# The Maintenance Framework

## Second Edition

English Version

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GFMAM

Global Forum on Maintenance & Asset Management

gfmam.org

# The Global Forum on Maintenance and Asset Management

The Global Forum on Maintenance and Asset Management (GFMAM) has been established with the aim of collaboratively sharing advancements, knowledge, and standards in maintenance and asset management.

The enduring objectives of the GFMAM are to:

1) Bring together, promote, and strengthen the maintenance and asset management community worldwide
2) Support the establishment and development of associations or institutions whose aims are maintenance and/or asset management focused
3) Facilitate the exchange and alignment of maintenance and asset management knowledge and practices
4) Raise the credibility of member organizations by raising the profile of the Global Forum

More on the Global Forum on Maintenance and Asset Management (GFMAM) can be found on-line at *www.gfmam.org*.

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# 1 Introduction

The Global Forum on Maintenance and Asset Management (GFMAM) has an objective to collaboratively share knowledge and standards in both maintenance and asset management.

As maintenance is an integral part of asset management, the Maintenance Framework complements the Asset Management Landscape document [1] and aligns with the ISO 55000 series of documents on asset management [2] [3].

This second edition, which expands in detail and clarity in several areas, represents the Global Forum's commitment to continuous improvement for its members and the global maintenance and asset management community.

## 1.1 Purpose

The purpose of the Maintenance Framework is to develop and promote a common understanding of the role and value of maintenance, and how it contributes to the delivery of business outcomes. Going into more detail than, and beyond the subject of Maintenance Delivery from the Asset Management Landscape [1], the Maintenance Framework provides information on:

- The discipline of maintenance and its management, including its role in asset management at all stages of asset life;
- Maintenance principles, subjects, and terminology; and
- Relevant international standards.

The Maintenance Framework also establishes the foundation for competencies in maintenance and its management, and the ability to benchmark maintenance practices.

## 1.2 Target Audience

The Maintenance Framework is intended to provide high-level guidance to individuals who work in maintenance, such as maintenance practitioners (new and experienced), managers, and service providers, as well as individuals who work alongside these maintenance roles, both internal and external to organizations. While the document is considered to apply across all industries, the amount of value drawn from organizations will depend on their level of maturity in maintenance and asset management.

## 1.3 Scope

This document is intended for the maintenance of physical assets, with consideration of the entire life cycle. It is designed to apply across all industries and as such does not attempt to cover unique industry-specific aspects.

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## 2 Definitions

The definitions listed below are primarily drawn from the International Electrotechnical Vocabulary (IEV) [4], with some from other international sources as cited.

**Asset –** item, thing, or entity that has potential or actual value to an organization [1] [2]

*Note 1: For the purposes of this document, assets are physical entities, whether fixed or mobile in nature.*

*Note 2: See also Asset System*.

**Asset System –** set of interrelated items/assets that collectively fulfil a requirement

*Note 1: Asset and asset system are often used interchangeably in this text.*

**Availability –** ability to be in a state to perform as required

*Note 1: Availability is the key driver of value creation of the asset and is a function of Reliability, Maintainability, and Supportability.*

**Condition-Based Maintenance** – preventive maintenance based on the assessment of physical condition.

*Note 1: See also Maintenance.*

**Corrective Maintenance** – maintenance carried out after fault detection to effect restoration

*Note 1: In this text, also applies to maintenance carried after an asset exhibits a functional failure*

*Note 2: See also Maintenance.*

**Failure –** loss of ability to perform as required

**Hazard –** potential source of harm

**Life Cycle Costing –** process of economic analysis to assess the cost of an item over its life cycle or a portion thereof

**Maintainability –** ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance

*Note 1: Given conditions would include aspects that affect maintainability, such as location for maintenance, accessibility, maintenance procedures and maintenance resources.*

**Maintenance –** combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required

**Maintenance Engineering –** a technical function to support asset availability

**Maintenance Management –** management of maintenance management systems, resources, programs, processes, and activities to support asset availability

**Predictive Maintenance –** action to monitor the condition of an asset and predict the need for preventive action or corrective action [2]

*Note 1: ISO 55000 defines predictive 'action'. In a maintenance context, 'action' is replaced with 'maintenance'. Thus, predictive action, preventive action, and corrective action are predictive maintenance, preventive maintenance, and corrective maintenance accordingly.*

*Note 2: Predictive maintenance is also commonly referred to as "condition monitoring".*

**Preventive Maintenance** – maintenance carried out to mitigate degradation and reduce the probability of failure

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*Note 1: See also Maintenance.*

**Proactive Maintenance –** maintenance work that is completed to avoid failures or to identify defects that could lead to failures. Includes routine preventive and predictive maintenance activities and corrective work tasks identified from them. [5]

*Note 1: Also includes maintenance work that will reduce the consequence of failure where failure is imminent.*

*Note 2: See also Maintenance.*

**Portfolio –** assets that are within the scope of an asset management system [2]

**Reliability –** ability to perform as required, without failure, for a given time interval, under given conditions

**Reliability Centered Maintenance –** systematic method for determining the respective maintenance actions and associated frequencies, based on the probability and consequences of failure

**Reliability Engineering –** the systematic application of engineering principles and techniques to achieve the inherent or required reliability of an asset or asset system

**Scheduled/Planned Maintenance** – maintenance carried out in accordance with a specified time schedule

*Note 1: See also Maintenance.*

**Statutory/Regulatory Maintenance** – maintenance tasks that are legally/statutory required to be completed at a prescribed frequency

*Note 1: See also Maintenance.*

**Supportability –** ability to be supported to sustain the required availability with a defined operational profile and given logistic and maintenance resources

*Note 1: Supportability of an item results from the inherent maintainability, combined with factors external to the item that affect the relative ease of providing the required maintenance and logistic support.*

**Risk –** The effect of uncertainty on objectives, measured as the combination of the probability of occurrence of harm and the severity of that harm

**Safety –** freedom from unacceptable risk

# 3 The Business Case for Maintenance and its Management

Maintenance of assets is an integral function of physical asset management, as shown in Figure 1. Therefore, to be successful in asset management, organizations need to be successful in maintenance and its management.

When assets fail to fulfill their functions as required by the organization, the organization generally incurs a loss, financial or otherwise. This loss can be immediate and direct, such as a loss of revenue from a stoppage in production or unnecessary costs due to premature failure. Losses can also be lagging in the form of stakeholder confidence and reputation, which inevitably lead to indirect costs. Proper maintenance can play a substantial role in preventing or mitigating these losses, and maintenance programs can be most successful when maintenance is considered at all phases of the asset life cycle.

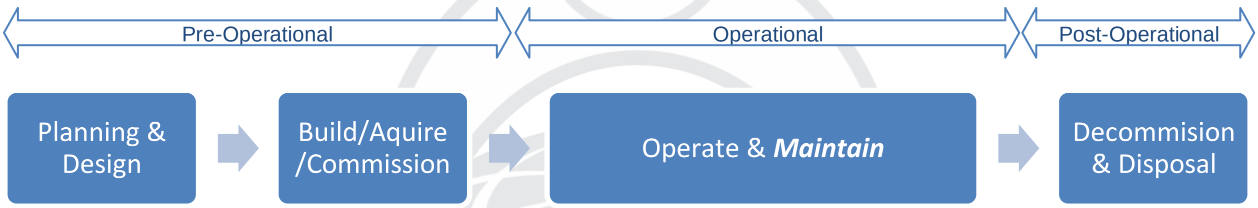


**Figure 1 - Major Asset Life Cycle Stages in Physical Asset Management**

Moreover, as organizations are continually seeking balance between cost, risk and performance, the benefits (value) of maintenance can be expressed in the following ways:

- **Performance** - Maintenance supports achievement of the asset performance objectives of the organization through reliability, availability, rate of production or level of service, and quality.
  - **Availability & Reliability** – Operational availability of assets is what makes value realization from assets possible. In commodity businesses, greater availability generally leads to increased production, resulting in increased revenue and lower unit costs. Maintenance considerations during the pre-operational life phases of assets can aid in ensuring that the designed asset reliability (i.e. inherent reliability) will meet the organization's operational requirements for availability and be maintainable. During the operational stage, effective maintenance will limit the loss of availability by minimizing operational disruptions or unscheduled downtime.
  - **Rate of Production / Level of Service –** At times individual asset availability can have little consequence on the availability of a system of assets, particularly when there is redundancy by design or designed capability exceeds requirements. However, the overall productive capacity or level of service of systems can suffer. Maintenance can assist in ensuring required system capacity or level of service is attained and in the most efficient manner.
  - **Quality –** Degradation in asset performance can affect the quality of services or products produced, resulting in increased warranty and latent defect claims and loss of consumer confidence. Maintenance assists in ensuring required quality is attained.

- **Risk –** Maintenance supports achievement of the risk objectives of the organization related to safety, the environment, and stakeholder confidence.
    - **Safety and Environmental Risk –** By proactively maintaining the integrity of safety and environmentally critical assets, maintenance can reduce safety and environmental risks. Unmitigated risks can result in financial losses in the form of remediation costs and penalties, as well as the ability to generate revenue due to a suspended or curtailed operational license.
    - **Stakeholder Confidence –** Beyond customers, organizations can have external stakeholders in the form of investors, shareholders, and regulatory agencies. By maintaining assets and performance objectives, and complying with regulatory requirements for inspection and testing, organizations can gain and maintain the confidence of external stakeholders. In regulated industries, regulator confidence is critical for organizations to gain or maintain their license to operate. Maintenance of assets is therefore important for stakeholder confidence and reputation.
- **Costs** - Life cycle costs of an asset are all costs occurred over the lifetime of the asset including design, acquisition, construction, operation, maintenance, and disposal. These can be seen in Figure 2[1]. These costs can be classified as either capital expenditures (CAPEX) or operating expenses (OPEX).
    - **CAPEX** - Capital investments in new or existing assets can be reduced by maintenance in several ways. Good maintenance can increase the asset useful life and delay the need for reinvestment in refurbishment or renewal. High asset availability utilizes the full capacity of the asset and may delay the need for capacity expansion. High asset reliability may reduce the need for investments in redundancy. It should be noted however that in some cases consideration of life cycle costs may cause an increase in capital investment.

      Capital expenditures also include investments in inventory spare parts and materials. While inventory of such items may provide for quick maintenance repair, inventory ties up an organization's working capital (cash). Furthermore, there is a cost to managing inventory, including the need for storage space. Assets that are designed with reliability and maintainability in mind, along with properly designed and executed maintenance programs, can reduce the dependency on inventory, freeing cash that could otherwise better serve the organization.
    - **OPEX** - Operating expenditures include not only raw materials and operating labor, but maintenance materials and labor, and utilities such as energy. In some industries, maintenance and operating costs can represent from 65% to 80% of total life-cycle costs. Assets that are designed and acquired with reliability and maintainability in mind, in addition to being properly maintained once in service, will achieve lower operational costs. Furthermore, declining availability or reliability can increase the cost of operating the asset in many ways over time, such as increased consumption of energy or raw materials. Effective maintenance therefore can also affect operational cost beyond preventing costly failures.

[1] This figure is for illustrative purposes only – distribution of life-cycle costs will vary by industry and various other factors. Such a representation is quite common, particularly for manufacturing & processing facilities.

In summary, maintenance affects an organization's balance of cost, risk, and performance in several ways. Effective maintenance can result in improved financial performance through increased revenue, reduced operational and capital costs, and controlled management of depreciation. For asset intensive companies, the impact of maintenance on their financial performance is significant.

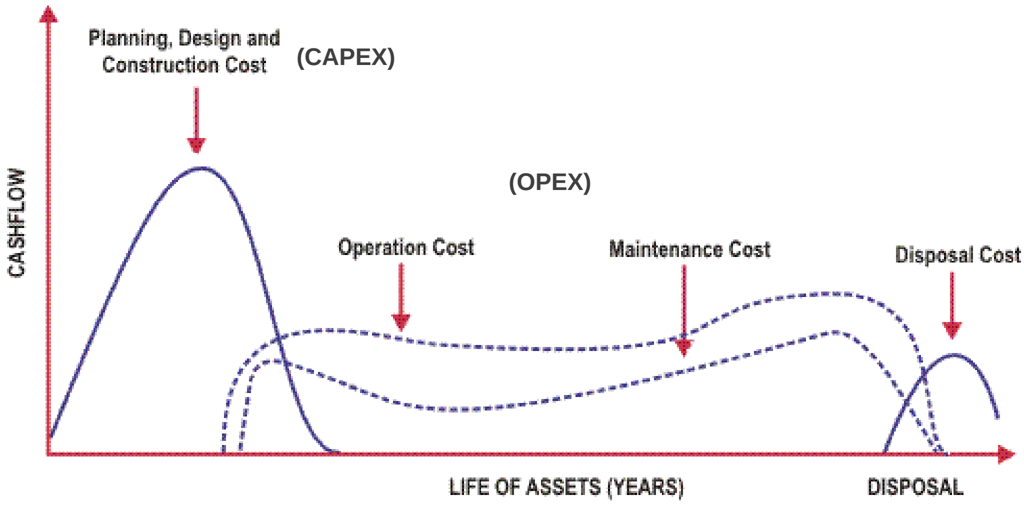


**Figure 2 - Example of Life Cycle Costs of Assets**

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# 4 The Evolution of Maintenance

The evolution of maintenance over time can be explained from both a maturity of management strategy and technological viewpoints. We can further describe maintenance maturity in terms of maintenance domains, as shown in Figure 3.

During the initial decades of the first industrial revolution, physical assets were generally over-designed and relatively simply constructed. Maintenance was considered necessary; however, maintenance management was not. When assets failed, they were repaired as quickly as possible. Organizations displaying this level of maturity, which exist even today, would be classified in the Reactive domain[2].

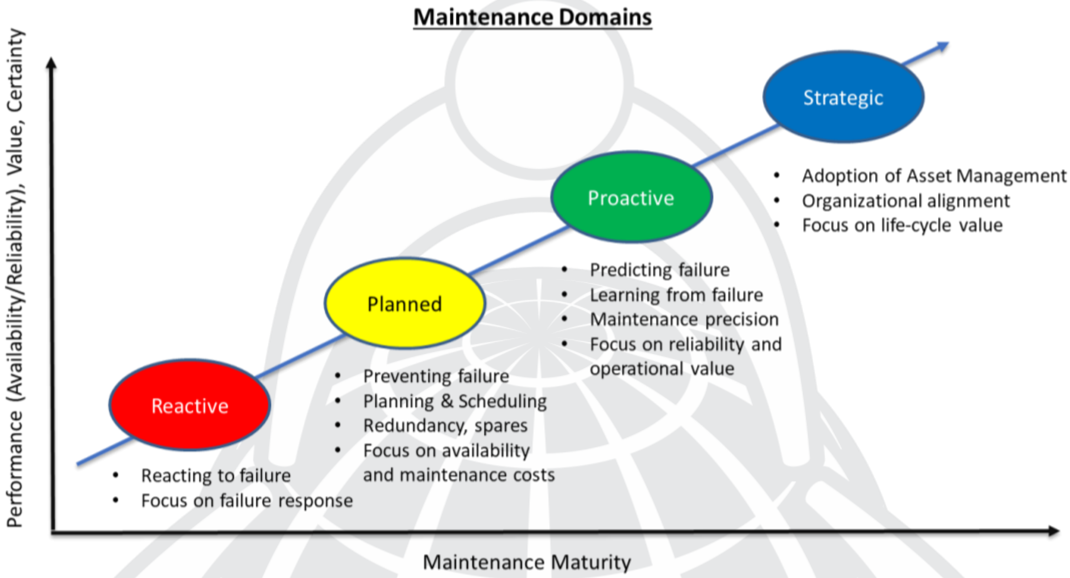


**Figure 3 - Maintenance Maturity Levels of Organizations**

By the time the third industrial revolution had arrived, assets had grown in complexity and demand for safety, reliability and financial accountability increased (and continues to increase today), especially in high-risk and asset-intensive industries where decisions around how assets are managed and maintained have significant impact to an organization.

As the ‘reactive’ paradigm was no longer acceptable, a more preemptive, systematic thinking began to evolve. People began to understand that taking certain actions before assets failed enabled higher asset availability, longer asset life, and lower maintenance costs. Preventive maintenance planning and control systems were thus introduced, initially manual then later computerized. Redundancy was also commonplace as a tactic to assure availability. This characterizes the Planned domain.

Since this time technology has developed substantially and assets have become so complex that traditional inspection maintenance is not effective in finding or predicting failure modes, and more scientific and risk-based methods are needed. The shift to the Proactive domain is characterized by the application of techniques such as RCM, FMEA/FMECA and “design for reliability”. It has now become possible, for example, to monitor the condition of equipment in real time to detect the need for repair or replacement of a critical part without invasive actions. Information and computer technology have evolved exponentially in the last several decades such that databases

[2] The reader is not to confuse the Reactive domain with reactive maintenance tactics (such as RTF- run to failure) which may be still a valid tactic in some cases, even in very mature maintenance organizations.

of assets and their maintenance requirements can be built up to assist with the difficult task of managing the maintenance of complex systems.

Finally, in recent years many organizations have come to understand asset management (notably through publications such as ISO 55001) and its value proposition, including being a competitive advantage. The alignment and integration of all facets of managing assets in organizations, including maintenance, characterizes the Strategic domain of maintenance maturity.

ISO 55000 defines Asset Management as*; "coordinated activity of an organization (3.1.13) to realize value from assets (3.2.1)". Realization of value requires the achievement of an appropriate balance of costs, risks and performance, often over different timescales.*

To contribute to the set of 'coordinated activities' of their organization, maintenance managers will need to expand their traditional technical focus to influence areas such as equipment selection and design and learn financial justification skills such as asset life cycle costing. They will also need to acquire an understanding of organizational, systemic, and cultural controls. This will in turn require understanding and appreciation of the role of human factors such as the essential "soft" skills. For their part, individuals outside of the maintenance organization must understand and appreciate the maintenance function and its contribution to organizational objectives and that all individuals have a role to play in maintaining or supporting maintainability of assets.

### Technological Evolution

Just as technology and the various industrial revolutions over time have provided benefits to industry and society as a whole, so have they to the maintenance function, regardless of which maintenance domain an organization is in.

Specifically, advances in technology have improved condition monitoring tools and sensors (increased precision, smaller size, lower cost) as well as decision-making support, as shown in Figure 4. No longer is technology limited to the detection of faults; it can now be used to predict failure or remaining useful life based on programmable discrete logic, and even artificial intelligence. Highly advanced systems can not only predict failure, but also prescribe the required corrective actions.

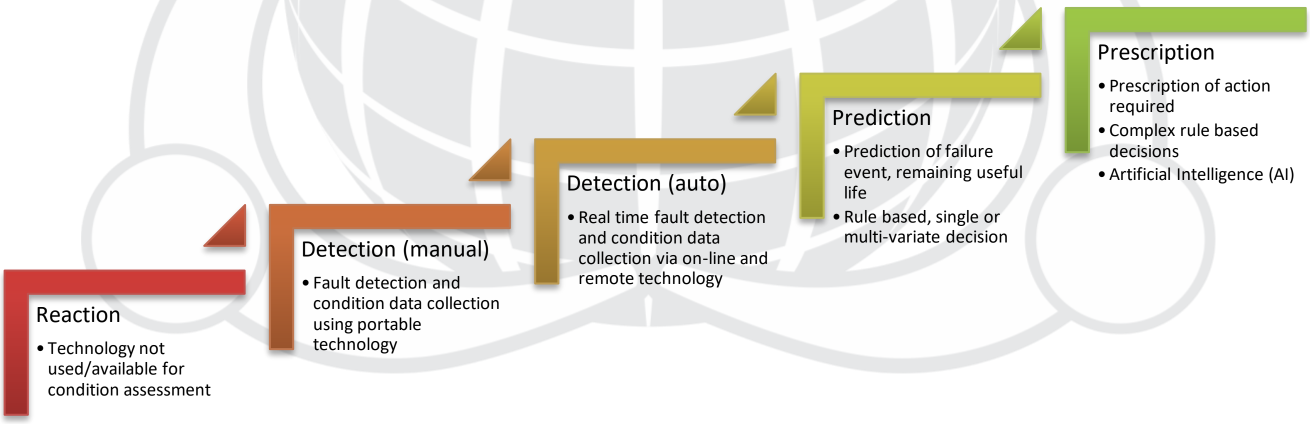


**Figure 4 - Evolution of Technology in Asset Condition Monitoring & Decision-Support**

Finally, advances in technology have also permitted improvements in the management of maintenance systems, and in worker tools (increased ergonomics, precision, smaller size, lower cost) which have resulted in improvement in maintenance worker safety, well-being, productivity, and quality.

# 5 Principles of Excellence in Maintenance Management

There are five principles that, notwithstanding detailed and specific requirements outlined with the framework, are required to achieve and maintain excellence in maintenance and its management.

**Principle 1 - Life Cycle Value**

Decisions made related to maintenance at any stage of the life cycle – be it during asset design, asset and spares acquisition, maintenance planning, etc., must be in support of maximum total life cycle value. While maximum value is often derived through minimization of costs, organizations should consider balancing costs with revenues, and the value of non-financial benefits, such as risk and reputation.

**Principle 2 - Risk-Based & Reliability-Focused**

To achieve optimal maintenance benefits during the operations and maintenance (O&M) phase, maintenance strategies must be balanced with risk and reliability requirements, which must be well understood.

**Principle 3 - Execution**

Disciplined and quality execution of maintenance tasks is essential to ensure implemented strategies realize their intended outcomes (i.e. are effective).

**Principle 4 - Supportive Culture**

Leadership and workplace culture are critical for achievement of asset management objectives, and this includes those specific to maintenance. In a culture supportive of maintenance, decisions made, and actions taken towards assets, at any stage of the life cycle, support the realization of maintenance objectives.

**Principle 5 - Continual Improvement**

Both the development and execution of maintenance strategies are rarely perfect. This is largely due to the often-necessary assumptions made and, at times, the limited availability of operational and asset failure data. As such, maintenance organizations must embrace and develop approaches that seek to continually improve efficiency and effectiveness of their activities.

# 6 The Maintenance Framework

The Maintenance Framework consists of nine subject groups as shown in Figure 5, with each group further described and defined in subsequent sections of the document. This Maintenance Framework covers basic principles in order to serve the majority of users. Its application may vary according to organizational circumstances.

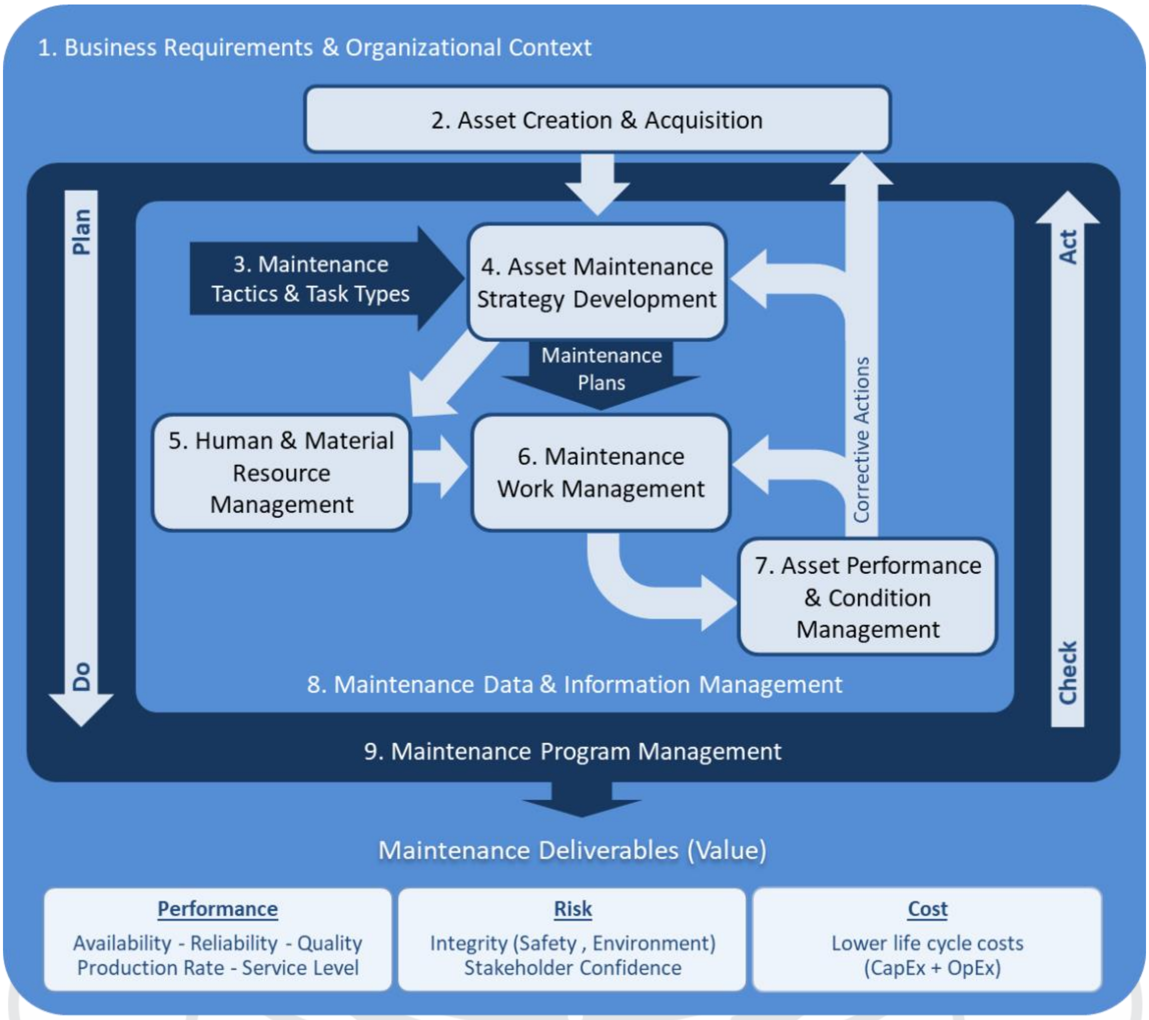


**Figure 5 - The Maintenance Framework Diagram**

For each of the subject groups in the framework, the following is provided:

- A definition;
- A context statement;
- The artefacts that would typically be produced or used in relation to the subject group;
- A listing of specific subjects related to or included in the subject group; and
- Relevant standards.

## 6.1 Business Requirements & Organizational Context

### Definition

Business requirements are those items that must be delivered to provide value and improved credibility in the eyes of customers, regulators, and other stakeholders. The provided value can include such things as safety, return on investment, return on assets, and return on equity and service levels. For some organizations, business requirements related specifically to physical assets may be translated into a strategic asset management plan (SAMP). Additionally, an organization's strategic decisions determine the relative importance of its various physical assets and therefore that of the maintenance activities.

Organizational context is the environment in which the organization operates. It considers external elements, such as social, physical, economic and regulatory environments, and internal elements, such as organizational culture, mission and values.

### Context

The maintenance function exists solely to enable business deliverables. Failure for the maintenance function to understand and adapt to business requirements and the organizational context can result in inadequate decisions and designs in all other areas of the maintenance framework.

As business requirements and organizational context can change, they should be reviewed regularly, based on the rate of change of all relevant risks, to ensure the maintenance strategy and ensuing plans are consistent with the needs of the business.

### Artefacts

Typical artefacts within this subject grouping include:

- Corporate asset management policy
- Strategic asset management plan (SAMP) that addresses:
  - The required asset management objectives
  - The requirements for the asset management system
  - The requirements for asset management plans.
- Stakeholder requirements
- Financial requirements or plans
- Safety plans
- Regulatory requirements
- Heritage requirements
- Human factor requirements
- Operating plans
- Investment plans
- Maintenance policy

### Related Subjects

- GFMAM Asset Management Landscape subjects and groups:
  - *Strategy and Planning:* Asset Management Strategy & Objectives, Asset Management Planning
  - *Organization & People:* Asset Management Leadership, Organizational Culture, Organizational Structure, Competence Management
  - *Risk & Review:* Risk Assessment and Management, Contingency Planning & Resilience Analysis, Management of Change, Stakeholder Engagement

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**Relevant Standards**

- ISO 14000 Environmental Management
- ISO 31000 Risk Management
- ISO 55000 Asset management – Overview, principles and vocabulary
- ISO 55001 Asset Management – Requirements
- ISO 55002 Asset management – Management systems - Guidelines on the application of ISO 55001
- ISO/IEC15288 Systems Engineering
- International Financial Reporting Standards (IFRS)
- International Accounting Standards (IAS)

## 6.2 Asset Creation & Acquisition

### Definition

This subject group covers subjects related to maintenance activities during the design, procurement, manufacturing, installation, and commissioning of assets and related systems.

This aspect of the maintenance framework starts with a clear definition of the organization's requirements (needs) of its assets. Through the various design and acquisition stages, these requirements are developed into specifications for design, procurement, manufacturing, installation, operations, maintenance, improvement/upgrade, and disposal of assets.

The result is installed assets that fulfill the user requirements, are operated and maintained according to design intent, with related systems that help enable performance throughout the intended life cycle of the equipment.

### Context

This is the initial stage in an asset's life cycle where the organization procures a certain functional capability to deliver against specific business requirements. It is at this point that the inherent capability of an asset is determined.

From a maintenance perspective, the user requirements will define parameters like availability, reliability, maintainability, and supportability. These needs are in turn related to the achievement of a desired life cycle cost and the associated revenue.

Depending on the method of acquisition, all the aspects (design, procure, manufacture, installation, and commissioning) may not be applied in the same manner. For example, the approach for off-the-shelf items differs from building a unique processing facility to manufacture bulk chemical products. Regardless of acquisition method, it is crucial for the organization to ensure that the user requirements (this includes maintainability requirements) are a constant guide to determine delivery of the solution. Participation by operating and maintenance personnel is thus a necessity to ensure that the final installed solution enables the practicalities of operating and maintaining the asset. This includes aspects like ergonomics, maintainability, asset standardization, spares holding, master data and legal requirements. Early participation will also ensure operational readiness to take ownership of the asset. This includes items like training, implementation of management systems, organization development, and inbound and outbound logistics processes (including spares). A key point is that support solutions and contracts should be defined and sourced at the same time as the asset procurement activities. This will usually secure the most favorable commercial terms and best interface with warranty considerations.

The asset creation and acquisition stage is certainly one of high cost intensity and a major and direct contributor to overall life-cycle costs of physical assets, as previously shown in Figure 2 (CAPEX). However, it is also the stage of significant impact to operating costs (OPEX), which includes maintenance costs. Proper consideration for maintenance and involvement of maintenance personnel at this stage will aid in ensuring total life-cycle costs of acquiring and maintaining assets are minimized.

### Artefacts

Typical artefacts within this subject group include:

- *User Requirement Specification* – Quantified, unambiguous, measurable definition of the need to be satisfied.
- *Pilot Models* – 3D digital models, or physical scaled models to enable assessment of ergonomics, maintainability, operability, and upfront training of operators.
- *RCM Analyses* – for upfront assessment of required maintenance practices.

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- *FMEAs* – early assessment of operability and maintainability by incorporating previous experience and best practices into design.
- *Reliability Block Diagrams* – this is commonly done with stochastic computer-based simulations to enable decisions on layout and sizing of equipment systems to achieve the intended system availability.
- *RAM - Reliability, Availability and Maintainability modelling (also knowns as RAMS when supportability is considered separately)* looks at these characteristics of an asset or asset system, preferably in the design phase. RAM modelling will identify potential causes of production losses and can be used to develop mitigation plans to reduce them to an acceptable risk.
- *Life Cycle Costing Models* – this enables decision making on trade-offs on various alternatives in equipment selection, materials, spares, etc.
- *Spares Management* – spares specifications, amounts, strategies (e.g., vendor stock, lead times, replenishment levels), bill of materials, standardization with existing installed systems.
- *Asset Purchase & Installation Specifications*.
- *Asset Data & Information* – this includes items required to operate and maintain the asset(s) and includes drawings & schematics, functional specifications, testing and commissioning records, design basis documents, and operating and maintenance manuals.
- *Legal Certificates* – various legislation exists that requires asset owners / operators / maintainers to show proof of adherence to statutory requirements.

### Related Subjects

- Requirements Analysis and Specification Writing
- Reliability Centered Design
- Reliability, Availability, Maintainability (RAM) Analysis or Reliability, Availability, Maintainability, and Supportability (RAMS) Analysis
- Reliability Block Modelling
- Stochastic Modelling
- Criticality Analysis
- GFMAM Asset Management Landscape subjects and groups:
    - *Strategy and Planning:* Asset Management Strategy & Objectives, Asset Management Planning
    - *Asset Management Decision-Making:* Capital Investment Decision-Making
    - *Lifecyle Delivery:* Technical Standards & Legislation, Asset Creation and Acquisition, Systems Engineering, Configuration Management
    - *Risk & Review:* Contingency Planning & Resilience Analysis, Management of Change, Asset Costing & Valuation

### Relevant Standards

- ISO 10007 Configuration Management
- ISO 14224 Petroleum, Petrochemical and Natural Gas Industries - Collection and exchange of reliability and maintenance data for equipment
- ISO 15686 Buildings and constructed assets – Service life planning
- ISO/IEC 15288 Systems Engineering
- IEC 60300 Dependability Management (Life Cycle costing, Maintainability, Planning and specifying maintenance services)
    - IEC 60300-3-1 Dependability management - Part 3-1 Application guide - Analysis techniques for dependability - Guide on methodology

- IEC 60300-3-4 Dependability management - Part 3-4 Application guide - Specification of dependability
- IEC 60300-3-10 Dependability management - Part 3-10 Application guide - Maintainability
- IEC 60300-3-11 Dependability management - Part 3-11 Application guide - Reliability centered maintenance
- IEC 60300-3-12 Dependability management - Part 3-12: Application guide - Integrated logistic support
- IEC 60300-3-14 Dependability management - Part 3-14 Application guide - Maintenance and maintenance support
- IEC 60300-3-15 Dependability Management - Part 3-15: Application guide - Engineering of system dependability.

- IEC 60706 Maintainability of Equipment (How maintainability characteristics should be specified in a requirements document or contract)
- IEC 60812 Failure Modes and Effects Analysis (FMEA and FMECA)
- IEC 61078 Analysis techniques for dependability - Reliability block diagram and Boolean methods
- IEC 61355 Classification and designation of documents for plants, systems and equipment
- EN 13269 Maintenance - Guideline on preparation of maintenance contracts
- EN 13460 Maintenance - Documents for maintenance
- EN 15628 Qualification of maintenance personnel
- API 691 - Risk-based Machinery Management
- MIL-STD-1629A Procedures for performing a failure mode, effects and criticality analysis
- MIL-STD-2173AS Reliability centered maintenance requirements for naval aircraft, weapons systems and support equipment
- SAE JA1012 Guide to the Reliability Centered Maintenance (RCM) Standard
- VDI/VDE 3694 System requirement / specification for planning and design of automation systems

## 6.3 Maintenance Tactics & Task Types

### Definition

This subject group covers the tactics and tasks that can be used in the development of asset maintenance strategies.

### Context

Regardless of methodology used, all maintenance strategies are based of the application of essentially two principal maintenance tactics and associated tasks.

- Preventive Maintenance[3] – as defined, preventive maintenance is maintenance carried out to mitigate degradation and reduce the probability of failure. The types of tasks that are performed with this maintenance tactic include:
    - Scheduled/Planned tasks are scheduled interventions based on some pre-determined frequency established using some unit of measure (e. g. calendar time, operating time, cycles). Such tasks include servicing (lubrication, calibration), and even removals of equipment or parts for either discard or rework. They are often used if the failure pattern is one of wear-out and the useful life is known.
    - Condition Monitoring tasks, also known as on-condition tasks or predictive maintenance tasks, are used to monitor asset condition to detect potential failures before they can cause a functional failure. They are often used if a failure pattern is random or unknown, or when Schedule/Planned tasks are not economically feasible. Findings from condition monitoring tasks can lead to corrective maintenance tasks, often referred to as condition-based maintenance.[4]
    - Functional Testing tasks, also known as failure finding tasks, are used to identify assets or components of assets that may have failed where failure is not able to be observed during normal operation.

  Preventive maintenance tactic tasks are what form asset maintenance plans.

- Corrective Maintenance – as defined, corrective maintenance is maintenance carried out after fault or failure detection to effect restoration. The types of tasks that are generally performed with this maintenance tactic include:
    - Repair / Adjust tasks, used to return an asset or one of its components to a predetermined standard.
    - Renew / Replace tasks, used where the asset meets predetermined criteria for replacement. The need for such tasks is to reduce long term (OPEX) costs to the business by replacing the assets rather than continuing to repair.

  While they may form part of an asset maintenance strategy, corrective maintenance tactic tasks are not defined in asset maintenance plans. They should nonetheless be pre-planned and reside in a job plan library and associated with the asset to minimize the amount time to plan the corrective tasks.

[3] Some texts will refer to this as Proactive Maintenance, preferring to limit the term Preventive Maintenance to the types of maintenance tasks that are pre-planned and pre-scheduled to 'prevent failure', shown in this text under Scheduled/Planned tasks.
[4] Condition-based maintenance, made possible from condition monitoring, is generally a far more efficient maintenance tactic, as it can prevent premature and possibly unnecessary maintenance intervention.

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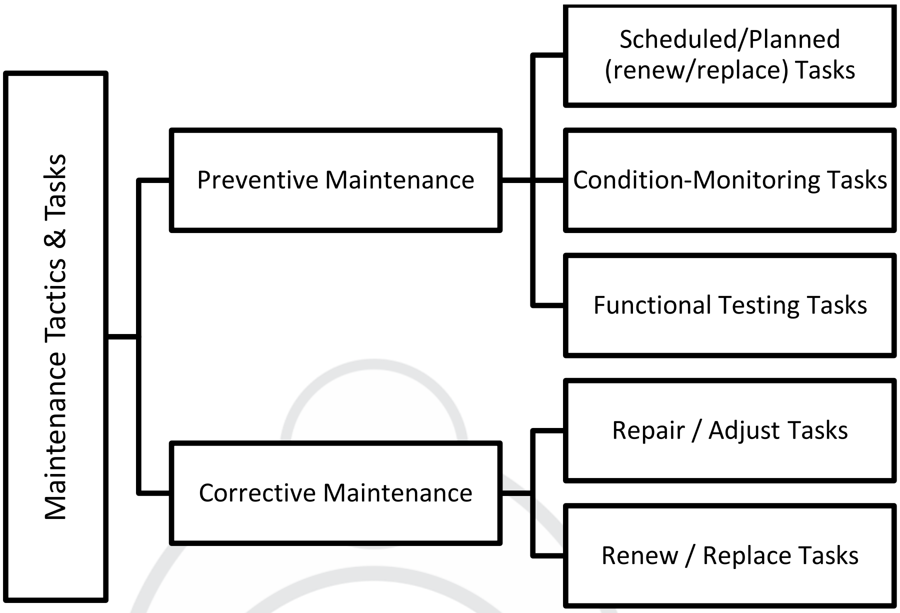


**Figure 6 - Principal Maintenance Tactics and Tasks**

### Artefacts

As this subject grouping does not depict a process, there are no artefacts.

### Related Subjects

- Corrective Maintenance
- Preventive Maintenance
- Predictive Maintenance
- Proactive Maintenance
- Condition-based maintenance
- Statutory/Regulatory Maintenance

### Relevant Standards

- EN 13306 Maintenance and Maintenance terminology

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## 6.4 Asset Maintenance Strategy Development

### Definition

This subject group includes subjects related to the development and subsequent life-cycle management of the maintenance strategy for an individual asset, system of assets, or even class of similar assets. Key deliverables of the strategy are the asset maintenance plans which detail the nature and frequency of proactive maintenance interventions to help achieve the required availability, reliability, and integrity levels dictated by the organization. Additional strategy elements may include critical spare parts management, operational controls, and failure response measures (i.e. pre-planned corrective maintenance plans).

### Context

While planning for maintenance must begin in the Asset Creation & Acquisition stage, the development of the Asset Maintenance Strategy is the formal 'Plan' step in the PDCA cycle of an asset or asset system in terms of maintenance.

Not all assets are created equal, and even similar assets may not impact the business in a similar fashion when failing or in a failed state. Understanding an asset's particular failure modes, operating context, and any operational history that may be available are key to developing an adequate strategy. Questions to pose when developing an asset's maintenance strategy include:

- How important is it to maintain the asset? That is, what are the consequences of the asset not properly operating or performing its function? This is answered through asset criticality analysis.
- What are the common causes of the asset not properly operating or performing its function?
- Are the causes and/or ensuing conditions preventable or even mitigated through proactive maintenance intervention? If so, should intervention be at a fixed internal of time, or upon achieving some condition?
- Would a pre-existing condition that leads to asset failure be evident? Easily detectable?
- When the asset is maintained, either proactively or reactively, are there certain requirements to doing so?

For highly critical assets especially, where demonstrability is a business and regulatory/legal imperative, risk-based and data driven analytical techniques (e.g. RCM, RBI, etc.) must be used in the determination of asset maintenance plans and tasks. Such analytical techniques must be able to:

1. Assure that the agreed and verifiable safety and environmental objectives of the organisation are achieved
2. Assure that the agreed and verifiable business and asset performance objectives are achieved, at an agreed level of assurance
3. Assure all are managed at a known and desired balance of the cost, the residual risk and the asset performance (including financial performance).

In order to achieve the above set of requirements, any analytical techniques must be:

- Fact-based and risk-based
- Fully traceable to system/asset output requirements and business needs
- Based upon good practice, international and national standards
- Compliant with statutory and regulatory imperatives
- Implemented by competent (certified) individuals
- Supported by verified technology (information and decision systems)

- Transparently and verifiably costed
- Able to provide the requisite deliverables in the agreed time frame.

On the other hand, for very low criticality assets, a "Run to Failure" maintenance strategy, that is, allowing the asset to operate without any maintenance until a fault is made apparent or it fails to functionally serve the organization, may be perfectly reasonable.

In either case, organizations should also apply a systematic approach to determining the value-added maintenance activities for maintenance plans that meet business requirements. A balance between level of maintenance and cost must be struck to ensure the optimal level of maintenance that will ensure maximum life-cycle value to the business. One must also regularly review influencing factors and changing circumstances and adjust accordingly.

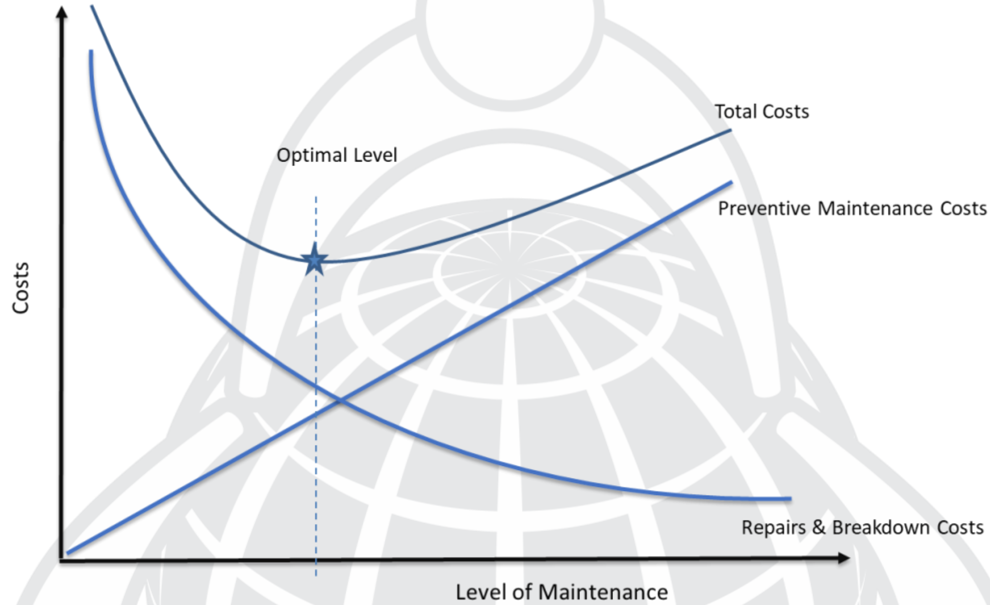


**Figure 7 - Relationship between Maintenance Level and Costs**

### Artefacts

Typical artefacts within this subject grouping include:

- Asset Information and Data needs to support the analytical processes
- Asset Data Standards to support the analytical processes
- Individual asset maintenance plans
- Operating limits and operational controls
- Maintenance procedures and instructions both for preventive and corrective (including failure response) activities
- Recommended spares, tools, & equipment
- Required technical skills

### Related Subjects

- Asset Criticality Analysis (ACA)
- Reliability Centered Maintenance (RCM)
- Failure Modes and Effects Analysis (FMEA) / Failure Modes Effects & Criticality Analysis (FMECA)

- Critical Spares and Redundancy Analysis
- Risk-Based Inspection (RBI)
- Reliability Block Modelling (RBM)
- Cost Benefit Analysis (CBA)
- Life-Cycle Costing (LCC) /Life-Cycle Cost Analysis (LCCA)
- GFMAM Asset Management Landscape subjects and groups:
    - *Asset Management Decision-Making:* Operations & Maintenance Decision-Making, Resourcing Strategy, Shutdowns & Outage Strategy
    - *Lifecyle Delivery:* Technical Standards & Legislation, System Engineering, Configuration Management, Maintenance Delivery, Reliability Engineering, Resource Management, Shutdown & Outage Management
    - *Risk & Review:* Contingency Planning & Resilience Analysis, Management of Change

**Relevant Standards**

- ISO/IEC 15288 Systems Engineering
- ISO 31000 Risk Management
- IEC 60300 Dependability Management series
    - IEC 60300-3-1 Dependability management - Part 3-1 Application guide - Analysis techniques for dependability - Guide on methodology
    - IEC 60300-3-3 Dependability management - Part 3-3 Application guide - Life cycle costing
    - IEC 60300-3-10 Dependability management - Part 3-10 Application guide - Maintainability
    - IEC 60300-3-11 Dependability management - Part 3-11 Application guide - Reliability centered maintenance
    - IEC 60300-3-14 Dependability management - Part 3-14 Application guide - Maintenance and maintenance support
- IEC 60812 Failure modes and effects analysis (FMEA and FMECA)
- IEC 61078 Reliability block diagrams
- IEC 61649 Weibull analysis
- IEC 61703 Mathematical expressions for reliability, maintainability and maintenance support items
- IEC 62775 Application guidelines – Technical and Financial processes for implementing asset management systems.
- API 579-1/ASME FFS-1 Fitness for Service
- API 580 Risk Based Inspection
- API 581 Risk-Based Inspection Methodology
- EN 13306 Maintenance Terminology
- EN 16991 Risk-based inspection framework
- SAE JA1011 Evaluation Criteria for Reliability Centered Maintenance (RCM) Processes
- SAE JA1012 A guide to RCM standard
- NFPA 70B Recommended Practice for Electrical Equipment Maintenance
- NORSOK Z-008 Criticality analysis for maintenance purposes
- US Military Standard 390D Level of Repair Analysis (LORA)
- US Naval Aviation (Navair) 00 25 403 Reliability Centered Maintenance (RCM)

## 6.5 Human & Material Resource Management

**Definition**

This subject group covers topics related to resources, be they are material or human, that have a direct impact on the maintenance function and its ability to meet its objectives.

Human resources related to the maintenance function include maintenance technicians, craftspeople, planners, schedulers, as well as technical and supervisory personnel. These resources may be internal as employees of the organization, or external in the form of contracted forces to either periodically supplement internal resources or to provide specialized services. For internal resources, recruitment, development, and sustainment must be managed. For external resources, contractor management and master service agreements require continued review and evaluation.

Material resources include maintenance and repair materials, spare parts and components, and tools and equipment. As with human resources, material resources can be found internally, such as in inventory parts and materials, or provisioned from external supply sources.

**Context**

The success of even the best maintenance strategies depends on resources. Maintenance strategies require skilled and qualified people to physically perform preventive and corrective activities. And spare parts, tools, and materials are the means by which they do so. Developing and implementing optimum human and material resources management strategies is therefore paramount.

### 6.5.1 Human Resources

Skilled maintenance personnel will help ensure that issues will be properly diagnosed, that maintenance interventions are properly planned and scheduled, and that maintenance activities are efficiently and effectively executed. This will contribute to asset availability and reliability.

Workforce skill and qualification requirements should ideally emanate from the requirements of maintenance plans although in many cases an assumption of base competency is made. However, as skills can erode over time, it is imperative that plans are in place to sustain skill levels. In some cases, certification of personnel is also required and therefore must be managed.

Another consideration for organizations is the number and nature of personnel to fulfill the maintenance function, as well as the organizational model in which they will be structured. To do so, an organization must balance the collective needs of the various maintenance strategies against the context in which it finds itself which may include legal, economic, geographic, and regulatory aspects, as well as organizational maturity, or more specifically maintenance maturity. Highly reactive maintenance strategies will undoubtedly require more human resources than proactive strategies. A key consideration in determining the internal maintenance organizational model, will be the suitability, availability, and affordability of external human resources. Most organizations will depend on external service providers to some extent.

Finally, the human resource strategy to support the maintenance function must be periodically assessed for effectiveness. This can be done by periodic review and analysis of asset performance and other program-level data. As an example, root cause analysis of failure data can reveal skill deficiencies, whereas backlog analysis can reveal imbalances between maintenance resource demand and capacity. In addition, rework rate could be assessed to indicate the work quality and workforce competency.

### Artefacts

Typical artefacts within this subject grouping include:

- Subject-specific key performance indicators
- Collective bargaining agreements
- Outsourcing strategy
- Master service agreements / contractor service agreements
- Training and education plans
- Workforce certification levels
- Competency requirements, matrices (e.g. skills matrix)
- Apprenticeship programs

### Related Subjects

- Education, Training and Development
- Skills and Qualification Management
- Roles and Responsibilities
- Supply Chain Management
- Contractor management
- GFMAM Asset Management Landscape subjects and groups:
  - *Asset Management Decision-Making:* Operations & Maintenance Decision-Making, Resourcing Strategy
  - *Lifecyle Delivery:* Configuration Management, Resource Management
  - *Organization & People:* Procurement & Supply Chain Management, Organizational Structure, Competence Management

### Relevant Standards

- ISO 18436 Condition monitoring and diagnostics of machines. Requirements for qualification and assessment of personnel
- IEC 60300-3-16 Dependability management - Part 3-16: Application guide - Guidelines for specification of maintenance support services
- EN 13269 Maintenance - Guideline on preparation of maintenance contracts
- EN 15628 Maintenance - Qualification of maintenance personnel

## 6.5.2 Material Resources

Another crucial aspect of resource management in maintenance is the management of material resources to support maintenance activities. When assets are unavailable due to maintenance being performed, material resource availability can have a direct impact on the ability to restore asset availability.

Material resources include MRO consumables, equipment parts/components, as well as entire equipment assemblies. Equipment parts/components and assemblies are commonly collectively known as maintenance spares or spare parts. Spare parts that are of utmost importance to organizations are colloquially known as critical spares or insurance spares.

While many OEMs will recommend maintenance spares, identifying the required spares is best determined using several methods such as FMEA/ FMECA. This will ensure the organization's particular operating context and business requirements are considered in any decision making.

Once an asset's required spares are identified, they should be catalogued against the asset using a bill of materials (BoM) with unique material numbers (aka part numbers, SKUs, etc.). This will help in rapid spare part identification during the maintenance planning process and in the event of an urgent fault response. It also helps in identifying common spares needed to maintain similar equipment across the facility or the organization.

Once material resource requirements are identified, organizations must determine whether they need to be held as inventory on site or elsewhere within the organization (also known as part stocking), of procured as need needed. There are many different stocking methodologies to be considered based on cost effectiveness and performance. Among these methods are in-house spares inventory, OEM /vendor management inventory, shared spares inventory, and consignment inventory.

The criteria used to determine stocking strategy and levels would typically include material cost, asset criticality, expected usage (as determined by asset population, usage rate or failure rate), and material lead time (the time required for a material to arrive on site once requested from a vendor). Stocking the required spare parts and materials must be carefully studied and optimized to minimize the capital investment. Excessive investment in spare parts leads to higher costs to manage the inventory, ties up working capital, and risks waste due to obsolescence.

Finally, another important aspect that needs to be addressed in material resource management is the proper storage of spare parts. It is important that spare parts themselves reliability fulfill their intended function. Damaged or otherwise compromised parts can delay maintenance work and/or affect asset reliability and availability. For example, certain electrical and electronic parts need to be protected from moisture, and unmounted roller bearings need to be stored flat while mounted bearings should be periodically rotated.

### Artefacts

Typical artefacts within this subject grouping include:

- Subject-specific key performance indicators
- Master service agreements / vendor supply agreements
- Bills of Materials (BoM)
- Critical spares analyses
- Stocking strategies, including inventory settings (min/max, re-order point) per material
- Material specifications (storage & handing requirements, safety-data sheets, maintenance requirements)

### Related Subjects

- Supply Chain Management
- Materials Management
- Materials Requirements Planning (MRP)
- Inventory Management (including Inventory Maintenance, Cycle Counting, Storage)
- Obsolescence Management
- Job Kitting
- Repairable Spares
- Critical Spares and Redundancy Analysis
- Disposal Policy
- GFMAM Asset Management Landscape subjects and groups:
  - *Asset Management Decision-Making:* Operations & Maintenance Decision-Making, Resourcing Strategy
  - *Lifecycle Delivery:* Configuration Management, Resource Management
  - *Organization & People:* Procurement & Supply Chain Management

### Relevant Standards

- VDI 2892 - Management of maintenance spare parts

## 6.6 Maintenance Work Management

### Definition

This subject group includes subjects related to the execution of the maintenance strategy, including carrying out individual maintenance plan activities, by maintenance workers and other personnel. In many organizations this includes coordination with operations teams and other asset owners, as well as external service providers.

*Work Management* is the vehicle by which all maintenance work activities are managed during the operational phase of assets in their lifecycle. It establishes processes and responsibilities for various phases in the eventual execution of maintenance work to ensure it is done with maximum effectiveness and efficiency.

### Context

Maintenance Work Management is the formal 'Do' step in the PDCA cycle of an asset or asset system in terms of maintenance.

Maintenance strategies and plans aim to be effective and efficient at meeting business and stakeholder requirements. Work management assures that the work which needs to be done will be executed by properly trained and qualified people, with the right materials, per the right procedures, and at the right time with an accepted impact on the operating plan and little or no waste of human and material resources. Moreover, the documentation and data, critical business assets in their own right, are collected to document compliance with the stakeholder requirements and inform the continuous improvement of the maintenance strategy.

Key aspects of successful work management are:

- Clear objectives aligned to the business strategy
- Priorities based on risk-based approach and aligned to stakeholder requirements
- Business processes aligned to asset management accepted good practice
- Roles and responsibilities/authorities identified for each step of the business processes
- Metrics and key performance indicators that measure and review performance
- Audits to verify compliance and effectiveness
- A continuous improvement loop for the work management process
- Maintainer safety - formal JSAs (job safety assessments) are completed and signed (acknowledged) by both the maintainers and operators and integrated with the work permitting procedures and the procedures related to the control of hazardous energy.

This requires developed business processes and governance to ensure effective and efficient work management.

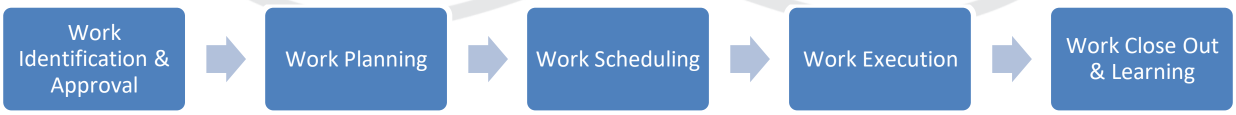


**Figure 8 - Work Management Processes**

Work management processes, shown in Figure 8, include:

- Work identification & approval process – to request maintenance services; identify, validate, prioritize, and approve work requests
- Work planning process – to develop work packages including scope, procedures, references, material, tools, equipment, services, testing, etc.

- Work scheduling – to produce work schedules, balance resources, monitor work backlog, manage break-in work, coordinate equipment access, etc.
- Work execution – to manage labor, material, and services; control productivity and work quality, ensure regulatory compliance, worker safety, etc.
- Work close-out – to document job completion details; close work orders (time & material consumption), create post-work documentation process, record failures, collect data, analyses and follow-up work orders, measure work management performance

The framework of work management processes is a critical part of a formal asset management system and is an essential component in managing maintenance.

### Artefacts

Typical artefacts within this subject grouping include:

- Instructions, guidelines, standards, and procedures including the hazards & mitigations associated with undertaking the task (e.g., isolation procedures, hazardous materials issues, etc.)
- Business processes
- RASI/RACI charts
- Work management training documents
- Key Performance Indicators (KPIs)
- Asset history
- Asset performance data
- Job Safety Analyses (JSAs) / Job Hazard Analyses (JHAs)
- Safety Data Sheets (SDSs)
- Permitting procedures, permits
- Equipment isolation procedures
- Partnership and service-level agreements between Maintenance and its customers

### Related Subjects

- Computerized Maintenance Management Systems (CMMS)
- Control of Work (CoW)
- Maintenance Backlog Management
- Precision Maintenance
- Quality Control / Quality Assurance
- Shutdowns and Turnarounds
- Standard Jobs, Pre-planned work
- Work Order Management
- Work Identification
- Work Planning
- Work Scheduling
- Work Execution
- Work Close-Out
- GFMAM Asset Management Landscape subjects and groups:
  - *Asset Management Decision-Making:* Operations & Maintenance Decision-Making, Shutdowns & Outage Strategy
  - *Lifecycle Delivery:* Maintenance Delivery, Resource Management, Shutdown & Outage Management, Fault & Incident Response

### Relevant Standards

- ISO 55001 Clause 6.2, 7.3, 8.1
- IEC 60300 Dependability management, Part 3-14: Application Guide – Maintenance and Maintenance support
- IEC 60706 Maintainability of equipment, Part 4: Maintenance and maintenance support planning
- EN 15341 Maintenance – Maintenance key performance indicators
- EN 13460 Maintenance – Documentation for maintenance
- MIL-P-24534A Planned maintenance system – Development of maintenance requirement cards, maintenance index pages and associated documentation
- DIN 31051 Fundamentals of maintenance
- NFX60-000 Industrial maintenance – The maintenance function
- VDI 2885 Standardized data for maintenance planning and determination of maintenance costs – Data and data determination
- VDI 2890 Planned maintenance; guide to drawing up of maintenance lists
- VDI 2895 Organization of maintenance – Maintenance as a task of management

## 6.7 Asset Performance & Condition Management

### Definition

This subject group includes subjects related to the assessment of the operational performance of a single asset or asset system, in terms of reliability and availability, as well as management of physical condition data for the purposes of fault detection and determination of remaining useful life.

### Context

Asset Performance & Condition Management is the formal 'Check' step in the PDCA cycle of an asset or asset system in terms of maintenance.

While asset and asset systems and their corresponding maintenance plans should be designed based on an appropriate understanding of an asset's criticality, failure modes, and the consequences (effects) of these failures, such designs are based on certain assumptions. Measuring asset maintenance performance, specifically characteristics of reliability (e.g., MTBF, MTBM), availability, and maintenance costs provides useful insights into how asset maintenance plans, either in terms of design or their execution, must be changed to improve life-cycle value. At the limit, changes could also include re-design of the asset itself.

Similarly, the collation and analysis of condition data provides insights into immediate and long-term maintenance interventions required. This is effectively known as asset condition monitoring and management, and it is a crucial element of any condition-based maintenance program.

For rotating equipment and other types of industrial assets, condition monitoring typically includes non-invasive measurement of physical properties such as vibration levels (vibration monitoring/analysis), temperature (thermography/infrared analysis), fluid and lubricant condition (e.g. oil analysis), sound level for the detection of gaseous fluid leaks, ionic discharge, and mechanical failures by way of emitted acoustic energy (airborne and structure-board ultrasonics), and measuring electrical equipment performance by analyzing electrical properties (e.g. electrical signature analysis). There exists also many NDE techniques for non-rotating equipment (e.g. tanks, vessels, and piping) to test for wear and structural integrity of materials of construction (including weldments) such as Eddy Current /electromagnetic testing (ET), liquid penetrant testing (PT), magnetic particle testing (MT), and radiographic testing (RT).

The collection of condition data is generally prescribed in maintenance plans and executed as part of work management.

### Artefacts

Typical artefacts within this subject grouping include:

- Subject-specific key performance indicators
- Structured history (failure date stamps, unplanned vs. operate to failure, failure coding to characterize failure, repair costs, spares, etc.)
- Condition data and trends

### Related Subjects

- Asset Condition Monitoring (ACM), which includes the following specific subjects:
  - Acoustic Emission Testing (AE)
  - Airborne/Structure-borne Ultrasonics
  - Electrical Signature Analysis
  - Motor Current Signature Analysis
  - Oil Analysis / Monitoring

  - Thermography
  - Infrared Analysis / Monitoring
  - Vibration Analysis / Monitoring / Testing
- Asset Integrity Management
- Fitness for Service
- Statistical Analysis / Analytical Methods (e.g., Weibull, Crow-AMSAA, etc.)
- Reliability Modelling
- Reliability Engineering
- Root Cause Analysis (RCA) / Root Cause Failure Analysis (RCFA)
- Machinery prognostics (e.g. remaining useful life)
- Reliability Performance Measurement (Availability, OEE, MTBF, MTTR, etc.)
- FRACAS (Failure Reporting, Analysis, and Corrective Action System)
- Preventive Maintenance Optimization
- Prescriptive Maintenance
- Condition based maintenance
- Non-destructive testing (NDT) / Non-destructive examination (NDE), which includes the following specific subjects:
  - Acoustic Emission Testing (AE)
  - Eddy Current /Electromagnetic Testing (ET)
  - Liquid Penetrant Testing (PT)
  - Magnetic Particle Testing (MT)
  - Radiographic Testing (RT)
  - Ultrasonic Testing (UT)
- Asset performance management (APM) systems
- Individual condition monitoring & management databases and systems
- GFMAM Asset Management Landscape subjects and groups:
  - *Lifecyle Delivery:* Maintenance Delivery, Reliability Engineering, Fault & Incident Response
  - *Asset Information:* Asset Information Strategy, Asset Information Standards, Asset Information Systems, Data & Information Management
  - *Risk & Review:* Risk Assessment and Management, Management of Change, Assets Performance & Health Monitoring, Asset Management Systems Monitoring

**Relevant Standards**

- ISO 2041 Mechanical vibration, shock and condition monitoring — Vocabulary
- ISO 13372 Condition monitoring and diagnostics of machines — Vocabulary
- ISO 13379 Condition monitoring and diagnostics of machines - Data interpretation and diagnostics techniques — Part 1: General guidelines
- ISO 13381-1 Condition monitoring and diagnostics of machines - Prognostics - General guidelines
- ISO 17359 Condition monitoring and diagnostics of machines — General guidelines
- ISO 22400 Automation systems and integration - Key performance indicators (KPIs) for manufacturing operations management
- IEC 61703 Mathematical expressions for reliability, maintainability and maintenance support items
- API 579-1/ASME FFS-1 Fitness for Service
- API 580 Risk Based Inspection
- API 581 Risk-Based Inspection Methodology
- CEN/TS 17385 - Method for condition assessment of immobile constructed assets
- EN 16991Risk-based inspection framework

## 6.8 Maintenance Data & Information Management

### Definition

The maintenance function depends on competent people and systems to continuously make sound business decisions using sound processes and above all, sound information. For information to be sound, it should be supported with data.

This subject group includes subjects related to the creation and control of maintenance documentation and the collection, storage, and usage of maintenance data, operations data, cost data, spares data, risk data and related information.

### Context

Data-driven business decisions are dependent on the ability to acquire, manage and manipulate data and then quickly convert the data into knowledge that can be used to manage the day-to-day maintenance activities, as well as plan for the future (improvement). Typical maintenance data collected is:

- Master data at the asset level – Make, model, manufacture, design and performance characteristics, asset age, current condition
- Asset criticality related explicitly to business context
- Associated bill of materials
- Maintenance procedures, work instruction, detail job plans, quality control plans
- Repair cost - all materials, parts, tools rental equipment and internal and external labor
- Repair frequency (MTBF) or other related failure information
- Failure codes
- Details of the cause and effects of failures
- Remedy codes
- Meter reading and indication of run time or equipment usage and/or other related measures
- Results of condition-based inspections and actions and/or trending information
- Results of operator inspections and actions and/or trending information

In most organizations, an Enterprise Asset Management (EAM) system, Enterprise Resource Planning (ERP) system, or dedicated Computerized Maintenance Management System (CMMS) is used to accommodate the volume of maintenance data and number of users who require instant access to the data. Secondary specialized systems also exist such as Asset Performance Management (APM) systems. While the need for, and potential value of such systems is almost certain, organizational discipline and good business processes must be in place for the installation, configuration, and use of such systems so that the maximum return on investment is achieved.

### Artefacts

Typical artefacts within this subject grouping include:

- Data and records management policies, standards, procedures, and instructions
- Asset data
  - Asset master data including functional data, physical data, derived data, analytical data
  - Asset transactional data including inspection and repair history (work done, parts used, labor consumed, etc.)
  - Asset performance data
  - Condition/health data

  - Preventive maintenance and repair procedures
  - Bill of materials / parts list
  - Operational usage data, such as operating time, cycles, etc.

- Data systems:
  - Computerized maintenance management systems (CMMS)
  - Enterprise asset management (EAM) systems
  - Enterprise resource planning (ERP) systems
  - Asset performance management (APM) systems
  - Asset investment planning (AIP) systems
  - Individual condition monitoring & management databases and systems
  - Supply chain / parts catalogue
  - Inventory systems
  - Operational data historians

- GFMAM Asset Management Landscape subjects and groups:
  - *Lifecycle Delivery:* System Engineering
  - *Asset Information:* Asset Information Strategy, Asset Information Standards, Asset Information Systems, Data & Information Management

### Related Subjects

- Master Data Management /Governance
- Document Management Records Management
- Data Assurance Management
- Asset Management System
- Industrial Internet of Things (IIoT)
- Artificial Intelligence, Machine Learning
- Data Architecture

### Relevant Standards

- ISO 10007 Configuration Management
- ISO 13374 Condition monitoring and diagnostics of machines
- ISO 13381-1 Condition monitoring and diagnostics of machines - Prognostics - General guidelines
- ISO 14224 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment
- ISO 15489 Information and documentation – Records management
- ISO 15926 Industrial automation systems and integration — Integration of life-cycle data for process plants including oil and gas production facilities
- ISO 19650 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling
- ISO 27000 series S1000D An international specification for the procurement and production of technical publications
- ISO 55001 Section 7.5 and 7.6
- IEC 60300 Dependability management – Part 3-2: Collection of dependability data from the field
- IEC 60706 Maintainability of equipment – Part 3: Verification and collection, analysis and presentation of data
- IEC 62027 Preparation of parts lists
- IEC 82045 Document management

- EN 13460 Maintenance - Documentation for maintenance
- BS 6548 Maintainability of equipment – Part 3: Guide to maintainability, verification and the collection, analysis and presentation of maintainability data
- NF X60-200 Maintenance – Technical documentation associated with an item throughout its life cycle
- ASQ D600300-3-2 Application guide - Collection of dependability data from the field
- API STD 689: Collection and exchange of reliability and maintenance data for equipment
- MIMOSA CCOM (Common Conceptual Object Model) - Information model for the exchange of asset information
- MIMOSA OSA-EAI - Open System Architecture for Enterprise Application Integration
- MIMOSA OSA-CBM - Open System Architecture for Condition-Based Maintenance

## 6.9 Maintenance Program Management

### Definition

This subject group is the collection of subjects specific to the development, management, and continual improvement of a holistic maintenance program for a grouping of assets[5] which collectively deliver the requisite assurance that business needs will be achieved by the program.

### Context

While methods exist to develop asset-specific maintenance strategies and requirements to support those strategies (maintenance plans, resource requirements, etc.), maintenance program management is about the overall orchestration of said various strategies through the lens of the various framework elements. Whereas individual asset maintenance strategies serve functional requirements of assets, an overall maintenance program serves to achieve organizational business requirements of a system of assets and the overall asset portfolio, all within the organizational context. And as the organizational context changes, so too must its maintenance program.

Developing a maintenance program in an organization requires alignment of objectives, methodologies, and approach between all functions of the organization. It also requires all the elements of the maintenance framework to be in place. Maintenance programs must also strive for both efficiency and effectiveness to attain excellence. Being very efficient at executing maintenance activities is certainly beneficial but doing the 'right' maintenance is just as important, arguably even more in some cases. Periodic review of both these attributes is thus imperative.

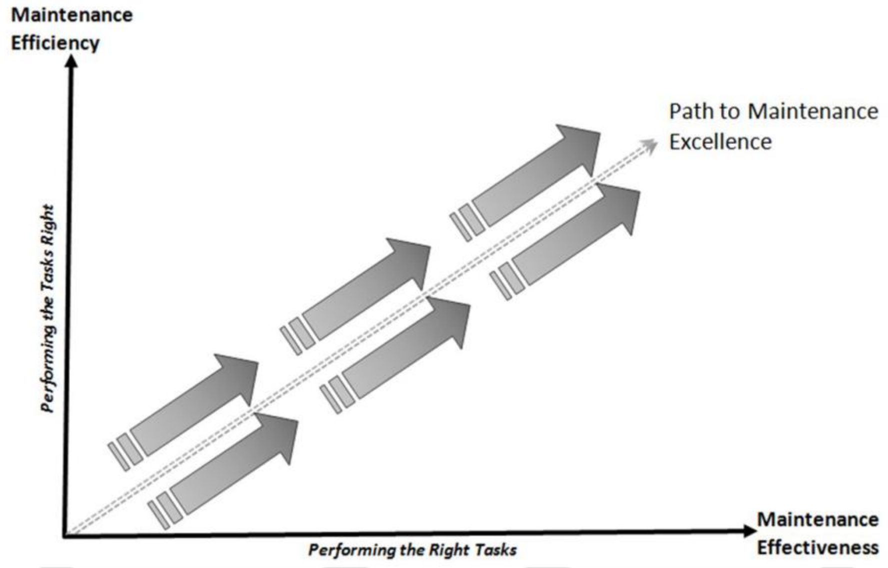


**Figure 9 - Maintenance Program Management Path to Excellence [6]**

The performance measures of a maintenance program are distinct from those of individual assets. For example, metrics such as maintenance costs, availability, reliability, etc. while availability is relevant at an asset level, must specifically be looked at from an asset system and asset portfolio level to ensure overall organizational business objectives are met. At these levels, some additional performance measures may exist. For example, in the case of maintenance costs, these are often unitized to overall production or service level.

[5] May also be known as an asset portfolio, or asset system, the latter defined by ISO 55000 as a grouping of assets. [2]

Finally, as with individual asset strategies, continual review and improvement of performance measures at the program level is also important to counteract the ever-increasing costs of maintaining assets due to natural ageing and external influences such as increasing cost of labor and materials, regulatory requirements and marketplace competitiveness. It is an opportunity to seek and implement the ever-increasing opportunities that advances in materials and technology can afford the maintenance function.

### Artefacts

Typical artefacts within this subject grouping include:

- Maintenance policy statements
- Maintenance program manuals
    - General programs
    - Specific technical programs such as Risk-Based Inspection (RBI) programs, Electrical Integrity programs, Mechanical Integrity programs, Structural Integrity programs, Vibration Monitoring programs, Lubrication programs, etc.
- Maintenance budgets (annual, multi-year)
- Maintenance cost reports
- Maintenance management business processes and procedures
- Collective bargaining agreements

### Related Subjects

Complemented by all the subjects previously identified, the following are the subjects specific to this group:

*Continuous Improvement*

- Program Performance Management, Key Performance Indicators (KPIs), Benchmarking and Auditing
- Preventive Maintenance Optimization
- Six-Sigma / Lean / TPM

*Organizational/People*

- Organizational Models/Structures
- Change Management
- Human Factors

*Maintenance related data systems*

- Computerized Maintenance Management Systems (CMMS)
- Enterprise Asset Management (EAM) systems
- Enterprise Resource Planning (ERP) systems
- Asset Performance Management (APM) systems
- Asset Investment Planning (AIP) / Asset Investment Planning & Management (AIPM) systems

*Financial / Accounting / Cost Management*

- Maintenance Budgeting & Cost Control, including Zero-Based Budgeting

*General / Other*

- Maintenance Program Models
- Lean Manufacturing, including 5S and Overall Equipment Effectiveness (OEE)
- Quality Management / Total Quality Management

- Total Productive Maintenance
- Theory of Constraints
- Business Process Management / Process-Based Management
- Process Reliability
- Systems Engineering
- GFMAM Asset Management Landscape subjects and groups:
    - *Strategy and Planning:* Asset Management Strategy & Objectives, Asset Management Planning
    - *Asset Management Decision-Making:* Capital Investment Decision-Making, Operations & Maintenance Decision-Making, Resourcing Strategy, Shutdowns & Outage Strategy
    - *Lifecyle Delivery:* Technical Standards & Legislation, System Engineering, Configuration Management, Maintenance Delivery, Reliability Engineering, Resource Management, Shutdown & Outage Management, Fault & Incident Response, Asset Decommissioning & Disposal
    - *Asset Information:* Asset Information Strategy, Asset Information Standards, Asset Information Systems, Data & Information Management
    - *Organization & People:* Procurement & Supply Chain Management, Organizational Structure, Organizational Culture, Competence Management
    - *Risk & Review:* Risk Assessment and Management, Contingency Planning & Resilience Analysis, Management of Change, Assets Performance & Health Monitoring, Asset Management Systems Monitoring, Management Review, Audit & Assurance, Asset Costing & Valuation

### Relevant Standards

*Technical*

- ISO 31000 Risk Management
- ISO/IEC 15288 Systems Engineering
- IEC 60050-192 Electrotechnical Vocabulary (IEV) - Part 192: Dependability
- IEC 60300-3-14 Dependability management - Part 3-14: Application guide - Maintenance and maintenance support
- IEC 61078 Reliability block diagrams
- IEC 61703 Mathematical expressions for reliability, maintainability and maintenance support items
- NORSOK Z-008 Risk based maintenance and consequence classification

*Financial / Accounting / Cost Management*

- IEC 60300-3-3 Dependability management - Application guide - Life Cycle Costing
- International Accounting Standards (IAS)
    - IAS 16 Property, Plant and Equipment
    - IAS 36 Impairment of Assets
- International Financial Reporting Standards (IFRS)
    - IFRS 13 Fair Value Measurement
- SAE JA6097 Using a System Reliability Model to Optimize Maintenance Costs A Best Practices Guide

*General / Other*

- ISO 55001 Asset management — Management systems — Requirements
- EN 13269 Maintenance - Guideline on preparation of maintenance contracts
- EN 13306 Maintenance Terminology
- EN 15341 Maintenance - Maintenance Key Performance Indicators

- EN 16646 Maintenance - Maintenance within physical asset management
- EN 17007 Maintenance - Maintenance process and associated indicators
- IAEA Nuclear Energy Series NP-T-3.8 Maintenance Optimization Programme for Nuclear Power Plants
- FAA 8900.516 - Continuous Airworthiness Maintenance Program (CAMP) Guidance and Policy
- REGDOC-2.6.2 Maintenance Programs for Nuclear Power Plants
- IPWEA International Infrastructure Financial Management Manual (IIFMM)

# 7 *Appendix 1* – Abbreviations

| Abbreviation | Full Form |
|---|---|
| ACA | Asset Criticality Analysis |
| ACM | Asset Condition Monitoring |
| AIP / AIPM | Asset Investment Planning / Asset Investment Planning & Management |
| AIM | Asset Integrity Management |
| AM | Asset Management |
| APM | Asset Performance Management |
| ARV | Asset Replacement Value |
| BOM | Bill of Material |
| CAPEX | Capital Expenditure(s) |
| CM | Corrective Maintenance |
| CMMS | Computerized Maintenance Management System |
| EAM | Enterprise Asset Management |
| ERP | Enterprise Resource Planning |
| EUL | Expected Useful Live |
| FMEA / FMECA | Failure Modes & Effects Analysis / Failure Modes, Effects, & Criticality Analysis |
| FRACAS | Failure Reporting and Corrective Action System |
| GFMAM | Global Forum on Maintenance and Asset Management |
| JHA | Job Hazard Analysis |
| JSA | Job Safety Analysis |
| KPI | Key Performance Indicator |
| LCC | Life Cycle Cost |
| LORA | Level of Repair Analysis |
| LOTO | Lock Out Tag Out |
| MLDT | Mean Logistics Delay Time |
| MM | Maintenance Management |
| MRO | Maintenance, Repair & Overhaul / Maintenance, Repair, & Operations |
| MRP | Material Requirements Planning |
| MTA | Maintenance Task Analysis |
| MTBF / MOTBF | Mean Time Between Failure / Mean Operating Time Between Failure |
| MTBM | Mean Time Between Maintenance |
| MTTM | Mean Time to Maintain |
| MTTF | Mean Time to Failure |
| MTTR | Mean Time to Repair / Mean Time to Restoration |
| NDE / NDT | Non-destructive examination / Non-destructive testing |
| O&M | Operations and Maintenance |
| OEE | Overall Equipment Effectiveness |
| OEM | Original Equipment Manufacturer |
| OPEX | Operating Expense(s) |
| PAM | Physical Asset Management |
| PdM | Predictive Maintenance |
| PM / PvM | Preventive/Preventative Maintenance |
| PTW | Permit to Work |
| RACI | Responsible, Accountable, Consult, Inform |
| RAM | Reliability, Availability, and Maintainability |
| RASI | Responsible, Accountable, Support, Inform |
| RUL | Remaining Useful Live |
| RAV | Replacement Asset Value |
| RBD | Reliability Block Diagram |
| RBI | Risk Based Inspection |
| RBM | Risk Based Maintenance, Reliability Block Modelling |
| RCA / RCFA | Root Cause Analysis / Root Cause Failure Analysis |
| RCM | Reliability Centered Maintenance |
| RAM | Reliability, Availability, Maintainability |
| RAMS | Reliability, Availability, Maintainability, Safety |
| SAMP | Strategic Asset Management Plan |
| TPM | Total Productive Maintenance |

# 8 *Appendix 2* – Works Cited & References

[1] The Asset Management Landscape, Global Forum on Maintenance & Asset Management, 2014.

[2] International Standards Organisation, ISO 55000 Asset management – Overview, principles and terminology, International Standards Organisation, 2014.

[3] International Standards Organisation, ISO 55001 Asset management — Management systems — Requirements, International Standards Organisation, 2014.

[4] International Electrotechinical Commission, *IEC 60050 International Electrotechnical Vocabulary,* International Electrotechinical Commission.

[5] Society for Maintenance & Reliability Professionals, *SMRP Best Practices 5th Edition - Maintenance & Reliability Body of Knowledge,* Society for Maintenance & Reliability Professionals, 2017.

[6] D. Dhaliah, Physical Asset Management: An Organizational Challenge, FriesenPress, 2016.