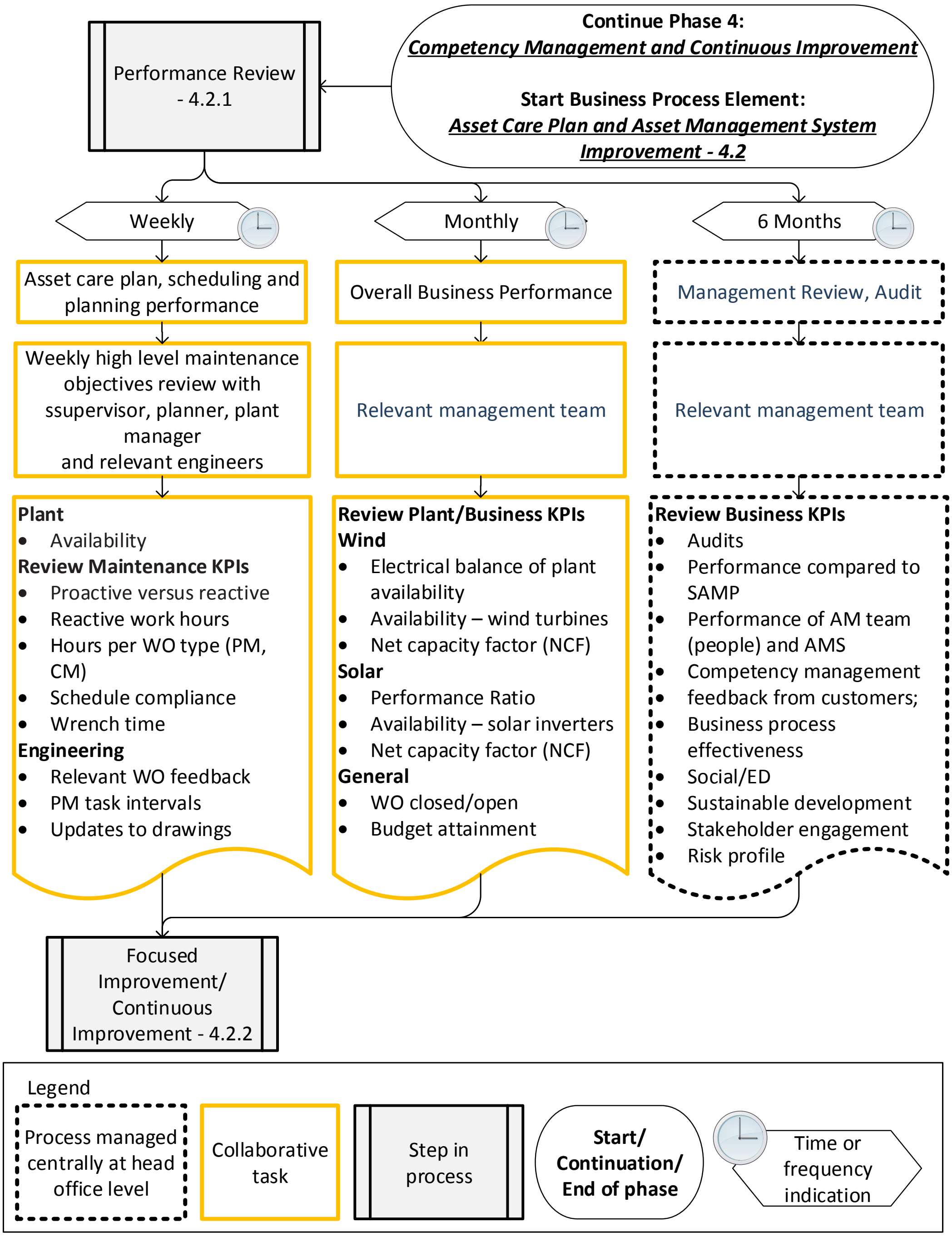


Figure C.28: Performance Review – 4.2.1

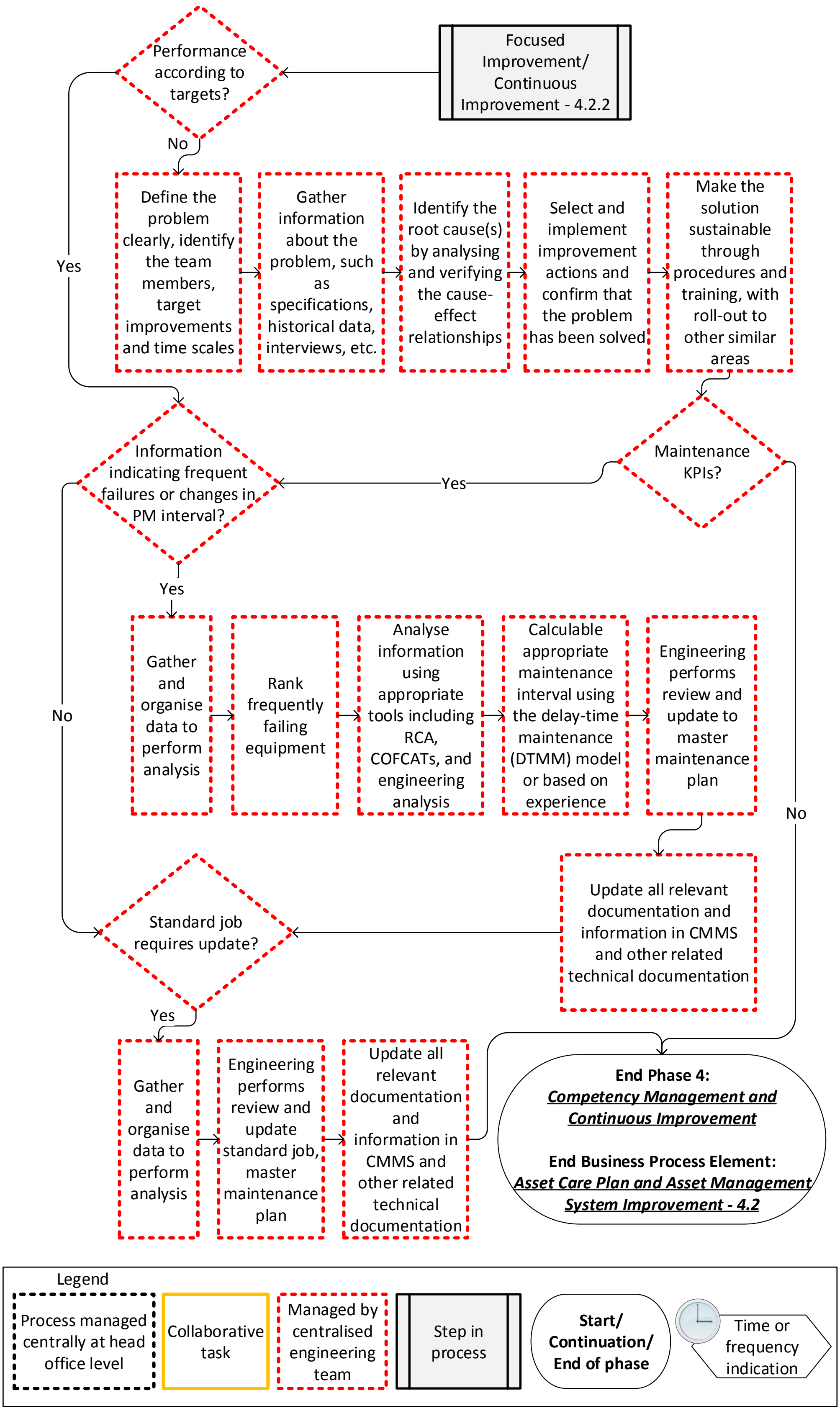


Figure C.29: Focused improvement/continuous improvement – 4.2.2

Appendix D

Craft Designations Within the Wind and Solar PV Renewable Energy Sector

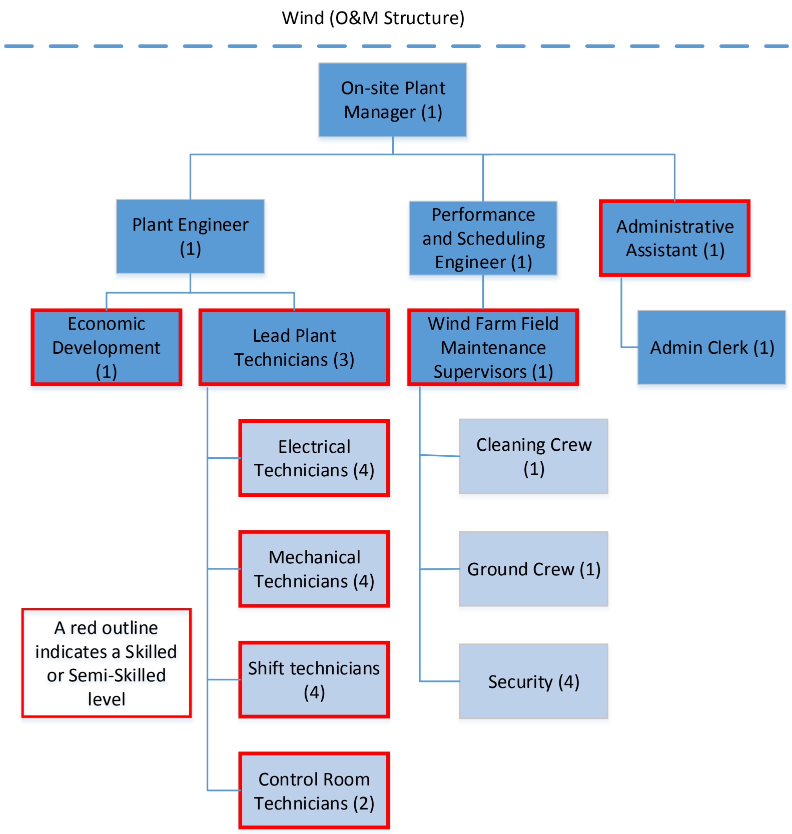


Figure D.1: Wind plant O&M structure (Adopted from Stands *et al.* (2014, 103))

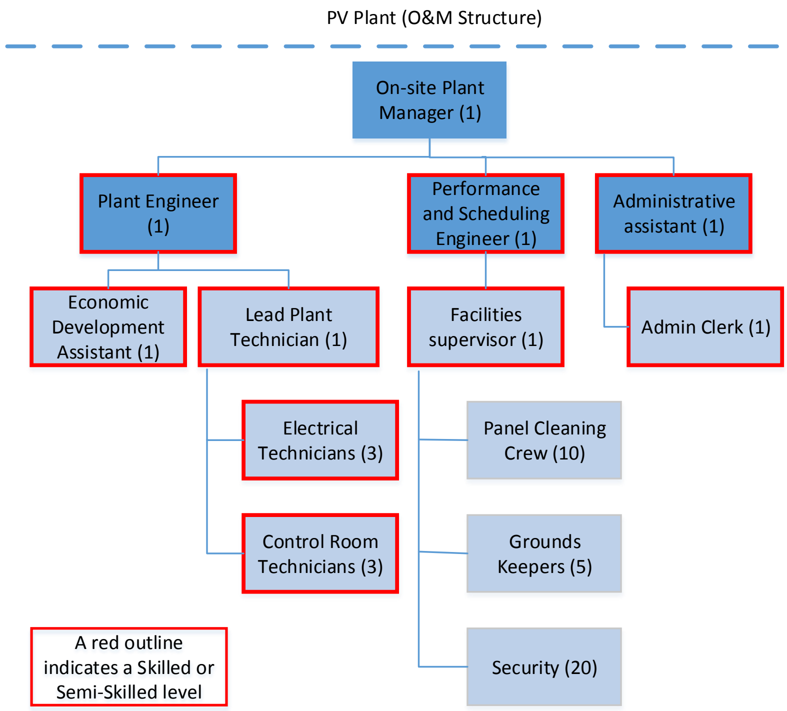


Figure D.2: PV Plant O&M Structure (Adopted from Stands *et al.* (2014, 105))

Appendix E

Priority Codes

The priority of maintenance work will often be referenced throughout this study and has a significant impact on the scheduling process. A priority system needs to be established as a means of identifying and scheduling the most critical work. A priority system should also be confirmed with the operations team and updated on a regular basis.

New WOs are assessed by planners in order to code them according to the plant coding system. The coding system designates the appropriate priority as well as the type of work (reactive or proactive) or whether the work is minimal or extensive. Codes are later used for analysis of maintenance work and as an example all the codes that indicate work requiring an outage can be gathered (Palmer, 2006, 602).

In the case where a CMMS system is being used the first digit of the priority code carries equal weight but assist in more detailed categorisation during analysis (Palmer, 2006, 603).

- S - Safety
- H - Heat rate
- E - Environmental or regulatory
- R - Reliability or availability
- G - General

The second digit indicates the priority preference (Palmer, 2006, 603):

- 0 - Emergency conditions that relates to the complete loss of production capacity or poses an HSE risk.
- 1 - Urgent conditions that relate to significant or potential loss of production capacity or has a significant potential to violate an regulatory or HSE requirements.
- 2 - Serious conditions that could potentially damage critical plant equipment, has the potential to violate an regulatory or HSE requirements or

required as part of proactive maintenance.
- 3 - Non-critical maintenance on production equipment
- 4 - Non-critical maintenance on non-production equipment.

WOs with a priority of *1* should generally be handled as emergency work and can commence ahead of issuing a WO of priority *2* items. In the case of a well maintained plant WOs with a priority of *0* and *1* should not frequently be raised, while priority *2*, *3* and *4* WOs should dominate due to a high level of proactive maintenance work.

The WO can also be assigned a status code to indicate where in the WO process it is situated. Examples of WO status codes are (Palmer, 2006, 604):

- **WAPPR** - Waiting for approval. The plant manager still needs to approve the WO.
- **APPR** - Approved. The WO has been approved and waiting to be planned.
- **WSCH** - Waiting to be scheduled. The WO has been planned and is now waiting to be scheduled.
- **HOLD-MATL** - The WO cannot be started or continued due to material or tools not being available.
- **HOLD-OTHER** - The WO cannot be started or continued due to other reasons than material or tools.
- **PROJ** - Project. The work is with the project team and maintenance teams are not responsible.
- **SCHED** - Scheduled. The WO has been included in the one week advance schedule.
- **ASSGN** - Assigned. The WO has been assigned to a maintenance crew/person as part of the daily schedule or execution.
- **INPRG** - In progress. Work has been started.
- **COMP** - Completed but not closed. The WO has been executed but the completed WO and related documentation and information still need to be reviewed and analysed.
- **COMP-DWGS** - Completed but not closed, waiting on drawings to be updated.
- **COMP-OTHER** - Completed but not closed, waiting on other requirements to be met.
- **CLOSE** - Closed. The WO is closed and all the requirements have been met.
- **CAN** - Cancelled. This WO is not required as it is a duplicate, no longer required, or other plausible reasons.

The **Plan Type** is a broader category compared to the work type. The goal of the maintenance department is to focus on proactive work in order to reduce reactive work. Proactive work is generally not urgent and the planning team would prefer to plan these jobs as effectively as possible for the most efficient execution. However, the planning team needs to be able to recognise any emergency or reactive work in order to facilitate the speedy completion of the work (Palmer, 2006, 609).

Secondly the **Minimum and Extensive** coding can be used to indicate the required effort in planning the job. In the case of small jobs, a significant amount of time may not be needed for planning.

First digit – Reactive or Proactive (Palmer, 2006, 609):

- P - Proactive
- R - Reactive

Second digit – Minimum Maintenance or Extensive Maintenance (Palmer, 2006, 609):

- M - Minimum maintenance(work is less than 4 hours, no parts ordering required, work has no historical value)
- E - Extensive maintenance (all other work)

Outage code is important in order to identify work that can only be performed during an outage. An outage is when the entire plant has to be shut down and not just single piece of equipment. Work that requires an outage needs to be thoroughly planned. Examples of outage codes (Palmer, 2006, 610):

- 1. Forced short outage. Unit needs to be taken out of service in order to perform work.
- 2. Scheduled short outage. Unit needs to be take out of service to perform maintenance but can be scheduled and does not require a major outage.
- 3. Major outage. Work which can only be done during a major outage.
- 4. Not in use.
- 5. Forced derating. The maximum output of the unit needs to be reduced due to component/system failure.
- 6. Scheduled derating. The maximum output of the unit needs to be reduced due to component/system failure. However the derating does not have to be applied immediately and work does not have to be done during a major outage.
- 7. Potential outage, failure of equipment that has redundancy.

Appendix F

Probability and Consequence Ranking

Probability of Failure

- High - The occurrence of the failure mode is at least once or more times within a three month period.
- Medium - Failure mode has occurred in the past.
- Low - Failure mode has not occurred to date.

Consequence of Failure

High:

- The employee health, safety or the environment is affected by the failure mode.
- Equipment production output is affected by the failure mode for more than 4 hours.
- Failure mode affects grid code compliance.

Medium:

- The employee health, safety or the environment is NOT affected by the failure mode.
- Equipment production output is affected by the failure mode for less than 4 hours.
- Failure mode potentially affects grid code compliance.
- The total cost of the failure mode results in a loss of more than ZAR 500 000.

Low:

- The employee health, safety or the environment is NOT affected by the failure mode.

- Equipment production output is affected by the failure mode for less than 1 hour.
- Failure mode does not affect grid code compliance.
- The total cost of the failure mode results in a loss of less than ZAR 500 000.

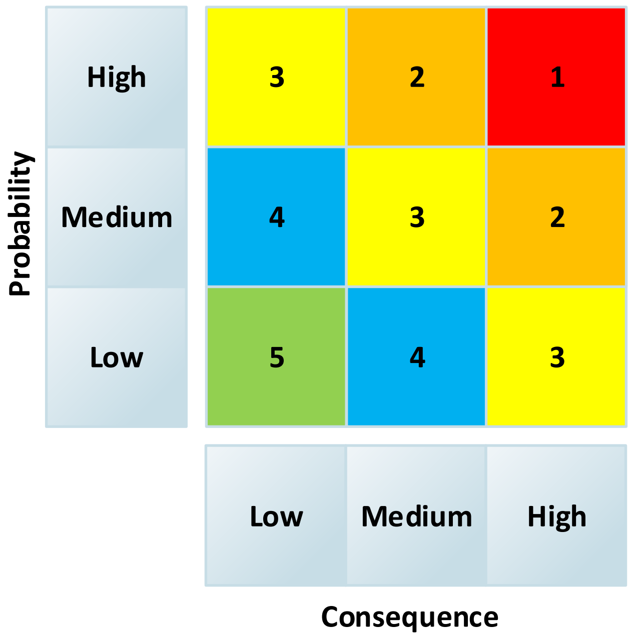


Figure F.1: Probability and Consequence Matrix (Adopted from (Plucknette, 2009, 47))

Appendix G

Validation - Questionnaire and Responses

Development of an ISO 55000 Compliant Central Management Framework for Asset Care Plans within a Multi-Technology Portfolio of Renewable Energy Power Plants in the South African Energy Sector

Compton Saunders August 2016

G.1 Introduction

Background

- Pr.Eng (Electrical and Electronic), Engineering Council of South Africa
- B.Eng (Electrical and Electronic), University of Stellenbosch
- Post Graduate Diploma in Renewable Energy, University of Stellenbosch
- M.Eng (Engineering Management - Candidate), University of Stellenbosch [2nd year]
- Member of the Asset Care Research Group of the University of Stellenbosch

G.2 Important Considerations and Information

- This interview will be handled confidentially; the participants will not be identifiable in any way.

- Participation in this interview is voluntary. Participants are therefore able to withdraw at any time and are not required to answer any questions posed.

Supervisors/coordinators for this study are:

- Dr. Wyhan Jooste (University of Stellenbosch)
- Email address: wyhan@sun.ac.za

Purpose of Interviews: Validation of Master's thesis research.

G.3 Face Validation Questionnaire and Feedback

Literature and practical experience presented key factors within the SA RE sector which needed to be considered such as the requirement to use more modern maintenance philosophies, the dearth of skills (competency), continuous improvement requirements of the ACPs and competency levels and the complexity of management and ownership structures within the SA RE sector. The problem is that there is no framework and supporting business processes for managing ACPs, continuous improvement and competency within a multi-technology REPP asset portfolio that is aligned with requirements of an AM standard such as the ISO 55000 series of standards and identifies organisational functions that can be centralised and those which need to remain decentralised.

The problem will be addressed by identifying potential maintenance philosophies and business processes that can be used to manage ACPs, within an organisation and centrally administered while remaining aligned within a larger AM framework. The management of ACPs will refer to the CMF and business processes that relate to the development of maintenance plans, planning scheduling, WO execution and closure or developed tasks, with consideration for continuous improvement of ACPs and associated competency requirements.

Objectives of face validation:

- Develop consistency between the view held by the researcher and that of a potential user regarding the problem.
- Establish whether problem that was formulated encapsulate the entire problem and is structured sufficiently to derive a credible solution.
- Function as a mechanism whereby feedback could be used to refine, revise and reformulate the prototype.

Objectives of user validation:

- To obtain a statement of the applicability of the framework and business processes by possible users.
- To assess the impact of the framework and business processes assumptions, simplifications, methods, and generic structure from independent users.

G.3.1 Asset Management Framework - Phase 1

- **[PH1-Q01] In your opinion, does phase 1 of the CMF cover the core strategic aspects required by an AM organisation?**
  - **[P1]** *"Yes I think it does. From my experience in my previous role as a wind farm manager and in my current role managing solar PV farms it covers the core aspects."*
  - **[P2]** *"Yes, according to our experience as AM practitioners and what we apply, I think it covers them all."*
  - **[P3]** *"Yes, I AM happy with what I have seen up to this point."*
  - **[P4]** *"Yes I do, however I think the thing that is missing is the feedback loop to business development or your supplier. So if you had to take the view of an AM organisation and insuring that you protect the interest of the AM organisation, you would not accept a project unless it has been delivered to a standard that is essentially defined by the CMF. I think the process will be very specific to the relevant organisation, but having said, what the framework does is what we as an organisation goes and put into our strategies plans and processes. Then say our policy is that a project has to be delivered with phase 1 of the CMF considered and if it is not built to this standard then we don't want to manage it."*
  - **[P5]** *"What is nice about it is that it touches on everything. It tells you of all the things that you need to look at. However, it is very high level and does not tell you exactly what to do - as an example it states that you need to manage risk but not exactly tell you how. I guess it is a framework and I should not expect too much detail. So yes it does - and you can take it and apply it to almost any aspect of the business and it will help to pull things together."*
  - **[P6]** *"Yes, it covers all the assets you would find in a RE AM organisation."*
  - **[P7]** *"Yes it does, I can not pick any gaps."*
- **[PH1-Q02] In your opinion, does phase 1 of the CMF cover the requirements of ISO 55001 in terms of strategy and planning?**
  - **[P1]** *"Based on my experience it would seem that way, however, I AM not completely familiar with all the other subjects but what I can say regarding ISO in general is it would seem as if all the core requirements are there. The manner in which it is structured looks*

correct."
- **[P2]** *"Yes I think it covers it excellently and you did a good job in terms of covering the ISO 55001 requirements."*
- **[P3]** *"Yes, as it has the same vocabulary."*
- **[P4]** *"So based on my understanding of ISO 55000 it covers the core requirements."*
- **[P5]** *"Yes it seems to do so based on the brief overview of the ISO requirements."*
- **[P6]** *"I think yes, it is quite clear on what each document does and what each section is supposed to cover. I remember from sessions with an AM consultancy what the sort of basic requirements are and it seems to cover the basics here."*
- **[P7]** *"Yes, it covers the core items."*

• **[PH1-Q03] The weak points?**
- **[P1]** *"Someone that does not understand some of the basics might perhaps not understand what the different areas are."*
- **[P2]** *"Well, to be honest I could not identify any specific weak points in there."*
- **[P3]** *"To me the weak point is that it does not specify the amount of effort that is required to do all of those things. I do not know if it is relevant but it gives the impression that it is quite easy or simple but many of theses things, especially the AMPs, is not a once off activity. So although it is very nicely mapped to ISO 55001 - and when talking specifically about AMPs - I struggle to get the concept that you will not just do it once. I AM aware that continuous improvement at a later stage might cover it. So it would be nice if there is an indication of the amount of effort these actions would require."*
- **[P4]** *"The weak point is not necessarily a weak point of the phase 1 - it's a weak point in ISO 55000 where the jargon can be confusing. If you are very engaged it is easy - but if the engagement is distant is will remain confusing for a long time. It could be that at various levels of the organisation where not everyone at all levels will understand what a SAMP means. The challenge is thus the ISO 55000 terminology itself. In the South African context there are a lot of these terms - what makes it even more challenging is that the first language of many are not English. The language barrier might pose an additional challenge when trying to convey the cultural context - as going in South Africa might not be the same as in Australia. It is also not also clear who is the owner of the specific sections. "*
- **[P5]** *"I do not have much comment on the details at this stage."*
- **[P6]** *"Having more clearly defined deliverables. As an example - you have a step that states a SAMP - is that a document, or is it a high level document, detailed document - something that needs to be*

approved by the organisations. Is it something that gets developed and given to the business. Some of this detail is not specified."

- **[P7]** *"I don't think that anything is missing, but it needs to be considered that there are different stakeholders involved with different agendas - you have different community groups, environmental organisations, Asset Owners, government and there is balancing act required. I think that where it could manifest is when you do a risk analysis that when you look at what you are doing as a company might meet the needs of other stakeholders or not. I think that it is important understand from who's perspective you do this and that is not quite clear."*

- **[PH1-Q04] The strong points?**
  - **[P1]** *"Very well set out, it makes complete sense to me, especially as an engineer. Not sure if it would make sense to a non engineer. I like the way it is done in flow diagrams."*
  - **[P2]** *"I think the details you have regarding the AMPs is actually a strong point it is much more than what ISO 55000 covers. In fact ISO 55000 is very unspecific about the AMP and it is often a question that we as AM practitioners have neglected. I think you have lifted it out there every well and structurally given good indication on what is required. It is something I like. The fact that it specifies the detail in my mind is a strong point."*
  - **[P3]** *"I think the other thing that we missed is that this speaks to the AMPs and then there are the plans for the AMS . I do not see the plans for the AMS in the diagrams. The SAMP splits into two parts - the one part you cover well and is a strong point where you cover the AM plan of the SAMP but I do not see the consideration for the AMS . So although this aspect might covered in the text it would be good to cover it within the diagrams."*
  - **[P4]** *"It's very clear if you take the time to look at it. The details makes it daunting but makes it more useful as a tool."*
  - **[P5]** *"It is very broad and touches on everything. Other than resources requirements. It touches on all aspects of the business risk management, maintenance policy, culture, etc."*
  - **[P6]** *"The flow is very clearly defined. It provides you will a clear process of how to potentially approach this."*
  - **[P7]** *"It looks very thorough and if you do this and do this comprehensively then it's definitely a solid process. You will uncover all kinds of things."*
- **[PH1-Q05] Please specify possible improvements for phase 1 of the CMF and the supporting business processes?**
  - **[P1]** *"There could potentially be clearly defined responsibilities of the different teams within each phase. As an example the operations teams and maintenance teams, EPC teams, AM teams. It*

can be business units within the same organisation or outside of the organisation, it would be nice to know where within the process they have a role to play. Stated differently, what sections are these different teams responsible for is not quite clear. You as an AM have this plan, but where do you bring in the O&M or EPC. Furthermore, having this framework beforehand will assist in enforcing requirements on contractors within the contracts during early stages of the project life-cycle."

– **[P2]** *"We have touched on a few points - apart from that we have discussed before it would be nice to mention the amount of effort as well as define the process to address the AMS as part of the SAMP."*
– **[P3]** *"Also back to the examples of objectives, AM is very much about value. So the organisational objectives should include some financial objectives. You need to try and bring together financial KPIs that include aspect of the assets such as energy production as a function of maintenance cost such as cent per MW. Also you can indicate how often this entire phase 1 process needs to be repeated as the as organisational objectives can change. It would be worth while to specifically note this and it can be included in your continuous improvement process."*
– **[P4]** *"So the clarity on who owns what. Then also specifying what is a business process. It depends who you are writing this for - based on the level of the organisation that the tool will be useful for. If you look at it for an organisation that is a start-up but has a history of AM in a parent company. Some of the business processes are inherited. An example is the financial reporting that comes from the parent company. There was no decision on the process. If you look at a start-up who does not have any business processes in place and tell then that they have to go and build your business processes. Define what a business process is and what business processes should be defined upfront or that is required to support this. Then there is the feedback loops to other parts of the organisation - suppliers, business development. There could be something that shows a clear line between developing the AMS and what the inputs are and what the outputs are. That can be somewhere in the end it doe snot have to part of phase one."*
– **[P5]** *"Adding a typical time-line would also be good, so that you know how long such a process could typically take."*
– **[P6]** *"It could be more clear what the outcome should be or what the deliverable should be. Also the resource requirements would be a good addition."*
– **[P7]** *"So in your interviews you will be talking ot people in my kind of position in industry, meaning a senior experience managers within a , what of the opinion from government - it could be good to*

get their view. I don't know if this the right point - but if I think it through. What the aim of the RE Asset Manager people will generally be aligned in terms of the objective is to maximise sustainable profit for the shareholder - then you have environmental suitability and sustainable jobs and skilled people in SA and sometimes there are direct benefits for the company and the two are aligned and sometime there are indirect benefits such as training people and building a pool of skilled people in South Africa that then means you have more options as an organisation - sometimes they quite altruistic like environmental - how is this captured in this process. Or even if you training people you do it for the greater good. You cannot rely on that they will come back to your organisation but you are training for the industry. You need to think about a triple bottom line and make it clear that it is part of your organisational strategy. It might also be good to include some examples or prompts that relate to other aspects such as reputation and people in your diagrams that are not normally considered even though it is implied within your text. We have these preconceptions of asset which is hard to shed."

G.3.2 Asset Care Plan Development - Phase 2

- **[PH2-Q01] In your opinion, does phase 2 of the CMF cover the core requirements of developing an ACP for REPPs?**
  - **[P1]** *"I reckon so. It's very detailed. You obliviously would have to adapt it for a specific organisation. At the end of the day the core concepts are all captured."*
  - **[P2]** *"Yes, I think for ACPs in general. I cant really comment if it's different for a REPP but i think it should be fairly generic from that point of view. Short answer is yes."*
  - **[P3]** *"Yes. I think it covers it in quite a bit of detail all the things that is required to develop good ACPs."*
  - **[P4]** *"Yes I think the core requirements are covered."*
  - **[P5]** *"Yes definitely and I can see you applying this to any type of asset and industry."*
  - **[P6]** *"This can be applied by any RE AM organisation that has to do maintenance."*
  - **[P7]** *"I did not see any omission in there. I think it covers it. It seems very comprehensive, sequential and methodical."*
- **[PH2-Q02] In your opinion, can the processes be classified as more sophisticated than what is generally seen in practice and in the RE industry in South Africa?**
  - **[P1]** *"Much more detailed and sophisticated that what I have seen thus far. Sometimes people would touch on some of the areas but*

not cover all the key aspects such as in this case. It is very well structured as well."

- **[P2]** *"Ya again, from a specific industry the elements of preparation in terms of your team to do it is very valuable. There are previous experiences where we were faced with obstacles due to not having the correct team around the table. So generally, yes it is more sophisticated, as to comparing it with the RE industry, it's early days, maybe in 6 months I can tell you."*
- **[P3]** *"Yes there are some very specific characteristics that we don't normally see related to ensuring the correct skills and very relevant the question related to obsolescence of component, so yes I think there is evidence that there is specific attention paid to the specific industry."*
- **[P4]** *"Yes, this is more sophisticated than what I have seen within my extensive experience in the RE industry in Europe and in the few years in the South African RE industry. Even within my current organisation we are very advanced compared to most other Asset Managers of REPPs - yet we are not close to this sort of level of sophistication but it is ideally where we would like to be."*
- **[P5]** *"I AM not sure what all the other Asset Managers do but I do believe it is more sophisticated as what we see mostly is the use of TBM and if something fails they would go and change it. The type of maintenance we see is more reactive or elective maintenance and not too much CBM. The foreign OEMs with O&M agreements with South African REPPs also have challenges with having key critical spares available. Often they will not have small inexpensive components that are required for operation available locally. At the end of this day this impacts their targets and the overall plant production."*
- **[P6]** *"Based on experience within the wind industry prominent wind turbine OEMs only do time-based and reactive maintenance as part of their O&M agreements. When looking at the data that can be used for preventative maintenance they do if after instead of before of. So only after there are failures they would consider looking at data. You can see that they don't have such a system or framework in place."*
- **[P7]** *"I would say definitely, because we are all relaying on - at this point in time - multinational, OEMs who are importing - we hope, their tried and tested systems and plans. Often they do not give us the ability to scrutinised the detailed information and we in the South African RE industry are only now just learning what it is that we are looking for. So yes definitely. The individuals working here at the OEMs have often only been here for one or two years - and the knowledge transfer takes time."*

- **[PH2-Q03] The process requires that each task be associated**

with an AM objective or AM strategy, in your opinion does this provide sufficient Line-of-Sight between the AM objectives and AM strategies and the OSP?

- **[P1]** *"I would say yes, except I would have added extra things, like a minimum and maximum on or contractual required targets and what are the actual targets regarding the level of service."*
- **[P2]** *"Ya, I think it is better than most in term of achieving the Line-of-Sight"*
- **[P3]** *"Ya, so I think there is that provision for the level of service, once again it will be up to the facilitator to ensure that he populates that in line with the AM objectives. I think it is a bit of a balance between how complex you make the spreadsheet while still maintaining the Line-of-Sight. That one column indicating the level of service will at least give you the opportunity to create that Line-of-Sight."*
- **[P4]** *"I think it does exist in the process. However the facilitator will play a key role in bringing the bunch of techno-geeks in the room back to the reality of what they are trying to do - as people can easily get side tracked. The facilitator thus needs to reinforce the Line-of-Sight."*
- **[P5]** *"This creates a nice link between things which seem unrelated like the a fuse and an organisational objectives. But if you do this and you can see the impact of what a component can have and it creates the Line-of-Sight. You then get to understand why you would do the reliability assessment on something like a fan or a bearing and understand why something that would seem small or insignificant could have a high criticality rating and also tied everything nicely together."*
- **[P6]** *"Yes, so when you ate deciding on a component. You can look back to what it affects. You can easily map the component function back to the organisational objectives."*
- **[P7]** *"I think that there is a risk fo that now happening. When you have engineers sitting around table talking about a particular component they can definitely lose sight of the relevance of that to the whole company. So does it provide sufficient Line-of-Sight, perhaps not in itself if it is not brought up on a regular basis and people are reminded of that. Do I have any other suggestions - note really. That happens in every organisation, people dive into detail and you need someone with oversight that can apply more or less emphasis on particular things based on the overall picture."*

- **[PH2-Q04] The process requires that clear thought is given to the skills required to perform a specific section of analysis, in your opinion would this mitigate the risk that the sufficient skills that are relevant would not be available?**
  - **[P1]** *"Yes, you would know there is a skill required and you would*

make a plan."

- **[P2]** *"The point of the process is to identify the most appropriate skill or resource. That will mitigate the risk but does not guarantee the availability of the resource. Especially if it is a scarce resource. Like an inverter specialist. But if you know upfront you can flex your schedule around the availability of the resource. So mitigation - yes for sure."*
- **[P3]** *"Yes we identify them to say that we need this skill. This needs to be done before the session. And then from practical perspective it is still a nightmare to get the people together. There might still be a risk that people will not be available. The other risk is that due to arranging the skills up front - that in the session you might realise that you need a different skill - you might have a transformer specialist and then in the session you realise you actually need a oil specialist. So I think it reduces the risk - there are still risk that remains."*
- **[P4]** *"So addressing the fact that there might not be the skills within your organisation - yes. You also have to remember that there might be challenge finding the specialist in South Africa. You might be able to find a gearbox specialist here in the mining and shipping industry, although a wind turbine gearbox is not special in itself the failure modes and other things that will be important is very different from a normal gearbox. It's not so your process but the reality in South Africa."*
- **[P5]** *"It will help but it cannot completely remove the risk. Yes, you can remove a significant amount of the risk that you will nit have the skills available. Having the correct people available will definitely help you to understand the failure modes and failures."*
- **[P6]** *"If you have the correct skill it will help you complete the analysis. Having the correct resource available will help you identify the risk and as a result you will be able to mitigate the risk. Having the skilled person will help you."*
- **[P7]** *"Yes, it mitigates to an extent. Thinking about the skills required means you are more inclined to proactive seek out the skills required or at least have a plan in place to acquire those skills if you need to. That might be to develop the skills or to develop relationships with service providers or experts that you can bring in - so yeah it does mitigate the risk."*

- **[PH2-Q05] In your opinion what are the key skills shortages within the RE technologies to develop ACPs?**
  - **[P1]** *"There are key skills gaps like millwrights that are scarce and inverter specialist. You struggle to get guys who understands the mechanical and electrical aspects. You need that all rounder a guy who knows everything. It is a issue and especially in South Africa,*

our industry is not geared for that especially due to companies that Eskom that forces you to become a specialist. I also notice that even on our solar plants we need someone who understands electrical and mechanical as most of our plants are tracking plants. So you need a mechanical person, but you cannot just have a mechanical person as they might not be able to do the high voltage switching. Or you need an electrician that you can train on mechanical items, or you need a millwright who knows something of everything and also knows about machines and electricity. And in the case of wind, the scenario is very similar. So im my mind you need the same core skills for wind and solar PV. You need the combination and their scarcity makes them more expensive."

- **[P2]** *"At this stage I might be a bit too early for me to comment on this."*
- **[P3]** *"Here I do not have too much experience, but probably around the balance of plant you should be fine. But specifically to wind turbines and panels I haven't met any local specialist it's normally fly in guys from the OEMs. So ya - I may be the wrong person to ask."*
- **[P4]** *"The key skills that we really would be lacking from a wind perspective we are very weak in South Africa regarding blades, gearbox, control systems and there are not a lot of people who can understand the SCADA system data to perform diagnosis of errors. So if you are looking at the hydraulic system as an example you can go and find a hydraulic specialist, but what you are not going to find is someone who can look at the SCADA data and tell you what patterns and parameters to look at to see if there is a problem and what the problem is. To me a good sign of maturity in a maintenance organisation is when you go from just changing components to where you have a department in the organisation that can diagnose a problem. So the skills shortage is the experience and the diagnosis of errors. PV modules there is a skills gap, inverters are not too bad. But there are very technology specific things like control and SCADA, blades, and PV modules. This is just wind and solar there will be more for a technology like CSP."*
- **[P5]** *"I also think that there is a lack of skills in understanding of metallurgy or skills on PV panels or the structure of a wind turbine. We do not have the skills on the finer details such as why bearings in a wind turbine would fail by having an understanding of the operating environment or metallurgy and lubrication. These days component also just get changed - people cannot understand and analysed. You cannot study in South Africa to become q WT engineer. You are an electrical engineer that becomes a wind turbine engineer."*

- **[P6]** *"We do not have people with skills on specific technologies. In South Africa you will have an electrical engineer that knows a bit about transformers and a but of inverters. But you will not find the guys who is the inverter expert. In wind we do not have any skills on the wind turbine itself."*
- **[P7]** *"Wow - where to begin. There are general skills available in South Africa but it just takes time. Let me think where do we struggle. I think we are taking steps to develop those skills but at this point for certain things, directly or indirectly, we are still paying for people who are earning salaries in other currencies and that is expensive. There is no doubt that we have, and will continue for some time to have a dearth of skilled technicians or wind turbine technicians in the industry. Related to the proposed ACPD process we have a real risk on one particulate wind farm that has a short O&M agreement with the turbine supplier where we have a real risk. Also it is challenging keeping these skilled people in rural locations for years on end. Then again there are wind farms that have O&M agreements with OEMs that are almost as long as the design life of the plant and then there is no major risk. Getting site managers are also a challenge. So I think there are a range of skills that shortages of and sometime the locations of the project are a real key challenge. Just because you find the skills in Cape Town or Johannesburg and send them to the rural locations and think they will be settled. You can find young guys who are ok to be out in the rural areas for a year or two but then they get tired of it or board and want to leave. Even on strategic level there is a challenge - we get approached on a weekly basis with job opportunities, that tells you there is a lack of managerial skills that have been building or managing these projects. There is no doubt about that."*

- **[PH2-Q06] In your opinion, will the requirement of the process to develop SJs which are loaded into the CMMS while all the required expertise are available assist unskilled planners and schedulers to plan more effectively while centrally located?**
  - **[P1]** *"Yes, for sure."*
  - **[P2]** *"Apart from the CMMS specifics I think this is a very valuable part. I attach a lot of value to the standardisation and repeatability of jobs and to leave that over to the abilities of the planner and schedulers of which you rightly say are more and more in a centralised space with less and less skill this will go along way to address that. Especially if they are centrally based planners and schedulers that has easy access compared to decentralised planners, this will serve a good purpose."*
  - **[P3]** *"Yes when you are specifying some details for SJs. Yes it will definitely assist the planners and schedulers. The problem is that*

there is always someone that after the session someone needs to turn this ACP. The one thing however that we can maybe mention a bit later is - is that if you for example would like to capture the MSSS in Ellipse the columns that you have to describe the failures and consequences need to be coded. Otherwise it becomes difficult to translate that into codes that must be linked to one another in the CMMS."

- **[P4]** "I think if you don't do it in the ACPD session - it will take you a lot longer to do and longer to implement. So if you walk out of the session with the experts and have your SJs - all you have to do is make it happen. I think if you are relaying on people who dont have the profound understanding of the problem and the solution and not been part of the process to designing it they are going to battle to build a SJ. I think without the SJs the central planners will battle."
- **[P5]** *"Definitely - otherwise they will probably just thumb suck."*
- **[P6]** *"I think having all the detail ready within the SJ that was developed by a skilled person already gives the planner an scheduler the ability to quickly see via the SJ what the information is that needs to be provided to the technician on site. I think having that information available in the SJ is critical as planners an schedulers will likely not have the knowledge."*
- **[P7]** *"Yes there is no doubt about that."*

- **[PH2-Q07] In your opinion, will understanding the process requirements assist in negotiations with EPC and O&M contractors to make the correct information, data sheets, documents. procedures, manual and access to data available?**
  - **[P1]** *"Yes, for sure."*
  - **[P2]** *"Yes definitely. One of the considerations when we spoke about the total cost of ownership and LCC is to consider all the implications of the asset care activities - but actually transferring that to a contractual requirement which is the more difficult part. I think this is clarified by the process and detailed and that is even a further advantage - once it is done for the generic asset types in a REPP then it would be even more valuable in renegotiating or new contracts for new or similar plants."*
  - **[P3]** *"Yes, I think it is becoming more and more the norm these days to specify contracts up front that contractors have to specify a maintenance plan defended by some FMEA . I think this process will support that. Realistically more and more end users would like to obtain the basic FMEA from the OEM and then just supplement it with region or context specific failure modes. The expectation is more and more that you receive up to 80% of the FMEA from the OEM and then supplement their maintenance plans . So going*

through this process there are many little things that will at least prompt you to say we need to tie that down contractually as there is no easy mitigating action afterwards - so yes I think it will definitely assist."

- **[P4]** *"Yes, however I AM not sure if it will help during the negotiations but it will give you a far better understanding of what your starting point should be when you draw up your employers requirements. It is going to make it much clearer for the people negotiation these contracts - what is important what you can give up on as a negotiation is always a two way thing where you give something up to gain something else. So if you have not gone through this process the guys deciding on what to give away in the negotiations will do so on gut feel and not on what he knows to be important during the negotiations due to understanding the details of the CMF."*
- **[P5]** *"It can, hopefully they will not claim that it is intellectual property as we currently see in the industry. You can definitely specify more detailed information."*
- **[P6]** *"I think going through this whole process - will put you in a positions that when you are considering a new contract it provides you with insight into how to specify contract requirements but also helps you to provide better technical specifications for the O&M or EPC contractors. For instance with EPC contractors you can provide more specific employers requirements and also offer guidance on what you want them to deliver."*
- **[P7]** *"Yeah, for sure. When I started in my current role I joined the organisation before the contracts were negotiated. And knowing what I know now there are a few things I would tweak."*

- **[PH2-Q08] The weak points?**
  - **[P1]** *"A possible weak point is that it could potentially be challenging for someone who does not understand the area and the processes well might find it a bit difficult to follow. You will also have to spend a lot of time on this. Ideally would need the skill internally."*
  - **[P2]** *"I would just emphasise the challenge get the people together and keep them together for that amount of time to complete the process with all the details that it requires. However, the strengths lie in the details and if you start skipping it you lose all the details."*
  - **[P3]** *"It always easy for us to shoot holes in anything. I think from a purely facilitating perspective it is a daunting task to firstly open that spreadsheet up and you know you need to complete all of those columns. I would say there is some room for optimisation where some of the columns might not be really required. So you have to consider how you can make it more practical tool that can easily facilitate the discussions over a typical 4 day period. Another weak point which I mentioned specifically before which is related MSSS*

and the coding of the fields. So you can allow free text and then will become difficult later when you translate that to codes to use later for failure analysis in a CMMS. It could be useful to specify - prepare yourself for a four day session."

- **[P4]** *"The visual complexity of the excel sheet. I can understand why you use excel but I AM not convinced that it is the most effective tool. You need a more text based sort of document or a fish bone style. This has to be visible - and using an excel sheet to present to the team - however if you have it in a more attractive interface the usability and the way people interact with the information will be better. The feedback loop of assumptions regarding decisions on maintenance is not clear. How and when do you check if the selected maintenance is working to correct?"*
- **[P5]** *"I cannot see any clear weak points - I have not really picked up anything. There could be more details around costs of components and spares."*
- **[P6]** *"It might be good to have someone who is more of a generalist and understand the system you are working on not just the component. You might need a oil specialist but having a overall transformer specialist will also be helpful in understanding what the overall transformer criticality is."*
- **[P7]** *"Just looking on the face of it - there is no were I see the degree to which you assess this. It seems like you select a competent and apply it to the same degree for each one. The process does look at the prioritisation . I think you need some scale especially consideration the amount of time and people you need to do this as the process is very binary as it currently is."*

* **[PH2-Q09] The strong points?**
  - **[P1]** *"It is a very detailed well structured process."*
  - **[P2]** *"I just want to emphasise on what we touched on previously. The development of the SJ is definitely a plus. The risk assessments is important where the risks are prevalent - high voltage high energy situations."*
  - **[P3]** *"The specific focus on obsolescence. It is often something that we ignore or skip over. The devil is in the details. Because there are few asset types you should be able to do this detailed analysis."*
  - **[P4]** *"A core strong point is that you cover almost everything. The process also says that you have a process to check implementation. The level of detail is also very good. Also classically what would also happen is that you develop a reliance on subcontractors an then upper management would after a while say you spending too much money on subcontractors please do something about it - it is difficult to do something about it because you do not know what you really need. This can also help you identify the core skills that you*

require. Then you can also consider it from a cost perspective to understand the economic viability of subcontracting or bringing the skill in-house, or will it never make financial sense to bring the skills in-house due to training, payroll etc. So the other things is that in a world where you are still building an organisation - you keep going to management saying you need people - but you do not have any evidence of why you need people. If you go through this process it will help you defend the amount of people and also economically justify it through a skills LCC. It will be difficult for top management to say no."

- **[P5]** *"It is very detailed. Not much left to chance. It also not just based on opinion but using information and experts. It is relevant industry information that is used."*
- **[P6]** *"The obsolescence is a very critical points and really a strong points. Also the process is detailed and broad enough to cover all your basis."*
- **[P7]** *"It's a very structured process that most of us in the RE industry do not follow but often do in haphazard way and doing it sequentially like that is very thorough . It is very detailed. "*

- **[PH2-Q10] Please specify possible improvements for phase 2 of the CMF and the supporting business processes?**
  - **[P1]** *"As I mentioned earlier in the level of service requirements I would perhaps add minimum maximum of the KPI as well as what the contractual KPI and actual or internal targets target KPI is. So a broader scope of aspects. An example you can have different performance ratios - and you can specify which one you are interested in and also what the current value is."*
  - **[P2]** *"Talking about the component criticality - one of the things that were a bit subjective was the choice of the components that needed to be analysed. There should be a more clearly defined approach to defining an objective criticality. If you rely on experts and their judgement that could also work. What often happens that you have a functional digram and that can be used to show that you have considered all the components and can also be used to select the components that are important."*
  - **[P3]** *"I will just emphasise the consideration around coding and being able to load the analysis output into a CMMS. Then there is the considerations around all the columns - will all the columns add value. Potentially some could be removed. Then there is one I have not mentioned before which is the ranking of the components criticality - I would have preferred to handle it a bit earlier in the process. So just from a risk perspective you would start with the more critical components."*
  - **[P4]** *"So if you look at a fleet of 60 turbines - you decide not to*

change the oil but to install oil quality metering and decide only to do maintenance when the oil measurements get bad. So for one turbine it can be 5 years and another turbine it can be 8 years. How do know if the decision you took to wait so long on the oil causes turbines to start failing systematically. In a more mature environment - especially considering getting information out of the OEMs on failure rates is impossible - you have to be very careful about your assumptions. The risk is that you become conservative in your assumptions so you dont extract the maximum value and that you are running on gut feeling. So when you make a assumption on something regarding maintenance strategies there should be some idea of what the risk is on the assumption that you can make part of the process. Then in your continuous improvement process you need to decide how often to come back and assess your initial strategy to check if it has been effective or whether you need to make a change to the selected strategy. Also I think a possible improvement is to specify in your team to have someone who is not an expert like the planners and schedulers, operators, or even someone from finance. Sometimes someone who does not understand will ground the process in asking you are doing the following - why is it important."

- **[P5]** ""
- **[P6]** *"I think that you should also use experts to assist with overall system criticality rankings. You develop a methodology in the strategy and planning section or phase 1. However think you need someone who understand the bigger picture to help select the criticality of the system - link in the example help rate the criticality of the transformer. Further - it is difficult to understand what the benefit is of using this type of process. How do you quantity the benefit opposed to not using it."*
- **[P7]** *"So once again the only comment would be to apply some scale and add a prompt to consider to what degree to we apply this to a component. It could also have some value to have non technical people or someone that looks at it from a contractual perspective to ask questions and bring a different perspective is good. You can have technicians join so that they understand where the maintenance plans they are executing comes from and understand the value of filling in good feedback information on work orders."*

G.3.3 Work Planning and Control - Phase 3

- **[PH3-Q01] In your opinion, does phase 3 of the CMF cover the core requirements of the planning, scheduling and a work order system?**

- **[P1]** "*Most of it, I would not say completely.*"
- **[P2]** *"Yes it definitely covers all the core requirements. I cannot think of anything that is not there in terms of our own reference."*
- **[P3]** *"The relevant activities are all covered. Perhaps one thing that not clear is the feedback analysis - but you mentioned that it is in the continuous feedback loop - it is very important to link back to the continuous improvement."*
- **[P4]** *"Yes i think it is very detailed and there is not much that is missing."*
- **[P5]** *"Yes it does."*
- **[P6]** *"Yes."*
- **[P7]** *"Yes for sure."*

- **[PH3-Q02] The process requires that the planning, scheduling, work order creation and close out are dominantly centralised with a strong collaborative engagement with the on-site maintenance team, with work order execution and completion decentralised. In your opinion is this a feasible within the maintenance organisation design?**
  - **[P1]** *"Yes it should be feasible. It is feasible within my current organisational environment but I would change one or two things. However, the core idea around the centralisation of the planning and scheduling and decentralisation of the work execution is completely feasible even within my current organisation."*
  - **[P2]** *"It is definitely feasible. The one thing that I thought that can specifically considered is that there are a lot of status changes occurring during the day as work occurs on site - this status changes can be more readily linked to the centralised system. During the day there is not a lot of feedback to the centralised system. With the availability of modern technology there can be more interaction with the centralised system by the on-site team."*
  - **[P3]** *"I think it is feasible within the maintenance organisations design. There are one or two activities which one can argue should the decentralised team not do it but that would a function of the tools that they have access to - lets say they have mobile access to the CMMS some things might be easier. I think the good things is the centralisation of certain activities that we know sites struggle with that does not have massive maintenance complements."*
  - **[P4]** *"Yes it is - it can almost be a requirements. You need to have some sort of checking of the quality of the information coming back from the field otherwise your CMMS becomes useless. So if there are not brackets around what your technical teams are feeding back, the general weakness in technical teams is the paperwork, then it's not going to work. Yes I think it is feasible - it is something I have seen is difficult initially as technicians see it as micro management*

but if the relationship between the central planners, schedulers and technicians develop correctly it can be very positive.”
  - **[P5]** *“It is feasible. However organisations might need to implement first to get a real sense of the feasibility.”*
  - **[P6]** *“The centralised approach is feasible - the questions is just whether you have the resources to make sure if can be implemented. So yes if you have all the required resources it will be feasible.”*
  - **[P7]** *“I think it is feasible.”*
- **[PH3-Q03] In your opinion, will the requirement of the ACPD process to develop SJs which are loaded into the CMMS while all the required expertise is available add significant value to the quality and ease of planning and scheduling?**
  - **[P1]** *“Yes definitely it will.”*
  - **[P2]** *“I think referring back to the discussion on ACP develop the SJs is a powerful tool, especially where there is quite a distance between the centralised and decentralised teams - a geographical distance but also a skills differentiation between the two - experts on sites and given that standards jobs were done with the input from the experts - I think it is a definite value add.”*
  - **[P3]** *“We often see that where the maintenance execution resource was not involved in the development of the ACPs they quite often question the value that a centralised CMMS and planning function adds. It is very important that the execution team sees it as their maintenance plans and the more detail you define with the ACPD the more the pre planning is in a way done. So it would definitely assist the less technical or skilled resource to provide value - if a lot of the planning work has been done as part of the ACPD process.”*
  - **[P4]** *“Yes it will. You can do the scheduling and planning on a this has to be done basis by unskilled people but if you have detailed information available it makes it much easier.”*
  - **[P5]** *“Yes of course, if you have a new planner and scheduler and an expert already developed all the detail - the understanding can come later. It defiantly adds value - it also takes a lot of the guess work out of the process.”*
  - **[P6]** *“If you have the knowledge captured it is easy to implement - the quality of the SJs would be good due to the expert creating the SJ and not an inexperienced planner. It also cuts down the time on. It improves the overall efficiency.”*
  - **[P7]** *“Yes definitely. I can see through one of the European wind turbine OEMs doing the O&M on one of our plants that have challenges with this. So yes it definitely makes it easier to perform planning and scheduling.”*
- **[PH3-Q04] In your opinion, does the CMF require a central CMMS system to function optimally?**

- **[P1]** *"It can be done without a central CMMS however a central CMMS will add a lot of value."*
- **[P2]** *"It does not require a centralised CMMS - it could - but I think the value of the centralisation is without a doubt. Especially if the technology repeats on more than one site. Then without a doubt. With common technology - as an example your electrical balance of plant will be similar at all sites - you get the advantage of a commonality at a central site."*
- **[P3]** *"Immediately if you had one wind warm and one solar farm, the argument might be ya you might get away. But the moment you have more of one type it is so much easier to optimise."*
- **[P4]** *"Yes it definitely needs a central CMMS - it is impossible to do with a paper based system."*
- **[P5]** *"I think it does. If you centralised the functions in a operations hub then it would make sense to have a central CMMS in the place where the planners and schedulers are located and also where the plants are monitored and initial faults can be detected."*
- **[P6]** *"Yes, if get a new site with a new CMMS you will have to RE-train people on a new system and load SJs in a new system. When you have a common central CMMS you can carry a lot of the knowledge over in a single system."*
- **[P7]** *"In one form or another you will need that central system."*

- **[PH3-Q05] The weak points?**
  - **[P1]** *"Through the execution I did not observe a lot of emphasis on the requirement to have someone with special skills to make the work safe. I think it is mentioned somewhere - however for our operating environment safety is a key concern and in most cases you would require a responsible person, according to ORHVS, that can authorise the work or must lockout/tag out and then take over again. In my experience a lot of our processes the authorised person goes and makes the systems/equipment safe and ready for work/maintenance and then hands the equipment over that has been locked out. Someone then performs the work and then gives the equipment back to the authorised person after they have completed the tasks. That whole process in my opinion is generally a sub work order from the main work order. As an example, you want to clean the transformer bay, the authorised person isolates the substation and then isolates the transformer station, lockout/tag out and everything. He then signs it over to the people who can continue with the work. The authorised person can leave or stay depending on the type of work but would generally hand over the work to the supervisor who will later hand the work back to the authorised person. So the lockout/tag out and switching is a sub process. I feel because it is something that is so specialised and needs to be recorded in the event that an accident*

occurs and someone dies. You have to record and show that the person completed the lockout/tag out correctly. So it could potentially even be a separate work order that you can track."

- **[P2]** *"One weak point that we touched is the initiation of the reactive work. If you describe or include that in your process that would add value. And a specific element to that which is similar to the SJ is a standard set of terminology of describing a problem so that it is not purely free text. I saw this a lot when I was working with a specific company. It is similar equipment, for instance a pump, that is at 10 different sites, you would have at least five different descriptions of the same problem. Now it gets up to the central point where it is interpreted and then this guy must make the call whether this is the same problem. So centralising or just including in your process for some types for coding problems or failure modes."*
- **[P3]** *"For me there were not really any. I think however that in your industry considering the weather is critical and one could potentially write a PhD thesis on it, For me that is the real differentiator in your industry is the weather that is much more unpredictable than what many other industries. But that is a focused thing on its own."*
- **[P4]** *"The weak points is that when you show this to someone they will ask you so what if something breaks during the day and the schedule goes to shit."*
- **[P5]** *"I think that perhaps it would also be good to indicate the effort and challenge of implementing this process. In a practical environment it will not always be this easy and simple - so there is not a clear indication of challenges."*
- **[P6]** *"I think that the interaction time will be challenging - what I mean by that is if you have a large portfolio of six plants you cannot have a single weekly or morning meeting. It will take too long and one plant will not be interested in the work happening on another plant. You might have to have a larger central team who can split off into different technologies or attend separate meetings which are manageable and practical."*
- **[P7]** *"Nothing that immediately comes to mind."*

- **[PH3-Q06] The strong points?**
  - **[P1]** "*The process is very detailed. Pretty much almost everything is covered. It is a very good way of informing someone of what his job is. And that the responsibilities are clearly defined, who is responsible for what and which parts are collaborative. It is always important to know what is one persons job and what is the other persons job.*"
  - **[P2]** *"A specific strong point is the centralisation, it is a definite strong point for technology and equipment that is repeated over sites or a site - I think it overcomes the inevitable staff turnover situation*

especially with planners and schedulers and in our experience there is a fair amount of turnover - and centralising that you improve the sustainability."

- **[P3]** *"Yes I fully support the view that the centralisation is a strong point. I think people under estimate the effort that is required to do the activities that is listed on-site in addition to also performing the maintenance. It is good to emphasise right from the start that these activities are to be performed by centralised staff. A strong point is to bring in things which are important in the RE environment like the weather."*
- **[P4]** *"The strong point is that it is very very complete. It is a very robust sort of process that covers the most type of probabilities."*
- **[P5]** *"It provides a good level of safety."*
- **[P6]** *"There are a lot of feedback loops and review processes which is good. Another strong point is the supervisor and RMC checking on quality of information."*
- **[P7]** *"A lot of the work is front end work - like getting the SJs developed that pays dividends. It is a very thorough process set out by the framework."*

- **[PH3-Q07] Please specify possible improvements for phase 3 of the CMF and the supporting business processes?**
  - **[P1]** "*The issue raised regarding the authorised person and plant safety. There could potential. Potentially in the planning stage you can state that there is a need for an auxiliary work order for to make the work safe. Also, if you only have one person available who can switch that day - you might have 10 jobs and only one person is switching - you need to manage your resources. I think that in the planning stage when you check for special skills requirements this is potentially an ideal place to handle this sort of requirement. It can also add value in understanding additional time requirements of jobs as it might take an hour just to lockout/tag out a specific piece of equipment. So it would be good not just to identify the need, but also how long this need is going to take. This also brings my attention to the fact that equipment also needs to be made alive again. This could even be included in the ACPD process. So it is important to specify the required time needed for this person to perform their part of the work. You could also include a special note in the daily scheduling when the morning review meeting occurs that special mention is made of the requirement for a authorised person. Can also be included in the work order execution process - just to make sure that the equipment is safe before commencing work, and notifying that the work is done and ready to be made alive by the authorised person.*"
  - **[P2]** *"We actually touched on a couple. One is improving the reac-*

tive work initiation. The other could be the intra day update cycle through a central system."

- **[P3]** *"I do not have anything major to add besied the comment that it is important to note specific considerations to the RE industry such as the weather - where you have noted it in your framework."*
- **[P4]** *"So what happens in process breakdown. What happens if you are doing preventative maintenance on one wind turbine and the wind turbine next door stops. This is something that we dealt with frequently in Europe on wind farms. The question is whether it is really more effective to stop the current maintenance in progress - pack up and go to the turbine that has stopped. Or do you actually say no, the total downtime for my assets will be more if I pack up and go, considering travel time etc. So it might be better to complete the current maintenance and then go to the other wind turbine. So it would be good to have a process or step showing what the decision criteria will be around deciding to complete current work before attending to a breakdown. It's more a presentation thing - if you present this to the technicians you can show then - they might think that if the work does not get done for the day they will get reprimanded - but that's more an education thing. You may just want to add a step to say that the operator has checked the SCADA to make sure there are no issues that needs to be added to the daily list. I would also put a time limit on the meetings - you have it in the text but a visual note can be useful."*
- **[P5]** *"I cannot see any immediate improvements."*
- **[P6]** *"The approval process for work orders. You could indicate a escalation process for work orders that needs approval should the primary persons that needs to approve not be available."*
- **[P7]** *"Do not reinvent the wheel. This has been done by various organisations for quite some time. There is no need to start from scratch. Sometimes organisations would guard this as their own intellectual property but this is not new. You should also leverage the people in your organisation that have done this in the past and there will be a body of knowledge that you can leverage. So in practice you might od this to the extent in practice. It is also important to drum it into the technician that the information and feedback is important. Perhaps it is also a good idea to have technicians part of the ACPD process. Perhaps you can have these RCM expert consultants join technicians in the field and try and show them why there is value in entering the information correctly in the work order feedback."*

G.3.4 Competency Management and Continuous Improvement - Phase 4

- **[PH4-Q01] The consideration for organisational culture is highlighted, does this in your opinion have a significantly relevant role to play within competency management and continuous improvement?**
  - **[P1]** *"Yes. It adds to the work being done the way you want it done."*
  - **[P2]** *"I agree - even more so in a bigger organisational culture or efficiency. It has a specific role in competency management but even more so in the business as a whole."*
  - **[P3]** *"Yes, as we said in ISO 55000 the whole aspect around leadership and organisational culture is a significant enabler or key success factor so it has a very profound effect in competency management and the bigger AM subject."*
  - **[P4]** *"Yeah, how you consider your employees in the organisation makes a great impact on how they perform. If you treat people bad they will not want to work and deliver quality. If you are the type of organisation that extract the maximum amount of value from people without considering their feelings - things are not going to go well. When organisations have gatherings - there are often questions around leadership and direction and not having clearly defined values and culture. If you had to ask people in the organisation what the organisational culture you would get an answer but you would not get the same answer from everyone. In respect to competency management you know it will be easier to explain to people why the way you mange competency matches up with a generally understood culture. It might not be absolutely essential but it can be important in helping that your competency system is accepted by staff."*
  - **[P5]** *"Yes definitely, if one of your culture items would be learning, training and coaching - it would help. Your staff and people would take it upon themselves to improve themselves. If you develop a culture of continuous training people will try and make the effort to improve their skills. Culture is important to establish the quality of work you would like to experience from your staff."*
  - **[P6]** *"It is important to develop the type of employees that you would like to have."*
  - **[P7]** *"It plays a huge role - possibly nothings else more relevant than that."*
- **[PH4-Q02] In your opinion, does phase 4 of the CMF cover the core requirements of competency management?**
  - **[P1]** *"Yes it does."*

  - **[P2]** *"Yes I think that all the core requirements are covered. I think it can however be represented outside of phase four as a separate phase."*
  - **[P3]** *"Yes, I think is nicely mapped to the sort of requirements that you stipulated in phase one to three."*
  - **[P4]** *"Yes - I would say that perhaps there is continuous improvement loop that is missing. Which is assessing performance of your people as way of assessing the performance of your competency management framework."*
  - **[P5]** *"Yes it states the requirement of developing a competency framework to assess the role requirements. And there is the continuous review process which will help keep competency requirements updated and understanding the competency you need in-house. It also helps you move people access roles as you will understand how their skills compare with other role competency requirements."*
  - **[P6]** *"It is important to get the competency matrix and makes sure the roles have been benchmarked. Also when you recruit for roles you know which competencies you need."*
  - **[P7]** *"It appears to, I think it does."*
- **[PH4-Q03] In your opinion, does phase 4 of the CMF sufficiently address the skills issue faced by the RE in South Africa over a time period?**
  - **[P1]** *"Yes it does."*
  - **[P2]** *"It will definitely be over a time period. It is continuous improvement and not focused improvement. It is not a focused improvement. We did start talking about the organisational structure - and just in terms of competency management - is the question that there is a need for a to short term recruitment gap analysis. What we often see in organisations is that there is a theoretical organogram designed but they have many vacant positions that cannot be filled due to al sorts of organisational obstacles. That actually hampers the achievement of business objectives. I have been involved with clients where specific service levels shortfalls were identified and it was linked back to shortages of resources. So once again this links not to the competency of the people but to the competency of the organisation."*
  - **[P3]** *"Yes so the competency management process as I recall it does not have a specific indication of how frequently to review. It will reduce risk over time yes."*
  - **[P4]** *"Yes it will - as longs as you stick to continuously try and understand or assess how well your framework is doing."*
  - **[P5]** *"It will help you to find the skills you lack and employ the correct people."*
  - **[P6]** *"Yes definitely - because where you lack the skills you will pro-*

vide training."
  - **[P7]** *"Yes, I can see that it identifies gaps and then attempts to close those competency gaps."*
- **[PH4-Q04] The competency framework is developed and managed centrally, in your opinion is this the appropriate place within the organisation?**
  - **[P1]** *"Definitely."*
  - **[P2]** *"Without a doubt I think that it needs to be centralised to achieve the standardisation in a sustainable manner."*
  - **[P3]** *"Yes I would fully support that it is centrally managed. Especially if you can share skills between sites. Sometimes it is not even necessary to have a specific skill for a long period at one site. You can have a skill say that he can do a job within a month period and the you can move him around. In a environment where you have multiple sites with similar technology I would manage competency centrally to give that flexibility across the different operations."*
  - **[P4]** *"For consistency it is something that you should develop centrally and acted upon and managed at the site level. If you don't have a central HR department to run this it will be challenging. Depending on the organisation design - but it could be beneficial to develop and manage the competency framework centrally with input from local site teams but actually making sure that the training gets done should be managed at site level or decentralised. So it is a bit of a mix. Developed centrally with input but day to day management should be decentralised. "*
  - **[P5]** *"Managed centrally yes - you can get input from the sites but it should be managed centrally. It also helps you to manage the competency of the teams better by understanding the level of skill each person has and where they might need to be up-skilled."*
  - **[P6]** *"You have similar sites and similar competencies at site - if you manage this centrally it would make sense."*
  - **[P7]** *"It is something that should be managed centrally with consultation from the sites."*
- **[PH4-Q05] The weak points?**
  - **[P1]** *"I don't see any weak points at this stage."*
  - **[P2]** *"I will link onto a point I was trying to make earlier with using focused improvement to strengthen the organisation to deliver on the organisational requirements. Otherwise - no specific. I would perhaps suggest splitting the compe and improve."*
  - **[P3]** *"I think it's more focuses on competency management. So I think the continuous improvement gets lost in the questions. That is another reason I would split it out. Then just one thing about the competency management - I cant recall a specific reference to the use of the CMMS to specify for example the number of resources.*

So I think it might be beneficial. We often get involved in arguments around motivating the number of people. It is one thing to say yes I need these skills but then to motivate the quantities. specially with the more execution resources and even the planning resources when you want to motivate the numbers required you need the maintenance history in the CMMS to motivate that - so I think i would just add something regarding using CMMS to motivate for the number of specific resources."

- **[P4]** *"It generally very difficult to implement. So the weak point is not the CMF but these softer subjects in the technical areas is difficult to deal with."*
- **[P5]** *"Nothing specific that I could spot."*
- **[P6]** *"Succession plans are not really specifically identified in the diagrams. It might be good to highlight it in the diagrams as it is an important aspect."*
- **[P7]** *"No specific weak points."*

- **[PH4-Q06] The strong points?**
  - **[P1]** *"I like the idea that the focused improvement process actually guides you in terms of how you will address the inefficiencies - as it is already explained. Sometimes people say there is a problem but they don't suggest how to fix it. This provides a potential process for how to fix it or address it at least makes it quite a good thing."*
  - **[P2]** *"The soft issues - the culture is a strong point. We made a point regarding ISO 55500 and the issues around leadership and commitment which you brought out in phase 1."*
  - **[P3]** *"Emphasising in a framework like this is that you might have the nicest process but if you do not have the people it is not going to work. It is good to see that in the framework there is so much focus on competency and even more so in the RE industry where we know that there is technical skills shortages which needs to be addresses centrally."*
  - **[P4]** *"The strength is the continuous improvement process where you apply the same logic to your competency as you do to your equipment. So you are treating it like an asset - it is essentially an asset - You get the cliché saying that people are our greatest asset but then it just gets forgotten about. Just having this will be a great step for most organisations."*
  - **[P5]** *"It is good that remuneration is considered - that is never a bad thing to consider and can motivate people to further themselves and the organisation never looses out."*
  - **[P6]** *"The frequency at which reviews occur. A lot of organisation say that you need certain s kills and they never make the effort to invest in people."*
  - **[P7]** *"Yeah, I link that it actually tries to look at specific needs and*

attaching a skill to it. It can be quite a painstaking process but the correct way to approach it rather than saying - ok what role do I need - I need a wind turbine technician, To look at the needs and buid up from there is the correct approach. I have not seen any organisation take the time to do so before. It would be very helpful when you have to recruit because sometime when we star recruiting we have like a wish list - and then you think - oops this person does not exist and then you have to compromise on a hole bunch of things."

- **[PH4-Q07] Please specify possible improvements for phase 4 of the CMF and the supporting business processes?**
  - **[P1]** "*Not a lot - however I did not see where you identify the core skills needed. What competencies you need and where you lack certain things for instance. I like the idea behind it but I would just add something that says what kind of skills and also attach a time frame to it. Lets say we are now a new centralised solar management organisation and we have no polices and procedures in place on how to do maintenance. Now you will have a need to populate all these procedures but you only need it once. Obviously you will need competency to update once a year but you might need a competency at first creation of the procedures could be a time-based or a short term situation. Or it could be attached to a specific job. Or you decide you want to change all the gearboxes so you will need a specific competency. So you could specify short term competency needs as well.*"
  - **[P2]** *"I think what you said was very aimed at, based on my interpretations, based on my in-sourcing or in house resources. The one statement you made - zero use of external consultants - In some cases there will be a need for specialist resources such as an inverter specialist. So to actually include in the phase four of the framework identification of the resources which you want to in-house and which you will outsource. Then one step further - is even for those that you outsource that you also have a competency framework for those skills. It could be in the text but I do not see it in the diagram."*
  - **[P3]** *"We touched on many things. Using the ACP and CMMS to motivate the number and type of resources. I would still recommend moving competency management out of phase four and into a seperate phase. There are a lot og things one can say about continuous improvement. You have a process there that I think covers the basics but that needs attention as a phase on its own."*
  - **[P4]** *"Yes, the assessment of the competency framework by assessing the people. So the idea is not to assess whether someone is performing good or bad but to assess whether your competency framework itself is providing the training of and competency to people to do their work correctly. Often organisations have personal performance*

reviews, however the gap in that is that if someone does not perform very well they do not get asked why - often understanding why that person has not performed relies on the line manager having sufficient understanding to ask the question - and nothing is formalised. So there can be a loop to question staff to see if they feel they are appropriately trained to perform their job. You can consider it in your continuous improvement loop - you can have feedback where you assessing the effectiveness of the competency framework to provide your staff with the required tools. Your competency framework tells you what training and skills you need but there is generally no feedback to understand whether your competency management framework is working and providing your team with what they need to do their jobs. Succession planning is not specifically mentioned in your framework. Succession planning in a new industry we know is going to be important. In all industries you have staff turn over and it is going to be quite violent in the RE space in SA for quite a few years to come as you have new projects coming and you want to poach experienced people. So I think potentially you need to consider your recruitment strategy, like an intern-ship programme to offset some risk and up-skill and identify talent. You should consider the turnover of people. It should be of real importance in South Africa as it is not like the US where you have a large pool of people you can pick from. South Africa has a general skill shortage and a very specific RE skill shortage."

  - **[P5]** *"Nothing which I could see."*
  - **[P6]** *"Adding succession planning in the diagrams as it is a key item to consider."*
  - **[P7]** "I think I mentioned in earlier questions."

G.3.5 Framework Synergy

- **[FS-Q01] Considering the research methodology which was followed to develop the CMF, what is your opinion of the potential of the CMF to support Asset Managers and owners in centrally managing ACPs while remaining aligned to the ISO 55000 series of standards?**
  - **[P1]** *"I think it is excellent, I think there is a lot of potential in here. I will effectively use some of the framework in my current organisation."*
  - **[P2]** *"There is definitely an upside. Especially where there are multiple sites and multiple technologies on the generation side. We know that the electrical balance of plant is very standard but not unimportant in availability of the plant and from that point of view I definitely think that there is a place for a CMF opposed to a de-*

centralised view."
- **[P3]** *"If someone had to set up a RE company from the start it would give them an idea of some of the key processes and people that is required to be successful. It also adds a lot of potential to the details related to the contractual agreements with the OEMs. I think there are a lot of things one can take from here if you paid attention to is and looked through the details and say which are the things which we can write into the contract that can assist with achieving the framework at the end of the day ."*
- **[P4]** *"Absolutely it will"*
- **[P5]** *"Great potential, you can actually use it and each phase seems to complement each other."*
- **[P6]** *"There is a lot of potential and anyone can take this framework and start applying it to their organisation or tweak it to their organisation and implement."*
- **[P7]** *"I think there is great potential for it to be of benefit and an aid. I think that what you have to bear in mind with any system like this is to use discretion as to when and where to apply it. Because it is extremely detailed and the application of it is where you need to apply your skills, experience and knowledge of the organisation. I guess it goes without saying you are putting in place a framework and one has to go through the framework and adjust throughout and it also forces you to think of things that you take for granted."*

- **[FS-Q02] Most aspects of the CMF is developed and managed centrally, in your opinion is this the appropriate place within the organisation?**
  - **[P1]** *"I believe so. Effectively yes, especially with our sort of specialised field and in a place specifically like South Africa where we don't have the skills maybe that is required."*
  - **[P2]** *"Collaboration with the sites is very important as we do not want a us and a them situation - and that is the one dancer of centralising it especially at a so called head office. It is very important that at the development stage there is also a collaborative. Even with the continuous improvement should always be collaborative. Everyone should be part of the AMS ."*
  - **[P3]** *"Very specific to multiple sites. For me more so if there is common technology. Because there is not a huge complements of people at site as we have in the mining or heavy manufacturing industries. Where you have little ot limited resources compared to the assets it just makes a lot of economic sense to handle many things centrally."*
  - **[P4]** *"If you want repeatability and a homogeneous approach to things and then you can set organisation goals you want to achieve you have to create the system centrally with making sure that it can*

be implemented practically and not do it from an ivory tower."

- **[P5]** *"Yes, based on my experience working in a organisation with a central head office and distributed REPPs it makes a lot of sense logistically and a smart way to manage these assets."*
- **[P6]** *"It makes sense to keep things central when you have multiple sites. It can make things easier to manage and reduce the number of employees required."*
- **[P7]** *"I think that parts of it can sit at the plant. It's a natural process - you grow organically. You start with someone centrally and then over time you hire and train and become increasingly confident in the skills and capability of your people out in the field and then gradually delegating and releasing some functions to them. So I think there are quite a few things you could decentralise. Also just on the decentralisation - something we have to bear in mind that it is not always about achieving the maximum efficiency by centralising, it is also about stimulating and empowering people - because the risk is that you hire these smart people to manage a plant but they are not fully challenged or utilised and then they get bored and leave. The more you decentralise and make them owners of these processes and accountable - the more stimulated they are and grow and surprise you all the time."*

• **[FS-Q03] In your opinion, does the CMF and business processes create an environment where the Line-of-Sight between the stakeholder requirements, organisational objectives, AM objectives and AM strategies can be linked to the daily activities performed by the AM teams?**

- **[P1]** *"I think that's actually one of the strong points - the whole follow through of the objectives from the top all the way to the bottom."*
- **[P2]** *"Yes I agree and for me personally the context - the bigger picture is also important at the shop floor level. In other words don't apply the mushroom principle - show the guy why he is important and what the effect will be of what he does on any specific day and any specific asset to the benefit of the business."*
- **[P3]** *"It brings up the Line-of-Sight issue and you showed us in pretty much all of those phases where the Line-of-Sight related activity is present even down to the work order level. So it will definitely enhance that visibility."*
- **[P4]** *"As long as it is kept visible yes. The CMF gives you the possibility of creating the Line-of-Sight but then it is incumbent on the organisation that the vision is maintained throughout via communication and understanding and visibility of KPIs. The system is fine but then it is the management of the application that will keep the Line-of-Sight visible."*
- **[P5]** *"Yes it does and helps link them all together. The guys on the*

ground understand how their work translates to organisational KPIs and can understand the impact of their work."

  - **[P6]** *"As an example when you do a risk assessment - you know why you are doing a risk assessment as it is linked to an organisational KPI of HSE. So that whole link is there and clear."*
  - **[P7]** *"I think definitely. We try and tell people why we are giving them work but probably not as enough as what is proper. So I think it is a very good process."*

- **[FS-Q04] Considering the research methodology which was followed to develop the CMF, what is your opinion is the potential of the CMF to understand/manage RE skills requirements/shortages using a competency framework?**
  - **[P1]** *"Yes it will work, it is difficult to say exactly, but yes it does. You might just have to add how many of the skills you require."*
  - **[P2]** *"Yes, the ACPD process can assist with identify skills and quantities."*
  - **[P3]** *"We did not go into details in the skills assessment - but the number of people you can get from the ACPD process and once you work through the activities you listed you can put roles next to them and identify the skills that are required."*
  - **[P4]** *"I think that it's a framework that will definitely assist in managing skills and competency requirements."*
  - **[P5]** *"It goes a long way in understanding the skills requirements and identify the skills gaps that you have in the organisation. Then it allows you to address these roles and scarce skills."*
  - **[P6]** *"During the whole process the CMF looks at gaps and by looking at those gaps you identify skills gaps which can be addressed."*
  - **[P7]** *"There is definitely potential but it might not be the full picture. I do find it interesting to look at the exact needs, attach a skill to it and then build up from there. If I have seen anything that I feel sceptical or even cynical about it could be this. This process is very scientific and when it comes to people I wonder - I have never been through such a process. I have hired people before for various different roles. You try and list the requirements and develop the job specification - then you interview 20 people - and sometimes you succeed at getting the correct person and at other times not. The process also looks like it takes things one step further - it seems very scientific. I have not done it and on paper it is a very detailed exercise and it does not necessary capture the difficulty of when it comes to people. I think it is a good attempt and worth doing and trying but I AM just wondering if you can take it that far. Just defining skills like that, if I apply it to a wind farm, I don't know, I cant say because I have never done it. It feels like it is very prescription and then there is an element of not chance but*

the people factor that can overshadow the scientific part. Let me give you an example. You find someone that on paper and the right skills, degree and has done the job before. Then you work with this person for a week and then you think - this is not going to work - why because they do not have the attitude that works in that particular place or in that particular organisation. This is very good due diligence process to do and a very good way to filter and say I need these skills but then there are a bunch of softer skills which in my experience are just an important. Then there is that you have essential skills and potential, where you can develop people - but they have the correct attitude and the correct transferable skills. It is not something that you would necessarily be reflected in your framework but I do think it's good to bear in mind that there is not a magic formula for hiring. There is definitely potential but it might not be the full picture."

- **[FS-Q05] In your opinion, does the CMF cover sufficient elements related to RE, please qualify your answer?**
  - **[P1]** *"Yes. To me it comes all back to the skills and the way we handle the assets which is a bit different to the other types of assets you get in the country. The way you have a SPV sitting in the one side, contractor here and the Asset Manager in the middle. It's different especially here in South Africa than what people would be use to"*
  - **[P2]** *"Yes and also from the point of the view of the complex owner and management structures in the RE industry in terms developers, EPC, O&M, Asset Owners and asset operators. That over a long term and someone who is currently in the business and want to expand with other sites - I think having a CMF in place will assist with some of the business development aspects to bring that in-line with what is currently in place."*
  - **[P3]** *"Yes, I think we saw evidence of this in phase one with the very specific stakeholders and KPIs and in phase two, three and four there were things from the weather to the very specific skills shortage. I would say from what we have seen there is very specific focus on the RE industry."*
  - **[P4]** *"Renewables is not an industry that is so much different to others. If you look at mining there are a lot of similarities. There are differences in that RE organisations is very lean. You might have to do these types of things in na environment where you do not have a lot of staff to create a task force and people have to be more multi skilled in RE than a classic industry where you have an engineering department of just more people to help. We discussed the potential issue around not having people skills to develop asset care plans."*

  - **[P5]** *"Yes, you look at RE skills, obsolescence, the weather resource, planning - so yes."*
  - **[P6]** *"Yes, but it addresses power plants in general as well."*
  - **[P7]** *"Yeah, you have to qualify this with the contractual situation that RE Asset Managers find themselves in. We are not that much different from other industries - the REPP is also just a factory."*
- **[FS-Q06] The framework is developed to be applicable to different RE technologies, in your opinion does the framework and business processes accommodate this?**
  - **[P1]** *"Yes, from my experience it would seem that it fits both solar and wind."*
  - **[P2]** *"There is no reason why it would not apply to different technologies. And especially where there is multiple of them and there are common technologies and infrastructure."*
  - **[P3]** *"There are a range of different technologies CSP, wave technology and what all others but these are all technologies we do not have skills for in South Africa and this is very relevant and especially where there are multiple sites."*
  - **[P4]** *"You can pretty much use it on any technology."*
  - **[P5]** *"It would seem to be universally applicable to any RE plant."*
  - **[P6]** *"Yes definitely. The process is good and can be applied to other technology."*
  - **[P7]** *"Yeah completely."*
- **[FS-Q07] In your opinion, what are the strong points of the research methodology and/or the CMF?**
  - **[P1]** *"It's quite detailed and well put together. it covers basically most of what I can think of."*
  - **[P2]** *"The other strong point is the reference or mapping to ISO or GFMAM. Coming back to the topic of having a CMF in place for an organisation that want to expand into new development I would imagine - I have not seen any proof - I would imagine that any investor that knows there is a ISO 55000 compliant CMF in place would see this as a very positive point. That is a strong point of the whole CMF."*
  - **[P3]** *"We can echo some of the things that we said we before. But as we go through it overall that what stands out is the fact that in bidding for new plants - the business development activities - there is a lot of things that you can take out of this framework. If you are aware of the framework you know this is the sort of ideal model of the operation requirements you can really make sure than the contract and business development process and the OEM contracts are fully aligned with the CMF requirements."*
  - **[P4]** *"There is a good agnostic view. The methodology and the CMF seems to be developed without any major preconceived idea around*

what such a framework or the processes should look like and developed organically - this is a major strength."
  - **[P5]** *"The CMF is good at identifying gaps and understanding where the shortfalls are. It also has a good focus on continuous improvement to make sure the gaps are addressed."*
  - **[P6]** *"The initial strategy and planning is a strong point and key to developing a based from which to operate. Everything flows from this and would move everything and everyone in the same direction."*
  - **[P7]** *"I think that my overall picture is that the strength of it is the comprehensiveness and the fact that it goes back to first principles by leaving all preconceived ideas at the door in terms of what systems and processes are appropriate to a REPP and built a framework from the ground up. That to me would be a strong point. Although it is a strong point you have to bear in mind what I said about the discretion as it is not always practical to apply these frameworks."*

- **[FS-Q08]** In your opinion, what are the weak points of the research methodology and/or the CMF?
  - **[P1]** *"I AM not quite sure link I said last time, perhaps the overview."*
  - **[P2]** *"I cannot specify any specific weak point. So academically it could be good but practically it might not be as easy."*
  - **[P3]** *"I would not say there is a overall weak point. The challenge however is always to keep it practical. Like the ACPD spreadsheet, the competence framework needs to be practical. So that is always the challenge."*
  - **[P4]** *"I think if I was about to start a new RE AM organisation and I picked this up - the questions I would ask is: How much will this cost? How many people do I need? How long is it going to take. Ideally somewhere you have to indicate that it is a long term complex process."*
  - **[P5]** *"The complexity shocks you initially - but once you get through the details it seems logical. So perhaps the initial perception of complexity can be a challenge."*
  - **[P6]** "The time to implement might be a weak point. It will take very long and a lot of effort."
  - **[P7]** *"The strong point could potentially be the weak point. If you had to give this to a few focused of engineers they could spend three years and a lot of time and money."*

- **[FS-Q09]** Please specify possible improvements to the overall CMF and business processes?
  - **[P1]** "*Potentially there is room for some kind of a broader overview that makes it easier for non engineers or non technical people that does not understand the business - or if you take it to the board. So something that says this is phase 1, phase 2, phase 3 and then a one liner what is being done in the phase and the key outputs of*

each. Because they would see all these nice phases, but what do they do for me? This will be very important to the CEO and these types of guys. It can be one slide, the point is that it is what is most important"

- **[P2]** *"Nothing else specific from my side."*
- **[P3]** *"I would specifically split out competency management from continuous improvement from phase four. But this might also be due to my own bias based on a similar framework that I have used in practice."*
- **[P4]** *"The question I ask myself. How would you actually do this. Once again the implementation - for someone who is not a AM practitioner it will be daunting. But there is nothing major I can spot at this stage. I can understand why you used examples in the flow diagrams to make it easier to understand - but perhaps it would make sense to explain to people that these are just examples and that it is not all of the possibilities. You can note it in the diagrams.*"
- **[P5]** *"There is not a clear implementation plan. So perhaps an overall plan for how this can be implemented. Perhaps this is a bit out of scope?"*
- **[P6]** *"The process is quite complete - so there are no real major improvements."*
- **[P7]** "Nothing to add"

G.3.6 Framework Architecture and Success Criteria

Please comments on the following architectural aspects of the CMF by noting whether it is: **Poor, Fair, Good, Excellent?**

- **[FA-Q01] Overall value that the CMF can add to the RE industry and usefulness to the AM of a REPPs?**
  - **[P1]** "***Excellent***"
  - **[P2]** "***Excellent***: *- I AM normally conservative but I would say Excellent."*
  - **[P3]** "***Good***"
  - **[P4]** "***Excellent***: *Dependant on organisational context but if you are a greenfield organisation that have RE plants to run it should become your bible."*
  - **[P5]** "***Excellent***"
  - **[P6]** "***Excellent***"
  - **[P7]** "***Excellent***"
- **[FA-Q02] Overall impression and ease of use of the CMF?**
  - **[P1]** "***Good***"
  - **[P2]** "***Good: Because of the complexity and comprehensiveness."***

- **[P3]** *“**Good: But if we tune the** RCM **based spread sheet I will change it to excellent**”*
- **[P4]** *“**Good**: Because it is very difficult to explain what is a complex process in simple terms. It is not something where you can just pick up the book and go and do it. So the clarity with which it is expressed is good.”*
- **[P5]** *“**Good**”*
- **[P6]** *“**Excellent**”*
- **[P7]** *“**Good: It is a lot. People normally don't have the persistence to persevere through this processes**”*

- **[FA-Q03] Logical description of the CMF?**
  - **[P1]** *“**Good**: However to someone who does not understand the detail might struggle.”*
  - **[P2]** *“**Excellent**”*
  - **[P3]** *“**Excellent**: Perhaps because we are in the field - but to me it was logical and there were not any places where I felt lost.”*
  - **[P4]** *“**Good**: In your flow charts I can see that you tried to make it easy to understand by using examples in the flow diagrams. There should be a special note that these are just examples and not exhaustive.”*
  - **[P5]** *“**Good**”*
  - **[P6]** *“**Good**”*
  - **[P7]** *“**Good**”*
- **[FA-Q04] How easily comprehensible is the CMF and all the different phases are?**
  - **[P1]** *“**Good**”*
  - **[P2]** *“**Good**”*
  - **[P3]** *“**Good**: Perhaps if you would split phase 4 we can change it to excellent”*
  - **[P4]** *“**Excellent**:the way it's laid out and broken down is great.”*
  - **[P5]** *“**Excellent**”*
  - **[P6]** *“**Good**”*
  - **[P7]** *“**Good**”*
- **[FA-Q05] Overall flexibility of the CMF?**
  - **[P1]** *“**Good**”*
  - **[P2]** *“**Good**”*
  - **[P3]** *“**Excellent**: It is applicable to all types of REPPs.”*
  - **[P4]** *“**Fair**: You cannot do a one size fits all - and it cannot be effective if it is too flexible.”*
  - **[P5]** *“**Excellent**”*
  - **[P6]** *“**Excellent**”*
  - **[P7]** *“**Good**”*
- **[FA-Q06] Cohesiveness of the CMF and all the different phases?**
  - **[P1]** *“**Good**”*

  - **[P2]** *"**Good**"*
  - **[P3]** *"**Good**: I think there is more potential for links such as the ACP feeding into indicating the number of people. And then I don't think we spent a lot of type on continuous improvement. But I think it's important to make links between the other process. I think there sis potential for more links"*
  - **[P4]** *"**Excellent**"*
  - **[P5]** *"**Excellent**"*
  - **[P6]** *"**Excellent**"*
  - **[P7]** *"**Excellent**"*
- **[FA-Q07] Overall ability of the CMF to support Asset Managers and owners in centrally managing ACPs while remaining aligned to the ISO 55000 series of standards?**
  - **[P1]** "***Excellent**: Especially for someone who does not understand it. I wish I had this a year ago.*"
  - **[P2]** *"**Excellent**"*
  - **[P3]** *"**Excellent**: due to the overall ability to create awareness with Asset Owners and managers."*
  - **[P4]** *"**Excellent**: as long as the intention going in is to be ISO 55000 complaint."*
  - **[P5]** *"**Excellent**"*
  - **[P6]** *"**Excellent**"*
  - **[P7]** *"**Excellent**"*
- **[FA-Q08] Overall ability of the CMF to address the development of ACPs for REPPs?**
  - **[P1] "*Good*"**
  - **[P2]** *"**Good**"*
  - **[P3]** *"**Good**: you added some additional stps such as SJs, risk assessments, obsolescence "*
  - **[P4]** *"**Excellent**: the COFCATs tool makes it easy and almost possible to do without reading the text."*
  - **[P5]** *"**Excellent**"*
  - **[P6]** *"**Excellent**"*
  - **[P7]** *"**Excellent**"*
- **[FA-Q09] Overall ability of the CMF to address work planning and control and work order execution?**
  - **[P1] "*Good*"**
  - **[P2]** *"**Good**: there is room for optimising in the intra-day feedback into the central system with the use of technology."*
  - **[P3]** *"**Excellent**"*
  - **[P4]** *"**Excellent**: excellent job at giving you the tools."*
  - **[P5]** *"**Good**"*
  - **[P6]** *"**Excellent**"*
  - **[P7]** *"**Excellent**"*

- **[FA-Q10] Overall ability of the CMF to support core AM activities and the ISO 55000 series of standards?**
  - **[P1] "*Good*"**
  - **[P2] "*Excellent*"**
  - **[P3] "*Excellent*"**
  - **[P4] "*Good*"**
  - **[P5] "*Excellent*"**
  - **[P6] "*Excellent*"**
  - **[P7] "*Excellent*"**
- **[FA-Q11] Overall ability of the CMF to create the Line-of-Sight between the daily AM activities and the organisational and business strategies and objectives?**
  - **[P1] "*Excellent*"**
  - **[P2] "*Excellent*"**
  - **[P3] "*Excellent*"**
  - **[P4]** "***Good***: *It will always be difficult.*"
  - **[P5] "*Excellent*"**
  - **[P6] "*Excellent*"**
  - **[P7] "*Excellent*"**
- **[FA-Q12] Overall ability of the CMF to address competency and training requirements for all involved within the organisational AM activities?**
  - **[P1] "*Good*"**
  - **[P2] "*Good*"**
  - **[P3] "*Good*"**
  - **[P4]** "***Good***: *the improvement is around the test of is my competency framework system working*"
  - **[P5] "*Good*"**
  - **[P6] "*Good*"**
  - **[P7] "*Good*"**
- **[FA-Q13] Overall ability of the CMF to facilitate continuous improvement of AM activities?**
  - **[P1] "*Good*"**
  - **[P2] "*Good*"**
  - **[P3] "*Good*"**
  - **[P4] "*Good*"**
  - **[P5] "*Good*"**
  - **[P6] "*Good: sometimes the continuous improvement links are not indicated clearly enough in the process.*"**
  - **[P7] "*Excellent*"**
- **[FA-Q14] Overall ability of the CMF to use performance measurement (KPIs) to monitor, control and improve the AM activities?**
  - **[P1] "*Good*"**

- **[P2]** *"**Excellent**: due to stressing the Line-of-Sight application of the KPIs and improvident."*
- **[P3]** *"**Good**"*
- **[P4]** *"**Excellent**: but very dependant on the appropriateness of the KPIs."*
- **[P5]** *"**Excellent**"*
- **[P6]** *"**Excellent**"*
- **[P7]** *"**Excellent**"*

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