National Manual of Assets and Facilities Management

Volume 5, Chapter 20

System Assessments and Monitoring

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1.0 PURPOSE

Successful operations of the Entities business functions rely on applying robust System Assessments and Monitoring (SA&M) techniques on all organizational processes using best industry practice such that there are no disruptions in services and the ultimate business goals are met.

This document presents, reviews, and analyzes best practice approaches under SA&M subject matter, to help Entities monitor/assess their operational activities and systems successfully and to improve the business processes.

2.0 SCOPE

The scope of this document is to guide the government Entities on the functional aspects of SA&M in the context of Operations and Maintenance (O&M) from System Engineering (SysE) perspective. Although references are made to commonly used SA&M methodologies within industry, each Entity shall establish their own individual SA&M goals, objectives, and models, according to their specific predefined mission, vision, and strategic plan.

This document does not intend to explain any specific SA&M framework, method, or process for any particular Entity, rather it demonstrates the key aspects of SA&M typical techniques, process, standards, tools, and analogies, while combining the SA&M viewpoints.

The advantages of SA&M can be realized by its various outputs such as ‘strengths, weaknesses, gaps, and opportunities’, which lead Entities toward strategic improvement and achieving a coherent operation mechanism.

Topics covered within this document include:

- Understanding the SA&M concept
- Types of SA&M
- SysE process and the concept of SA&M
- SA&M viewpoints
- Role of SA&M within an O&M domain
- Advantages of SA&M application during systems acquisition and qualification processes
- Description of steps involved in a typical system specific SA&M process i.e., planning, assessment, risk management & mitigation, monitoring and reporting
- Assets monitoring and assessment flows and controls using IDEF0 model

Entities should follow Expro standards and guidelines during system assessments or monitoring process.

3.0 DEFINITIONS

Term	Definition
Building Management System (BMS)	A building wide network which allows communication with a control of items of building engineering systems. It may also include any third-party systems
Calibration	When a device or instrument delivers a value that can compare to a standard value of known accuracy
Condition-Based Maintenance	A maintenance strategy that monitors the actual condition of an asset to decide what maintenance needs to be done. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure
Condition Monitoring	A measurement of data, indicating a condition of a system, which allows for the need to determine any maintenance of that system of device
Corrective Maintenance	A task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational

Term	Definition
	condition within the tolerances or limits established for in-service operations
Energy Management Control System (EMCS)	A computerized control system which regulates a buildings energy consumption by controlling the operation of such systems such as the heating, ventilation and air conditioning (HVAC), lighting, and water heating systems
Entity	Includes Government Ministry, EPMO, Engineering Management Company or any other agency authorized by the Government Ministry to work on its behalf
Monitoring and Assessment	Monitoring and Assessment concepts are strongly coupled. However, to enhance the understanding of these concepts, differences between them need to be clarified. The differentiation between the both concepts as follows: **Monitoring** is the observation process and recording of the current state and change in conditions for an asset, system, and/or process. While, **Assessment** is the utilization of that data (monitoring step outcome) to evaluate the monitored target (i.e., asset), in order to support the decision-making actions. Each concept uses different tools and/or techniques, in order to achieve predefined objectives of its functionalities
Operations and Maintenance	Operations and Maintenance of facility and assets. The entity may be required to enter into single or multiple agreements with second parties to perform O&M works or services
Predictive Maintenance	Is the work that is scheduled in the future based on analysis of sensor measurements and formulas
Preventative Maintenance	A task regularly performed on a piece of equipment to lessen the likelihood of it failing. It is performed while the equipment is still working so that it does not break down unexpectedly
System Engineering (SysE)	In the context of O&M, SysE process is a complete, iterative, and recursive solution, applied consecutively 'top-down' by skilled teams, in order to transform pre-defined requirements into systems and/or services
Transducers	A device converts physical quantity into an electrical quantity
Acronyms	
AE	Acoustic Emissions
AHU	Air Handling Unit
AMS	Asset Management System
AoA	Analysis of Alternatives
AP	Acquisition Process
BIFM	British Institute of Facilities Management
BMS	Building Management System
C&BA	Cost/Benefit Analysis
CA	Capability Assessment
CBM	Condition Based Maintenance
CMMS	Computerized Maintenance Management System
COTS	Commercial of the Shelf
CT	Current Transformer
DAU	Defense Acquisition University
DoD	Department of Defense
EMCS	Energy Management Control System

Term	Definition
ET	Electromagnetic Testing
FAA	Functional Area Analysis
FM	Facilities Manager
FMC	Facilities Management Company
FNA	Functional Needs Analysis
FSA	Functional Solution Analysis
GSE	Gravity Spike Energy
HAZOP	Hazard and Operability Analysis
HSE	Health Safety Executive
HVAC	Heating Ventilation and Air Conditioning
ICE	Instrumentation Control Engineering
IDEF0	Integration Definition for Function Modeling
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council on Systems Engineering
ISO	International Organization for Standardization
KPP	Key Performance Parameters
KSA	Kingdom of Saudi Arabia
NASA	National Aeronautics and Space Administration
NM & FM	National Manual of Assets and Facilities Management
MCC	Motor Control Center
MCSA	Motor Current Signal Analysis
MEP	Mechanical, Electrical and Plumbing
MIF	Maintenance Induced Failure
MOEs	Measures of effectiveness
MOPs	Measures of Performance
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
MV/LV	Medium Voltage/Low Voltage
NASA	National Aeronautics and Space Administration
NCLOM	The National Committee for Legislation and Standardization of Operation and Maintenance
NDT/NDE	Non-Destructive Testing/Non-Destructive Examination
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
PC	Personal Computer
PM	Predictive Maintenance
PPE	Personal Protective Equipment
PPM	Planned Preventative Maintenance
PSM	Process Safety Management
PTW	Permit-To-Work
QC/QA	Quality Control and Quality Assurance
QFD	Quality Function Deployment
QP	Qualification Process
RA	Risk Assessment
RA&M	Risk Assessment and Mitigation
RAMS	Risk Assessment Methods Statement
RCM	Reliability Centered Maintenance
RMP	Risk Management Planning
SA&M	System Assessments and Monitoring
SEI	Software Engineering Institute

Term	Definition
SFA	System Feasibility Analysis
SOAP	Spectrographic Oil Analysis Program
STP	Shielded Twisted Pair
SysE	System Engineering
THS	Thermographic Survey
TPM	Technical Performance Measures
UE	Ultrasonic Examination
UI	Ultrasonic Inspection
UT	Ultrasonic Testing
VA	Vibration Analysis
VT	Voltage Transformer

Table 1: Definitions and Acronyms

4.0 REFERENCES

- British Institute of Facilities Management (BIFM) – Sourcing strategies
- International Organization for Standardization (ISO 13374) – Condition Monitoring and Diagnostics of Machines – Data processing, communication and presentation, 2017
- International Organization for Standardization (ISO 17359) – Condition Monitoring and Diagnostics of Machines, 2018
- International Organization for Standardization (ISO 18436) – Condition Monitoring and Diagnostics of Machines – Requirements for Qualification and Assessment of Personnel, 2019
- International Organization for Standardization (ISO 55000) – Asset Management – Overview, Principles and Technology, 2016
- National Aeronautics and Space Administration (NASA) – Systems Engineering Handbook (NASA/SP-2007-6105 Rev1)
- National Manual of Assets and Facilities Management (NMA & FM) – Asset Management System Standard Requirements - ENT-ZAO-SD-000001
- National Manual of Assets and Facilities Management (NMA & FM) – Assets Register Standard Requirements - ENT-ZAO-SD-000002
- National Manual of Assets and Facilities Management (NMA & FM) – Condition Assessment Standard Requirements - ENT-ZCO-SD-000001
- National Manual of Assets and Facilities Management (NMA & FM) – System Knowledge Requirements - EOM-ZO0-PR-000092
- National Manual of Assets and Facilities Management (NMA & FM) – System Engineer Qualification Process - EOM-ZO0-PR-000096
- National Manual of Assets and Facilities Management (NMA & FM) – Dashboard Development Scope - EXP-ITO-PL-000005
- National Manual of Assets and Facilities Management (NMA & FM) – Monitoring and Evaluation Operating Procedure - EXP-P00-PR-000001
- Operations & Maintenance Best Practices – A Guide to Achieving Operational Efficiency, Release 3.0, August 2010
- Project of Survey and Study of the Current Operation and Maintenance Work Statues at Government Facilities – Executive Report (31 Jan 2016)
- System Engineering Fundamentals, January 2001, DoD System Management College

5.0 RESPONSIBILITIES

Role	Description
Entity	Utilize SysE approach as much as needed within their O&M activities, in order to achieve their optimal goals and objectives
Expro	Set the required SysE concepts in relation to O&M activities, and support Entities with any further SysE knowledge and implementation
Facilities Manager	The Facilities Manager is responsible for: • Creating document in accordance with this procedure as instructed by (Original Equipment Manufacturer) OEM of systems and equipment • Monitoring compliance with this procedure • Providing advice and guidance on the implementation of this procedure
Maintenance Manager	• Ensures this procedure is implemented and adhered to • Provides the appropriate personal protective equipment (PPE) for all employees and subcontractor personnel operating at the facility • Verifies the health, safety, environment and security matters • Ensures effective Permit-To-Work systems are implemented
Operations Engineer	The Operations Engineer is responsible for supervising all installation, maintenance, modification, overhaul, service, and repair of engineering systems. The duties include, but not limited to: • Ensure that the work performed is in compliance with blueprints, manufacturer specifications, and written and/or verbal instructions • Plan, schedule, and assign work and crews to ensure adequate resources for efficient performance of duties • Monitor jobs to ensure quality and compliance with standards, update records, report on performance, and resolve issues • Instruct personnel on activities related to system maintenance to ensure an acceptable work performance level • Supervise or assist in personnel actions including, but not limited to, hiring, performance appraisals, promotions, and scheduling time off • Perform other duties as assigned

Table 2: Responsibilities

6.0 PROCESS

6.1 System Assessments and Monitoring (SA&M)

SA&M in the context of O&M is a designed set of processes and activities that support an Entity to evaluate, control, maintain, and manage their assets in a systematic approach. Furthermore, SA&M techniques help to develop the appropriate handling plans and actions for any discrepancies or issues that are uncovered within their enterprise infrastructure, or O&M activities including assets and/or projects.

The SA&M, as a concept, is coupled with the overall Entity's strategy, risk and mitigation plans, decision management, and actions processes. Figure 1 shows a simple representation of the SA&M concept main process based on standards International Organization for Standardization (ISO) 55001 & 55002.

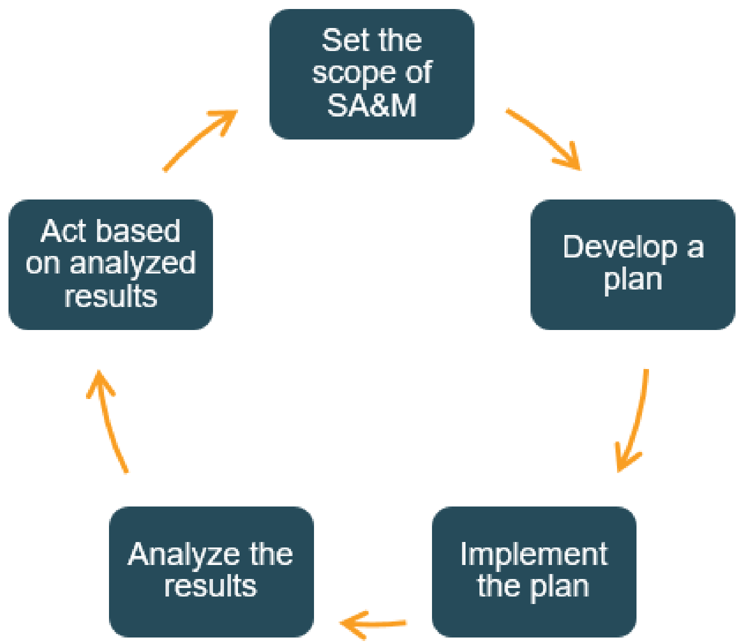

Figure 1: The Basic Process for SA&M Concept

6.1.1 Types

During O&M activities there are two major monitoring and assessment approaches that need to be clarified. A description of these are provided below:

6.1.1.1 Internal SA&M

This type of SA&M approach is mostly automated as it includes embedded modules (sensors) within the systems, which perform assessment and monitoring functions to detect anomalies in the equipment/processes. However, for some systems in an Entity, some additional checks and processes might be required, which need to be performed by the teams responsible for such systems e.g., calibration of devices, security and performance assessment procedures.

Most of the current O&M utilized technical systems are 'Commercial-Off-The-Shelf (COTS)', which have been developed based on the standard plug and play concept. A COTS system has embedded checks that inform the users of any issue within the system functionality.

Further guidance on this type of assessment is out of this document scope, although the processes included in this procedure are applicable for both types of SA&M (internal and external) activities.

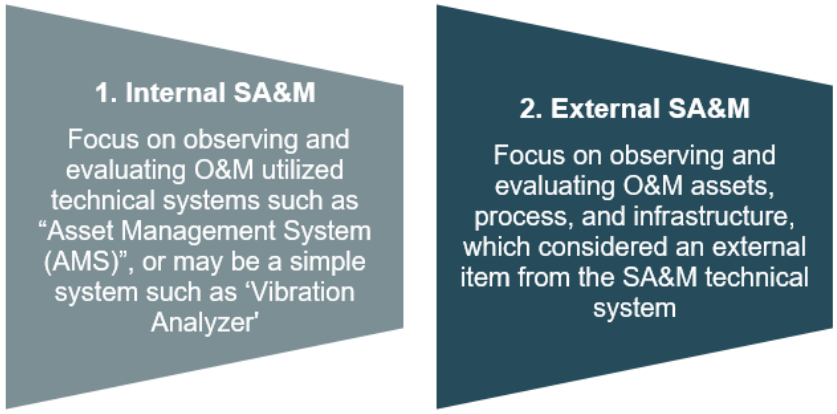

Figure 2: The Main SysE Types of SA&M within the O&M Context

6.1.1.2 External SA&M

External SA&M approach focuses on items outside the boundaries of targeted systems. External SA&M activities are undertaken on a periodic basis to measure operational success against predefined objectives.

The evaluation techniques should assist the Entity in deciding whether they need corrective or preventive actions against the objects, which have been measured.

External O&M items that should be monitored and assessed by SysE approach include:

- Processes
- Assets
- Infrastructures
- Behaviors
- Others (which could cover all the O&M general and/or specific activities, where applicable)

6.1.2 SysE Process and the Concept of SA&M

SA&M could either be the main Entity requirement, which will make overall SysE process focused on facilities and assets monitoring and assessment or could be part of the Entity requirements, which will be taken into consideration when developing SysE plan. The utilization and implementation of SysE approach should be done by experienced skilled personnel, or teams.

SysE process is illustrated in Figure 3 highlighting the SA&M component, as proposed by US Defense Acquisition University (DAU) standard.

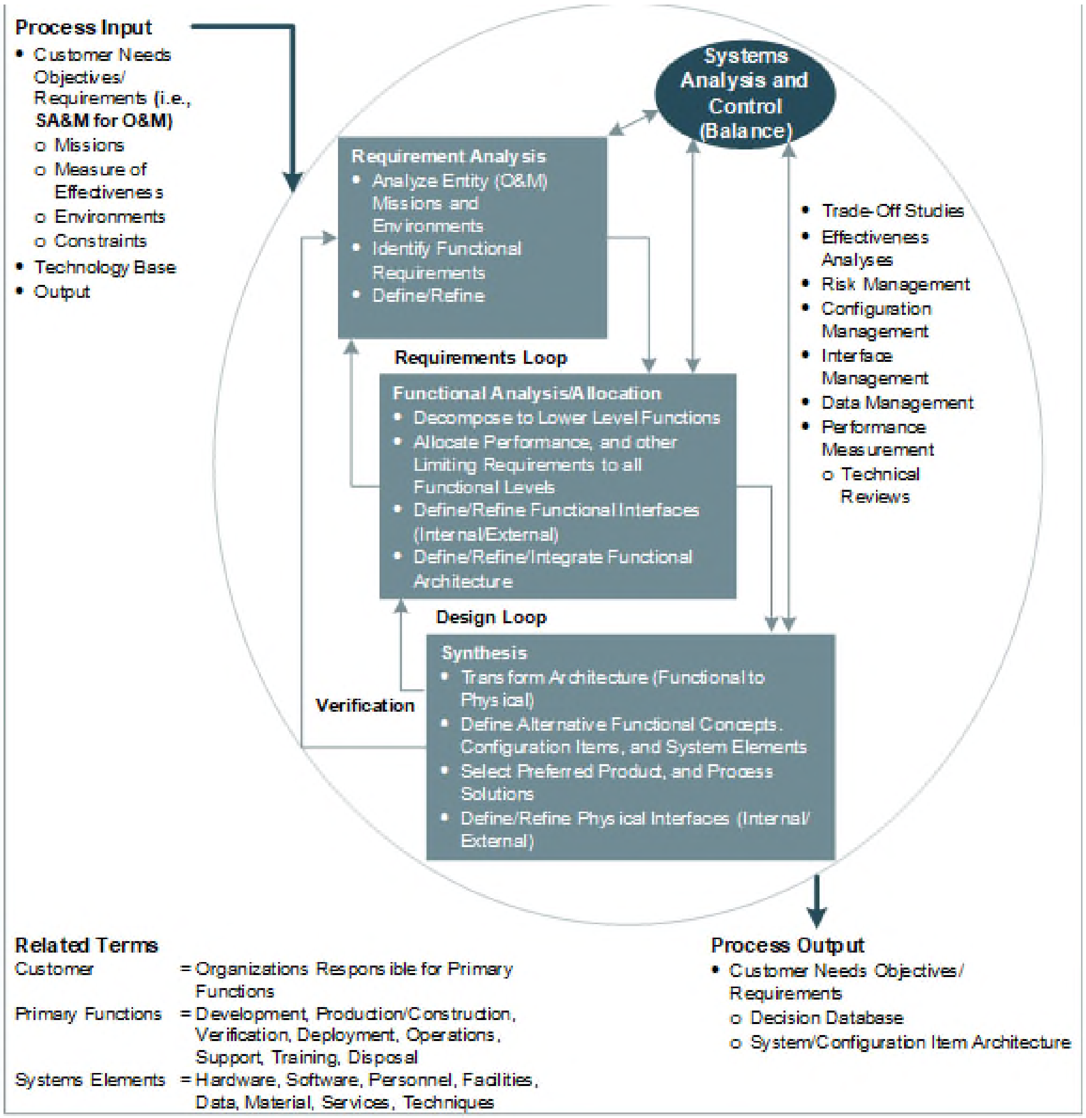

Figure 3: Common Standard SysE Process, after DAU, Scoped to O&M

SysE process could be altered to serve the Entity overall goal. The common standard components include:

- Inputs
- Requirements analysis
- Functional analysis and allocation
- Requirements loop synthesis design loop
- Outputs
- Verification and system analysis and control

Refer to standard ISO 15288, for further insights regarding employment of SA&M within SysE process, applied in various Entity modules.

6.1.3 Viewpoints

The best industry SA&M techniques develop the requirements that cover all viewpoints, with the right plans in place. Studying Performance Trends (SPT) is a wide domain, which could target all angles of an existing organization, project, process, or a specific subject matter, if required, as illustrated in Figure 4. The SPT approach takes significant effort and measurement, which should be undertaken according to a clear goal and overall strategic plan. The "goal, question, metric" paradigm (Basili 1992) emphasized that each collected data obtained from a specific measurement/metric should answer a question to satisfy a particular goal.

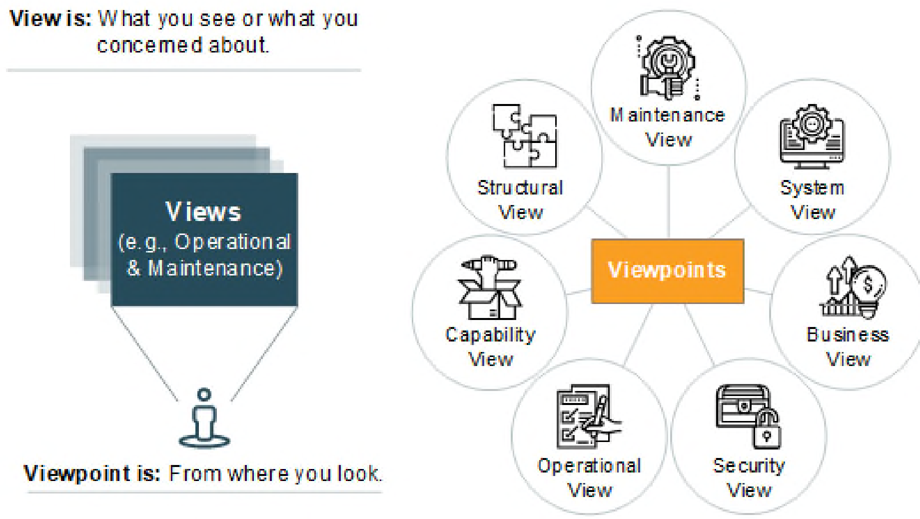

Figure 4: Example of O&M Views

6.1.4 Role of SA&M within an O&M Domain

The purpose of SA&M from SysE perspective is to provide Entities adequate visibility into their O&M domain including:

- Assets
- Processes
- Projects
- Systems

Based on Entities strategic plans, O&M management plans, SysE plans, or any other superordinate plans, applying SA&M techniques from SysE perspective serve wide range of ongoing O&M activities.

Assessment and monitoring by means of SysE approach allows Entities to take timely corrective actions when performance analysis results fail to reach the expected thresholds or values. On the other hand, Entities should apply preventative actions to ensure continuous operations and avoiding the need of corrective actions when unwanted trends are recognized in any aspect of O&M activities.

All SA&M plans, process, reviews, actions, and history should be documented in a scientific and proper manner. The standards and best practice (e.g., NASA 2007, SEG-ITS, 2009, INCOSE, 2010, SEI, 2007) are recommended to be utilized during SA&M development activities, where applicable.

Some of SysE assessment and monitoring characteristics that benefit O&M domain in general are as follows:

- Quantitative or qualitative analysis
- Systematic in nature
- Utilizing standards and best industry practice
- Comprehensive
- Using consistent measures
- Cumulative
- Diagnostic
- Utilizing informal, semi-formal, or formal methods, and languages
- Guidance-oriented

Furthermore, utilizing the SysE-SA&M approach will facilitate the Entities in performing the following tasks in an efficient manner:

- Monitoring and reviewing processes, projects, assets, and technical performance against pre-defined plans
- Monitoring technical and non-technical risks, prioritizing based on their significance and impact, documenting, and mitigating them through plans
- Investigating and analyzing issues and determining appropriate actions through the action plans
- Performing technical and non-technical reviews, where applicable, and reporting their outcome to the required stakeholders

6.1.5 Advantages of SA&M Based System Acquisition and Qualification Processes

Applying SA&M techniques during O&M system acquisition and qualification processes provide many benefits including, but not limited to:

- Traceability factors help to connect system (e.g., Asset Management System (AMS)) design requirements to test alongside the O&M objectives
- Reducing errors in system delivery by enabling validation/verification within assets/systems lifecycle from requirements to acceptance test as they are created/or purchased
- Improving system stakeholder's participation by establishing O&M requirements and benchmarking the processes
- Supporting management for any changes before/after system purchase process
- Assisting in risk management during the Acquisition Process (AP)
- Improving organizational learning during the Qualification Process (QP)
- Understanding organization (Entity) mission, vision, goal, and O&M objectives and then defining the Entity business needs concerning O&M domain, according to different analysis methodologies, such as:
    - CA (Capability Assessment)
    - RA&M (Risk Assessment and Mitigation)
    - FAA (Functional Area Analysis)
    - FNA (Functional Needs Analysis)
- Selecting the right system/service by performing necessary analysis, such as:
    - Functional Solution Analysis (FSA) from both sides, the Entity and the required system/service
    - Analysis of Alternatives (AoA) for solutions or other similar products in the market. Refer to Attachment 1 for main AoA steps, as an example
    - System Feasibility Analysis (SFA)
    - Cost/Benefit Analysis (C&BA) – Cost Estimation targeting required system/service and the benefits from acquiring such product to the Entity
    - Benchmarking
    - Other associated Entity-specific analysis techniques as may be employed

Refer to NMA & FM – System Engineering Qualification Process – EOM-ZO0-PR-000096, in addition to this document

6.2 Procedure

According to the best practice observed in industry and government sectors, a typical SA&M procedure is illustrated in Figure 4 below and explained in the following sub-sections.

Figure 4: SA&M Main process

6.2.1 Plan

SA&M plan will focus on O&M assets, facilities, process, and/or projects, and should outline:

- The technical assessment and reviews process
- Measurement plans
- Equipment utilized for monitoring and assessments activities.
- Mitigation plans
- Others as needed (Entity/sector-specific)

6.2.1.1 Technical Measures

These will identify and select a proper method for assessments such as:

- Measures of Effectiveness (MOEs)
- Tradeoffs analysis
- Benchmarking
- Measures of Performance (MOPs)
- Technical Performance Measures (TPMs)
- Key Performance Parameters (KPPs)
- Simulations
- Quality-function deployment (QFD)
- Hazard and Operability Analysis (HAZOP)
- Process Safety Management (PSM) approach
- Risk Management Planning (RMP) approach
- Process Integration and Product Improvement best practice, which was developed by Software Engineering Institute (SEI).
- The Capability Maturity Model Integration for Development (CMMI) - This approach covers development, services, integrated product, and acquisition processes
- Other methods, where applicable

6.2.2 Assess

In order to perform SA&M, the assessment requirements should be developed correctly as explained in NMA & FM Volume 5, Chapter 20 – System Knowledge Requirements (EOM-ZO0-PR-000092).

Following are examples of the requirements areas for SA&M in O&M Domain, which are provided by the IEEE P1220:

- Customer expectations
- Project and enterprise constraints
- External constraints
- Operational scenarios
- Measure of Effectiveness (MOEs)
- System Boundaries
- Interfaces
- Utilization environment
- Lifecycle
- Functional Requirements
- Performance Requirements
- Modes of operations
- Technical performance measures
- Physical characteristics
- Human systems integration

The four main processes that have been mentioned in Figure 4 could be elaborated further, if required by any Entity. Thus, as an example of the assessment process elaboration, Figure 5 below illustrates the National Aeronautics and Space Administration (NASA) approach for their SA&M, which is typically applicable to an Entity's technical O&M activities.

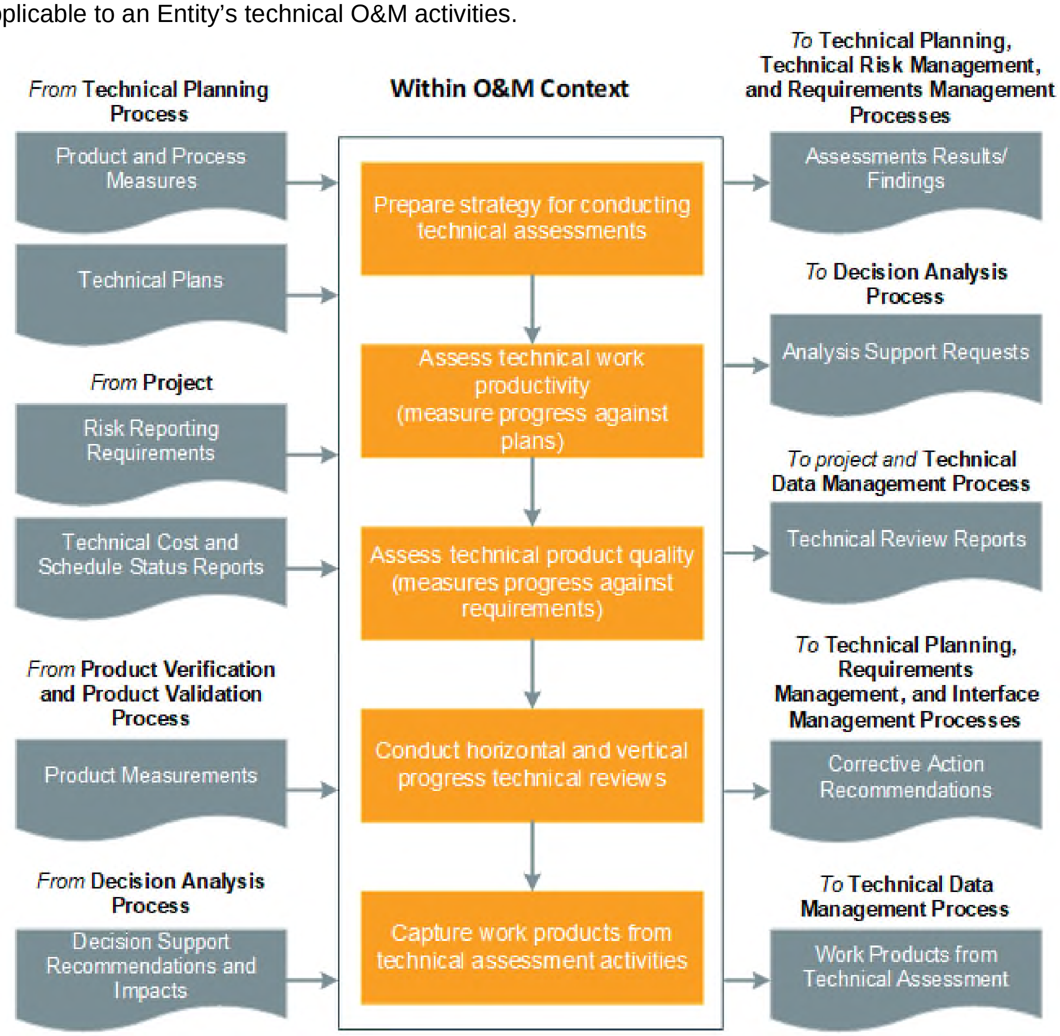

Figure 5: SysE Technical Assessment Process, after NASA with amendment

6.2.2.1 O&M Process Assessment against Capability Levels Scale

Part of SysE assessment concept is to evaluate the O&M process against Entity capability levels as proposed by 'ISO/IEC 15504' in Figure 7. The scope of the assessments should be defined by the Entity in the mapping process reference model as shown below:

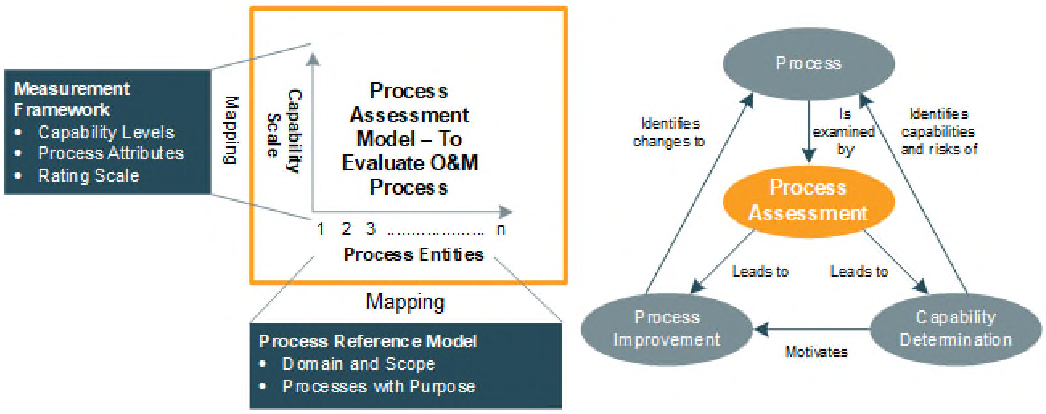

Figure 7: SysE Process Assessment Model, by ISO 15504, Scoped to an O&M Domain

6.2.3 Handle (Risk Management & Mitigation)

To demonstrate the usability of SysE models in the O&M SA&M context, Figure 8 shows risk identifications and priority matrix.

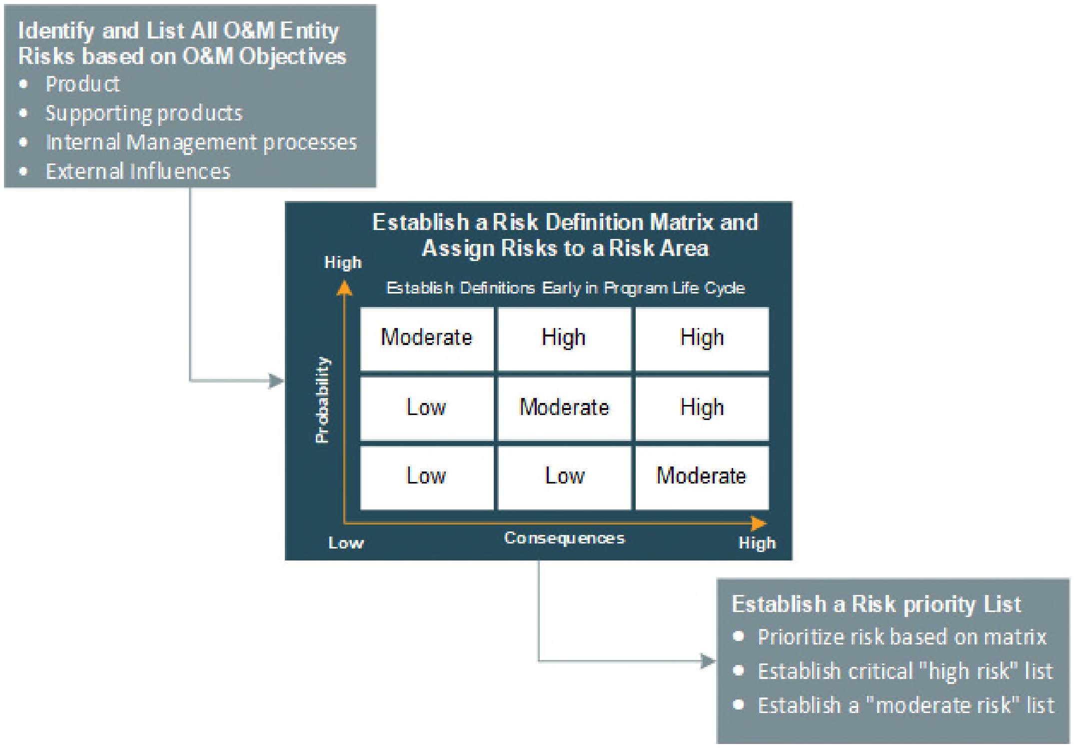

Figure 8: Risk Identifications and Priorities, Scoped to an O&M Domain

While Figure 9 below, indicates the risk assessment and feedback controls relationships.

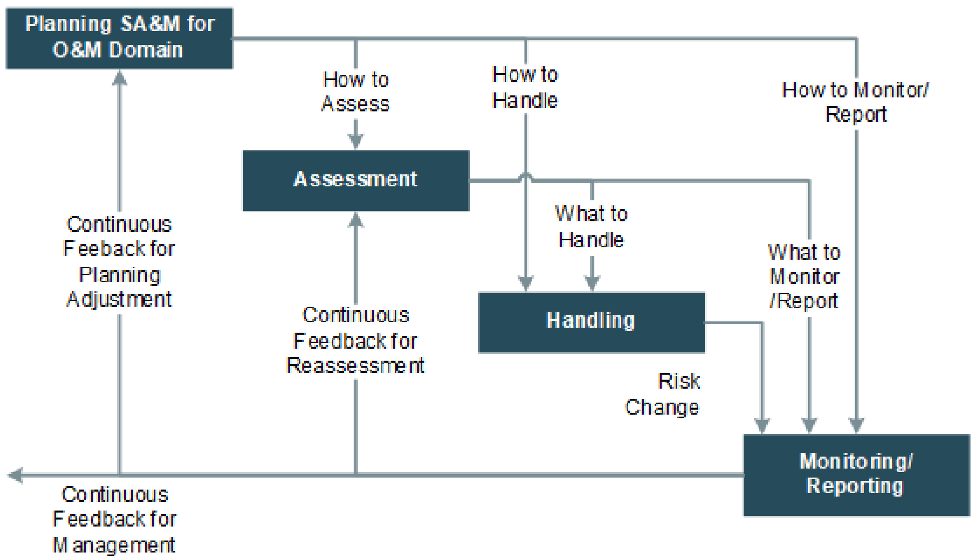

Figure 9: Risk Management and Controls Concept using SysE Modelling, after DAU, Scoped to an O&M Domain

6.2.4 Monitor & Report (System Specific)

The list give below is not exhaustive, only including a small section of emerging and existing technologies available, that have proved to be effective in the monitoring and reporting of an asset's condition:

- Condition Based Maintenance (CBM)
- Vibration Analysis (VA)
- Thermographic survey (THS)
- Ultrasonic Inspection (UI)
- Motor Current Analysis
- Corrosion Monitoring
- Oil/Fluid analysis
- Non Destructive Testing/Non Destructive Examination (NDT/NDE)

6.2.4.1 Condition Based Maintenance (CBM)

An example of CBM is monitoring of an Air Handling Unit (AHU). An AHU is designed to move large volumes of air within a facility through the ductwork to areas of the building. The air drawn from outside is passed across a series of filtration media to remove dust and particulate matter from the air for a healthy and pleasant user environment. A gauge will be fitted between the outside air and the secondary side of the filter to monitor the level of restriction to flow. A high value will indicate that these filters are becoming blocked and at a set value they must be cleaned or changed to allow the correct volumes to be provided and not reduce the level of comfort to users. This is a prime example of CBM where the filters are changed when they reach the end of their useful life. The advantage of undertaking maintenance in this manner is that the equipment is left to run without unnecessary maintenance until necessary. Undertaking the maintenance and reinstating the system back to normal function also has cost savings upon energy costs as leaving clogged filters until a scheduled maintenance period will increase fan resistance with a subsequent increase in motor current and utility cost.

Following on from the above example, the additional technologies are explained further here as they all form a collective term of CBM.

6.2.4.2 Vibration Analysis

Vibration Analysis is a form of data collection using a specialized monitor. The monitor is generally a portable device that can be operated by a technician without in-depth training on results interpretation. Typically, they revolve around two principles of operation where they will undertake the following readings:

- Gravity Spike Energy (GSE)
- Vibration velocity (mm/s)

Figure 11: Vibration Analyzer (TPI Technologies)

GSE is related to the ‘noise’ generated by a rolling element, when there has been wear and tear. The greater the wear and tear, the more the internal tolerances will be ‘opened up’ leading to noisier operation. The vibration equipment can be placed close to the bearing housing to monitor this level on a periodic basis, monthly being a good example. This reading will then be trended against previous and will generally show a small gradient rise over a period as the wear continues. A significant increase upon the gradient or values will demonstrate that the bearing is moving toward distress and as such will require to be changed. The trained operator can then use the gradient to predict when additional maintenance needs to be undertaken prior to ‘failure’ and program the resources accordingly. An example of a distressed bearing graph is shown below.

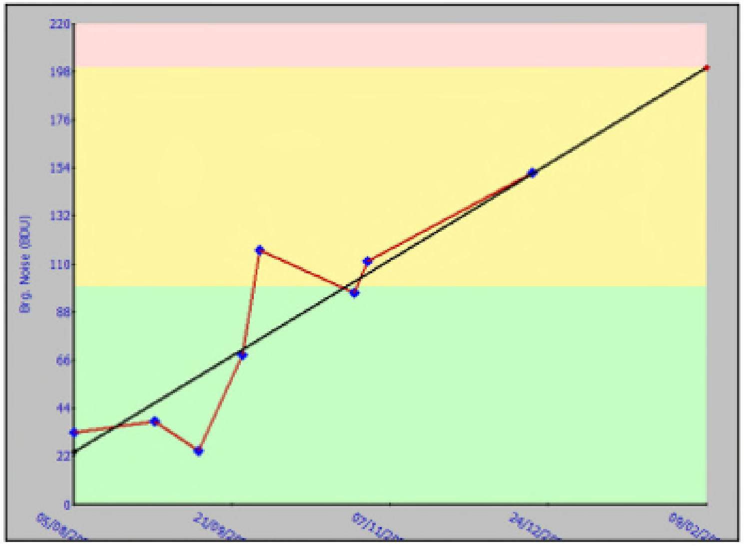

Figure 13: Gravity Spike Trend Graph

The same piece of test equipment can also be used to monitor the level of vibration within an item of rotating equipment. As the equipment wears out, the tolerances within will increase and lead to an increase in vibration. In addition, various other parameters can be monitored which will provide a 'health analysis' of the machine. Interpretation of the results needs to be undertaken by a specialist engineer trained in the interpretation of these results. Collection of the data can be undertaken in conjunction with bearing monitoring highlighted above. Specialist software is utilized with the equipment and the specialist engineer can program alarm points into the software at preset limits to notify when the equipment is showing signs of excessive wear and tear and needs attention. A typical example of the resultant graph is shown below. However, the interpretation of the results is beyond the level of this document

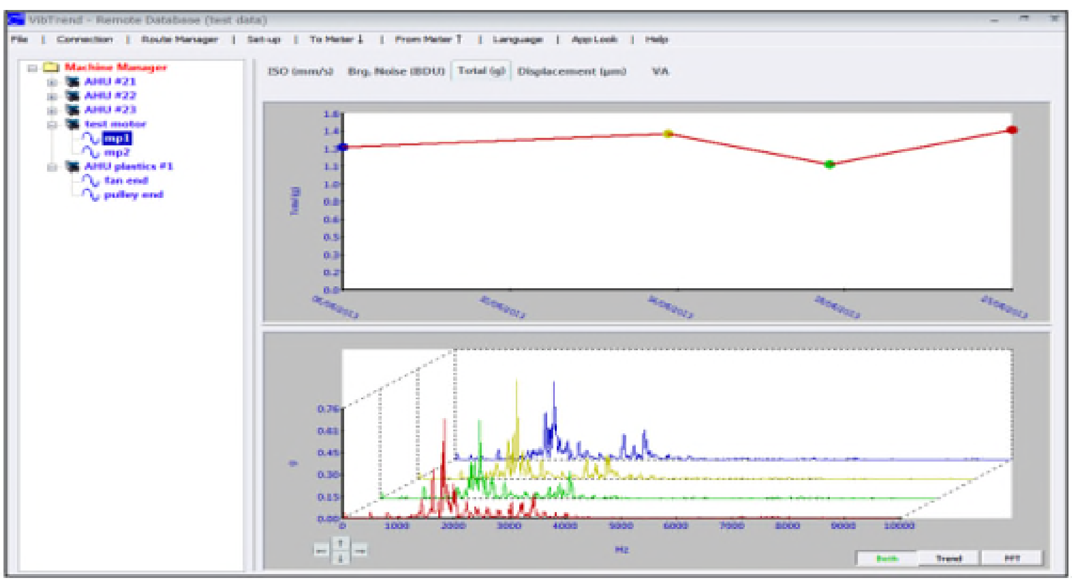

Figure 14: Velocity mm/s Vibration Trend Graph

6.2.4.3 Thermographic Survey

A thermographic survey is an assessment of the heat that is being generated from an item of plant or equipment. All equipment under running conditions will demonstrate an increase in temperature due to friction, electrical current flow, or the process involved. The level of heat can have a detrimental effect upon the equipment unless it is kept within design parameters. Typical examples of excessive heat can be from incorrect or inadequate lubrication or cooling. The imbalance might be caused by electrical load, poor connections to electrical terminals through loosening or over-tightening. A special camera is used to assess the temperature of the components being photographed or monitored and will give an indicative reading of the temperature. It will also give a representation of the temperature relative to its surroundings and adjacent components. These readings can be taken by the technician and the results interpreted by trained engineering staff. It is worth noting that setting up of the camera parameters is key to ensuring that the upper levels are indicated as often intrusive maintenance is undertaken due to incorrect set up. Trained engineers will understand some of the common faults and can take remedial action to resolve. An example of the equipment is shown below in conjunction with the output that can be achieved for an item showing a fault.

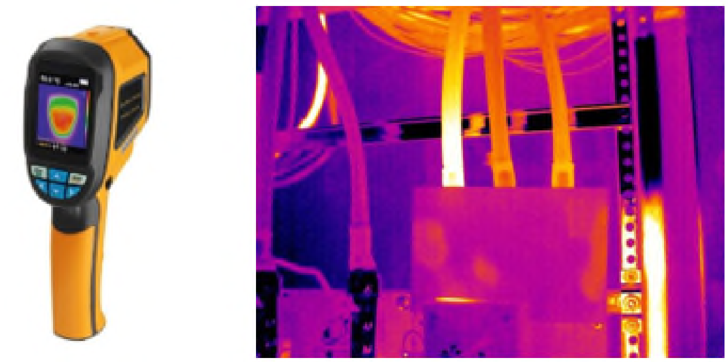

Figure 15: Thermographic Tester and Phase Imbalance Example

The special cameras can be inexpensive relative to the significant advantages that they provide in early detection of faults. It is recommended that Entities undertake Thermographic surveys on the following items of plant on an annual basis and incorporate these within the PPM schedule:

- MV/LV switchgear
- Transformer terminals (where accessible)
- Electrical Starter and contactor panels
- MCC (Motor Control Center) Panels
- Inverter drives
- Generator cables
- Large Induction motors
- Distribution panels

6.2.4.4 Ultrasonic Inspection

Ultrasonic detection is a more complex methodology for carrying out CBM. This would normally be undertaken by a specialist service engaged by the Entity to undertake maintenance on specialist/critical equipment. It is costlier than traditional methods due to the external engagement and equipment. Therefore, would only be considered as a special case.

The technology involves passing sound waves across the equipment under test and can identify anomalies in the sounds detected related to defects within materials or the system. For instance, uneven wear in an individual ball of a bearing race can cause periodic sounds to be detected at high frequency using the detection equipment. This can then be interpreted, following trend, for when the bearing may start to be distressed and lead to failure.

6.2.4.5 Motor Current Signal Analysis (MCSA)

Similar to Ultrasonic testing this is a specialized area of maintenance technique that is likely to be assigned to critical equipment that may not be isolated easily, due to its reliance for operations. It could also be used when Entity engineers suspect that there may be a system problem following observations on the system or through other methods highlighted above. As such it may be used in conjunction with a combination of CBM to 'diagnose' a problem and allow the management to target repair or investigate further.

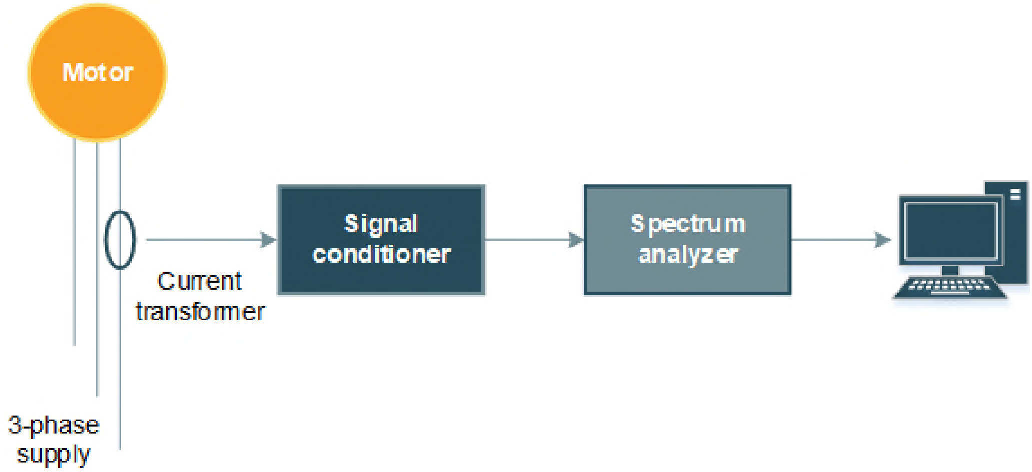

Figure 16: Motor Current Signal Analysis (MCSA) arrangem

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This methodology relies upon monitoring of the electrical supply characteristics of rotating equipment which can be affected by electrical and/or mechanical defects within the motor and connected equipment. It has the ability to detect winding faults within the rotor/stator of the motor through the use of 'harmonic analysis.' These faults may be attributable to:

- Insulation Fault
- Winding defect
- Rotor fault
- Eccentric rotor (change in air gap)

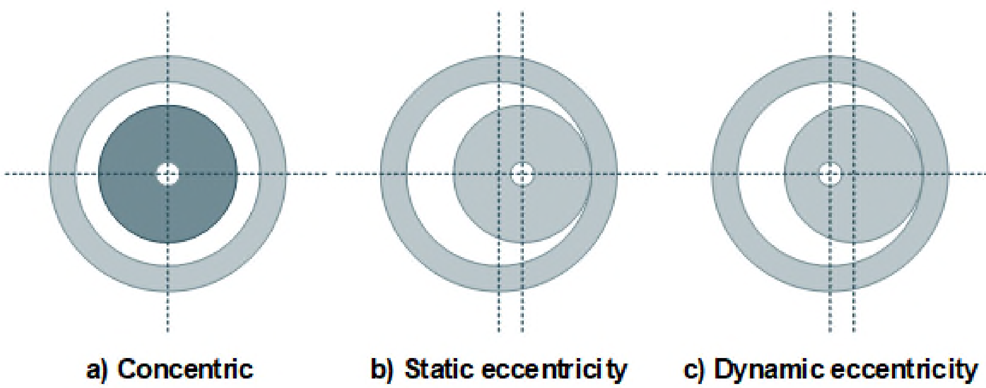

Figure 17: Physical Defects of Rotating Equipment

Additionally, using the applied logic within the monitoring equipment it can also detect certain mechanical faults like:

- Misalignment
- Bearing damage
- Torque loading

6.2.4.6 Corrosion Monitoring

Corrosion monitoring is a technique predominantly used in water systems that rely upon steel and alloys within the pipe systems connecting services. A common area for this method to be utilized within an Entity facility is monitoring of the Chilled Water System cooling towers. This can comprise the following common methodologies to be employed in the monitoring of 'rate of corrosion' within the system. There are many other methodologies available but only the following are highlighted here:

- Corrosion Coupons
- Electrical Resistance

A series of plates are contained within an installed holder inside the cooling tower, as shown. These contain different metals that have a defined weight and physical size. The coupons are left within the flow of the cooling tower condensing water for a set period and monitored for their rate of degradation over that period. This allows the water specialist company to assess the effectiveness of the chemical treatment within the condensing system and adjust the automatic dosing levels as required.

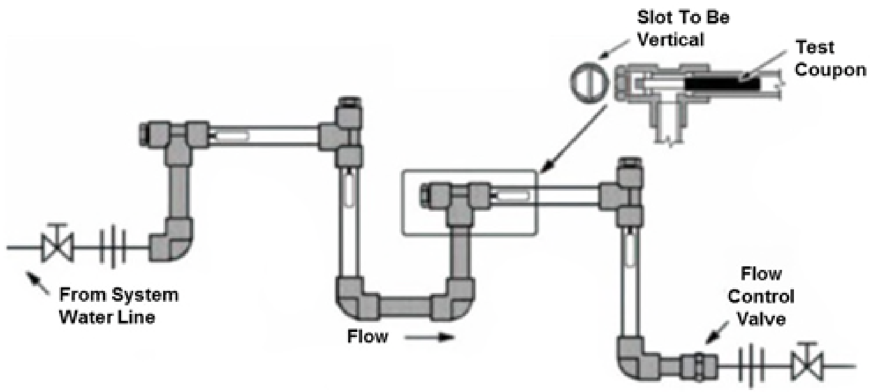

Figure 18: Corrosion Coupon Installation

An additional technology that may be employed is the use of fixed probes within the system that can be connected to a portable meter. This then allows closer monitoring of the levels of corrosion and input into a dedicated software system to predict the rate of corrosion and more accurately adjust dosing levels based upon conditions as they occur. The initial high cost of installing this method may be offset as a reduction in chemicals, particularly corrosion inhibitor, over the lifetime of the equipment. However, continuous calibration and probe replacement would need to be considered by the Entity.

6.2.4.7 Oil/Fluid Analysis

Engine and rotating equipment manufacturers predominantly recommend that lubricating and hydraulic oil be changed at certain periodicity as the lubricating and cooling qualities of the oil or fluid will ensure that the system is well maintained. Although, it has been proven that this is often an unnecessary task since the oil change requirement is based on several factors e.g., running hours, similar to that of motor vehicles. Additionally, used oil is classed as 'hazardous waste' and attracts further costs for its disposal, along with the associated environmental impact. An alternative method for the decision on changing the oil is an Oil Analysis program.

A small sample of the oil is taken at its working temperature and within the normal flow around the lubricating system. Operators should always be aware of the dangers and only trained personnel should undertake this. The oil sample is then sent to a recognized laboratory to undertake the tests on the oil to ensure that it still retains its quality. Typical parameters that are monitored are:

- Viscosity
- Carbon content (for ICE equipment)
- Water content
- Fuel Dilution
- Oxidation
- Base metals

Dependent upon the application, various other tests can be performed by the laboratory and undertaken on same sample. One benefit is the base metals test when used with generator engines, as this provides a health check of the components within the engine that cannot be seen. For instance, a high chromium level could indicate excessive levels of wear attributable to cylinder liners in certain designs of engines. Allowing a planned internal inspection to take place at the next opportunity to understand the cause and take any necessary action. The cost of the analysis test is usually considerably lower than that of the consumable, and associated costs of simply replacing the oil.

Entities should consider any warranty or OEM restrictions before undertaking this method so as not to impact costs or future second/third party contract obligations.

6.2.4.8 Non Destructive Testing/Non Destructive Examination (NDT/NDE)

These methods are again specialized areas of CBM and are normally undertaken when a fault is detected, or system performance has degraded that warrant further investigation. Numerous technologies are involved in this method such as:

- Electromagnetic testing
- Leak testing
- Magnetic flux leakage
- Liquid penetrating fluid
- Acoustic emissions

6.2.4.9 Significance of Monitoring

The above technologies have significant advantages over Planned Maintenance techniques as they can provide the following advantages:

- Reduction in maintenance on equipment that is still functioning at >90% efficiency
- Reduction in consumables/spare parts while undertaking maintenance
- Reduction in manpower allocation undertaking maintenance activities
- Many activities can be performed without the need for equipment shutdowns
- Improvements of reliability
- Reduction in maintenance induced failures

Maintenance Induced Failure (MIF)

Prior to considering any alternative methods for Entity O&M activities, the senior management and stakeholders must be actively involved in the decision process for deviating from the standard practice. In addition, where plant or equipment remains under the control and maintenance of the manufacturer or installer, there may be a contractual or warranty requirement to continue with prescribed methods. However, in all cases, there is no penalty in utilizing some of the above methodologies in addition to traditional maintenance. There are many documented cases where it has been proved that traditional methods can actually be detrimental to the life of the equipment due to a term known as ‘Maintenance Induced Failures.’

This phenomenon is the result of the equipment being disturbed during maintenance activities and the reinstatement not being carried out in the correct manner. This could be due to several factors but the most noticeable one is that of human intervention. There could be incorrect alignment, torque of fixings, and imbalance following reassembly. Therefore, the above techniques of monitoring the equipment during operation and only undertaking intrusive when necessary will help to reduce these failures.

Along with the reduction in maintenance tasks on equipment there is a complimentary saving that can be achieved by not replacing parts and consumables unnecessarily. This is possible only when they show signs of degradation, loss of performance or failure. Spare parts can be ordered and procured before the maintenance activities. Procurement departments may be able to negotiate volume discounts with suppliers and also reduce additional costs of short notice delivery. Particularly in the case of specialist systems that may be manufactured or sourced outside of KSA, where restrictions or customs clearance requirements may need to be taken into consideration.

Manpower resources for maintenance activities can be planned where information has been gathered upon the plant and equipment. In particular, where specialized technicians are required, they can be programmed to undertake the maintenance within a timeframe that is suitable to their own availability and also other stakeholders or facilities, if they belong to a shared resource. Mobilizing and accommodating staff at short notice is expensive and counter-productive to other maintenance and ongoing operational activities. The correct competency of staff can be planned so that maintenance is undertaken in a professional manner and without a knock-on effect of MIF from untrained staff. In addition, the collection of data that allows engineers to make decisions upon maintenance can be performed. The technicians are instructed on how to undertake the readings and input these into a computer system or the use of the collection tools to be uploaded to the specialist software packages. Many of these systems are inexpensive and tailored to the user requirements.

The use of non-intrusive techniques can often be undertaken with the equipment in its normal running state. Often this is a primary requirement in order to assess the health of the equipment. Typical examples are CBM and Vibration Analysis. These assess the current running status of the equipment and will indicate whether the equipment is operating outside of its normal parameters.

6.2.4.10 Reporting Methodology

Reporting methodology for SA&M should be identified based on stakeholder requirements to report technical outcomes regarding operational and safety risks, cost, schedule, and progress. Reporting methodology and tools should be identified and developed as per local requirements.

6.2.4.11 Summary

There are many techniques available to the Entity that could be used to undertake monitoring techniques and continuously evolve new technologies, however, there are multiple factors to be considered while selecting the right monitoring technique.

One of the main considerations may be that access to maintenance of plant may be restricted due to its requirement for continuous operation and downtime to be avoided. Therefore, ‘on load’ monitoring can prove to be very effective and allowing for maintenance activities to be planned well in advance knowing how systems operate, and the likely wear based upon known data. The availability of senior or technical teams can also be a part of the maintenance plan so that impact to other areas of the Entity can be mitigated.

Cost is a significant factor in the decision process of the above methods, that needs to be considered, which is not discussed here.

6.2.5 Assets Monitoring and Assessment Flows and Controls using IDEF0 Model

The Integration Definition for Function Modeling (IDEF0) diagram used in Figure 10, is a common modeling technique in SysE analysis. IDEF0 is used here to illustrate assets monitoring and assessments information relationship, ‘data and functional’ flows, and controls, for assets assessment life cycle processes.

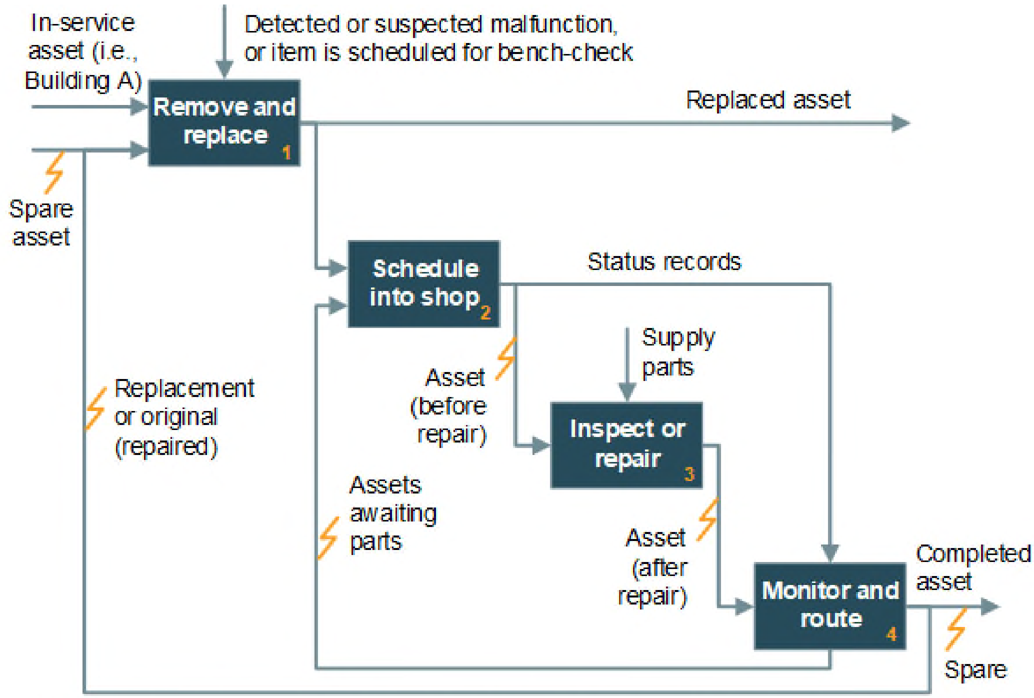

Figure 10: Assets Monitoring and Assessment Flows and Controls using IDEF0 Model, after DAU with amendment

There are numerous methods, models, languages, and tools within the SysE domain that can be utilized for O&M assessment and monitoring process. The purpose is not to describe every method, model, and/or tools from the SysE domain; rather, it is to increase the Entities' awareness regarding their SA&M activities and the opportunities from using the SysE concepts and advantages when possible and allow Entities to achieve their objectives successfully.

7.0 ATTACHMENTS

1. Check Matrix Example, Technologies, and Assessments template, by NASA
2. Common Predictive Maintenance Assessment Technologies, after NASA-2000
3. Process Assessment by ISO 15504
4. ISO standards Example for Process Configuration Management

Attachment 1 – Check Matrix Example, Technologies, and Assessments template, by NASA

Technologies	Applications	Pumps	Electric Motors	Diesel Generators	Condensers	Heavy Equipment/Cranes	Circuit Breakers	Valves	Heat Exchangers	Electrical systems	Transformers	Tanks, Piping
Vibration Monitoring/Analysis		X	X	X		X						
Lubricant, Fuel Analysis		X	X	X		X					X	
Wear Particle Analysis		X	X	X		X						
Bearing, Temperature Analysis		X	X	X		X						
Performance Monitoring		X	X	X	X				X		X	
Ultrasonic Noise Detection		X	X	X	X			X	X		X	
Ultrasonic Flow		X			X			X	X			
Infrared Thermography		X	X	X	X	X	X	X	X	X	X	X
Non-Destructive Testing (Thickness)					X				X			X
Visual Inspection		X	X	X	X	X	X	X	X	X	X	
Insulation Resistance			X	X			X			X	X	
Motor Current Signature Analysis			X									
Motor Circuit Analysis			X				X			X		
Polarization Index			X	X						X		
Electrical Monitoring										X	X	

Attachment 2 – Common Predictive Maintenance Assessment Technologies, after NASA-2000

Description	Comments	Maintenance Frequency			
		Daily	Weekly	Semi-Annually	Annually
Overall visual inspection	Complete overall visual inspection to be sure all equipment is operating and safety systems are in place	X			
Verify control schedules	Verify in control software that schedules are accurate for season, occupancy, etc.	X			
Verify set points	Verify in control software that set points are accurate for season, occupancy etc.	X			
Time clocks	Reset after every power outage	X			
Check all gauges	Check all gauges to make sure readings are as expected		X		
Control tubing (pneumatic system)	Check all control tubing for leaks		X		
Check outside air volumes	Calculated the amount of outside air introduced and compare to requirements		X		
Check set points	Check set points and review rational for setting		X		
Check schedules	Check schedules and review rational for setting		X		
Check dead bands	Assure that all dead bands are accurate, and the only simultaneous heating and cooling is by design		X		
Check sensors	Conduct thorough check for all sensors-temperature, pressure, humidity, flow, etc.- for expected values			X	
Time clocks	Check for accuracy and clean			X	
Calibrate sensors	Calibrate all sensors: temperature, pressure, humidity, flow, etc.				X

Attachment 3 – Process Assessment by ISO 15504

ISO 15504-5 Process: SUP.8 Configuration management Process outcomes/Process attribute achievements	Not Rated (0%)	Not Satisfied (0-20%)	Partially Satisfied (20-50%)	Largely Satisfied (50-80%)	Fully Satisfied (80-100%)
Process Attribute: PA 4.1 Process measurements attribute		X			
Process information needs in support of relevant business goals are established			X		
Process measurement objectives are derived from identified process information needs			X		
Quantitative objectives for process performance in support of relevant business goals are established		X			
Measures and frequency of measurement are identified and defined in line with process measurement objectives and quantitative objectives for process performance		X			
Results of measurements are connected analyzed and reported in order to monitor the extent to which the quantitative objectives for process performance are met		X			
Measurement results are used to characterize process performance			X		
Process Attribute: PA 4.2 Process control attribute		X			
Suitable analysis and control techniques where applicable are determined and applied		X			
Control limits of variation are established for normal process performance		X			
Measurement data are analyzed for special causes of variations			X		
Corrective actions are taken to address special causes of variations			X		
Control limits are re-established (as necessary) following corrective actions		X			
Process Attribute: PA 5.1 Process innovation attribute		X			
Process improvement objectives for the process are defined that support the relevant business goals			X		
Appropriate data are analyzed to identify common causes of variations in process performance		X			
Appropriate data are analyzed to identify opportunities for best practice and innovation			X		
Improvement opportunities derived from new technologies and process concepts are identified			X		
An implementation strategy is established to achieve the process improvement objectives		X			
Process Attribute:PA5.2 Continuous optimization attribute		X			
Impact of all proposed changes is assessed against the objectives of the defined process and standard process		X			
Implementation of all agreed changes is managed to ensure that any disruption to the process performance is understood and acted upon		X			
Effectiveness of process changed on the basis of actual performance, is evaluated against the defined product requirements and process objectives, to determine whether results are due to common or special causes		X			

Attachment 4 – ISO standards Example for Process Configuration Management

ISO/IEC 15504	Title
ISO/IEC 15504-1:2004	Information technology - Process assessment - Part 1: Concepts and Vocabulary
ISO/IEC 15504-2:2003 (Cor 1:2004)	Information technology - Process assessment - Part 2: Performing an assessment
ISO/IEC 15504-3:2004	Information technology - Process assessment - Part 3: Guidance on performing an assessment
ISO/IEC 15504-4:2004	Information technology - Process assessment - Part 4: Guidance on use for process improvement and process capability determination
ISO/IEC 15504-5:2012 (SPICE model)	**Information technology - Process assessment - Part 5: An exemplar software life cycle process assessment model**
ISO/IEC TR 15504-6:2008	Information technology - Process assessment - Part 6: An exemplar system life cycle process assessment model
ISO/IEC TR 15504-7:2008	Information technology - Process assessment - Part 7: Assessment of organizational maturity
ISO/IEC TS 15504-8:2012	Information technology - Process assessment - Part 8: An exemplar process assessment model for IT service management
ISO/IEC TS 15504-9:2011	Information technology - Process assessment - Part 9: Target process profiles
ISO/IEC TS 15504-10:2011	Information technology - Process assessment - Part 10: Safety extension