Ballot Draft #6309

Condition Based Maintenance for Well Control Equipment Systems

API RP16CBM
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Condition Based Maintenance for Well Control Equipment Systems

1 Scope

The objective of this recommended practice (RP) is to outline the essential criteria and supplementary instructions for data collection and analysis, with the aim of establishing a maintenance/inspection interval that deviates from traditional schedule-based programs. This RP also provides additional guidance on utilizing condition-based/performance-based data to create an effective inspection plan. Commonly known as Condition Based Maintenance (CBM), the program developed based on these guidelines must demonstrate comparable or superior levels of safety and reliability in comparison to the conventional calendar-based scheme, once fully established.

Several API SC-16 Standards state “as an alternative to a scheduled-based inspection programs, the inspection frequency may vary from the specified interval if the equipment owner collects and analyses condition-based data (including performance data) to establish a different frequency”

This document aims to offer guidelines for the application of condition-based maintenance techniques specifically tailored for drilling well control equipment systems used in various drilling rig settings, including land-based and marine-based rigs such as barges, platforms, bottom-supported structures, and floating rigs.

Well control equipment systems are designed with components that provide wellbore pressure control in support of well operations. The following components may be utilized for operation under varying rig and well conditions:

— Blowout preventers (BOPs);

— Choke and kill lines;

— Choke manifolds;

— Control systems;

— Auxiliary equipment.

2 Normative Reference

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies (including any addenda/errata)

API Specification 6A, Specification for Wellhead and Tree Equipment

API Specification 16A, Specification for Drill-through Equipment

API Standard 53, Standard Well Control Equipment Systems for Drilling Wells

API Specification 16C, Choke and Kill Equipment

API Specification 16D, Specification for Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment

API 16F Specification for Marine Drilling Riser Equipment

API 16Q Design, Selection, Operation, and Maintenance of Marine Drilling Riser Systems

API Standard 64 Diverter Equipment Systems

ISO 14224:2016 Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this standard, the following terms and definitions apply

3.1.1

baseline condition

The assessment of the equipment, that has been evaluated and determined to be Fit For Service.

3.1.2

baseline assessment

A methodology whereby damage or flaws/imperfections contained within a component or equipment item are assessed in order to determine acceptability for continued service.

3.1.3

batch data

Information that is collected and analyzed in a time frame which does not require real-time or near real-time. Typically, the time frame is measured in hours, days or greater.

3.1.4

certificate of conformance

COC

Document in which the manufacturer, remanufacturer or technical authority certifies that the assembly or pat is in conformance to the mentioned standard(s), specifications, in accordance with the original or current product definition (OPS or CPD), on the date of issuance.

3.1.5

certificate of service

COS

Document in which the equipment manufacturer, remanufacturer of technical authority, certifies that the equipment has been inspected, repaired and successfully tested in conformance with the requirements of the defined workscope and assures that the listed equipment on the certificate if fit for service on the date of issuance.

3.1.6

condition based data

Information used to evaluate equipment condition and detect potential failures. Condition Based Data examples;

a. Physical properties such as appearance, surface finish, color, weight, density, hardness, dimensions, chemical composition

b. Temperature

c. Pressure

d. Flow

e. Displacement & Acceleration

f. Vibration

g. Acoustics

h. Ultrasound

i. Fluid condition

j. Wellbore fluid records

k. Electrical (voltage, current, resistance, etc.)

l. Visual and Aided (NDT) inspection

m. Force and weight

n. Function/pressure test results

3.1.7

condition based maintenance

Is a maintenance methodology in which maintenance operations are performed depending on the current physical condition of the equipment.

3.1.8

criticality

Element or system that is deemed by the organization, product specification, or customer as mandatory, indispensable or essential, needed for a stated purpose or task, and requiring specific action (API 16D 3.1.34).

3.1.9

cycles

A measurable/inferable repetition of predefined operational parameters (i.e. status, load, direction, function, pressure)

3.1.10

data analysis

A process of cleaning, analyzing, interpreting, and visualizing data/records to establish valuable insights that drive smarter and more effective decisions. It is vitally important that the result of any analysis does not impact the equipment or system integrity.

3.1.11

data collection

Is the process of gathering quantitative and qualitative information on specific variables with the aim of evaluating and analyzing outcomes. Data collection requires a clear process to ensure the data collection is clean, consistent, and reliable.

3.1.12

failure

Termination of the ability of a system, structure, equipment or component to perform its required or intended function(s).

3.1.13

failure data

A set of historical records pertaining to equipment and components that has been found defective or not operated as per intended purpose

3.1.14

failure mode

The manner of failure.

3.1.15

fit for service

Equipment that has the integrity to operate and function under the requirements of the relevant design specification or standard as documented by the Product Definiitonand successful testing (function/hydro).

3.1.16

FMECA

Failure Mode, Effects & Criticality Analysis is a series of linkages between potential failures, the impact, and the causes. Typically, well control equipment systems will have a FMECA in place, this tool shall be used and referred to when assessing changes to existing maintenance schedule.

3.1.17

in-service date

Is the date that an inventory item (used or un-used) or new equipment is placed into service for operation.

3.1.18

life cycle data

Historical records of the physical loads, cycles, environmental conditions and preservation experiences by the item, assembly or system.

3.1.19

major inspection (traditional schedule based 5 yr inspection).

A detailed physical inspection of the individual components and subassemblies in accordance with the 5 yearly scope found in the equipment owner's maintenance system. This can include but not limited to dimensional, visual, MPI/UT and performance testing. The result of which are typically compared against the manufacturers acceptance criteria.

3.1.20

management of change
MOC

A documented management system for review and approval of changes in process or equipment prior to implementation.

3.1.21

management system

A management system is the framework of work processes and procedures used to provide assurance that an organization can fulfill all tasks required to achieve its objectives.

3.1.22

near real-time data

Information that is collected and analyzed where timeliness is important but reasonable delays are acceptable. Typically, the time frame is measured in minutes. Near real-time data is less time sensitive than real-time data but more time sensitive than batch data.

3.1.23

P-F interval

The amount of time, or cycles, from when a “potential failure” (P) is first detected on a piece of equipment until the equipment has reached “functional failure” (F).

3.1.24

performance data

Information, including testing, showing an equipment, assembly or system’s ability to meet functional design requirements.

This data provides a quantitative measure of the equipment’s ability to perform its intended purpose for example function testing, time to actuate and gallon counts.

3.1.25

primary data

Data collected directly from the equipment owner’s assets.

3.1.26

product history file

Composite file of records from a traceable API product, which includes all records associated with the API product manufacture, repair and remanufacture, including certification records required by the applicable specification/standard.

3.1.27

proxy data

Information or inspections from an area or piece of equipment that is then used to evaluate the condition or status of a correlating piece of equipment which is part of the same system and subjected to the same conditions but not physically inspected or evaluated.

3.1.28

qualitative data

Relies on qualities, descriptions and characteristics for example photographs or videos.

3.1.29

quantitative data

Data that is measurable, typically relies on numerical values.

3.1.30

qualitative risk analysis

A risk analysis using primarily subject matter expertise and experience to assign broad categorizations for POF and COF.

3.1.31

quantitative risk analysis

A risk analysis that uses primarily model-based approaches where numerical values are calculated and more discreet input data used.

3.1.32

real-time data

Information that is collected and analyzed within a short, requisite deadline. Typically, the time frame is measured in milliseconds to as much as a few seconds.

3.1.33

risk

Combination of the probability of an event and its consequence. In some situations, risk is a deviation from the expected. When probability and consequence are expressed numerically, risk is the product.

3.1.34

risk analysis

Systematic use of information to identify sources and to estimate the risk. Risk analysis provides a basis for risk evaluation, risk mitigation and risk acceptance. Information can include historical data, theoretical analysis, informed opinions and concerns of stakeholders.

3.1.35

risk assessment

Overall process of risk analysis and risk evaluation.

3.1.36

risk-based inspection

A risk assessment and management process that is focused on loss of containment of pressurized equipment in processing facilities, due to material deterioration. These risks are managed primarily through equipment inspection.

3.1.37

risk evaluation

Process used to compare the estimated risk against given risk criteria to determine the significance of the risk. Risk evaluation may be used to assist in the acceptance or mitigation decision.

3.1.38

secondary data

Data from secondary, indirect sources such industry lessons learned, failure databases, Proxy data is also deemed as a form of secondary data.

3.1.39

service life

The expected lifetime or the acceptable period during which a piece of equipment can safely and reliably perform within its intended operating envelop.

3.1.40

scheduled maintenance

Is the frequency of maintenance or inspection that has been recommended by the OEM or CEM known as the baseline.

3.1.41

stakeholder

Any individual, group or organization that may affect, be affected by, or perceive itself to be affected by the risk.

3.1.42

statement of fact

SOF

Document in which the manufacturer, remanufacturer, or technical authority declares that the repair and activity performed was in accordance with the scope defined by the service provider and equipment owner.

3.1.43

usage data

Information that is based on the “In-Service” period of the equipment for example wet days.

3.2 Abbreviations

For the purpose of this recommended practice, the following abbreviations apply

RBOP

ABOP

LMRP

CBM

FMECA

MTBF

SME

TA

4 Purpose

4.1 General

4.1.1 The objective of a CBM inspection scheme is to achieve a comprehensive understanding of the equipment, enabling an assessment of its fitness for service. This does not automatically imply a fixed inspection interval of 5 years; rather, the aim of the program is to optimize the inspection frequency by taking into account the actual usage and cumulative degradation of the equipment.

4.1.2 As an alternative to traditional schedule-based inspection program, a Condition-Based Maintenance (CBM) system may allow for an extended inspection frequency, based on justifiable evidence from collected and analyzed condition-based data. This principle is sometimes known as Reliability Centered Maintenance (RCM) or Risk-Based Inspection (RBI), where maintenance decisions are made based on the actual condition of the equipment, rather than relying solely on predetermined schedules.

4.1.3 Before developing a CBM scheme, it may be beneficial to review the fundamental maintenance flow, as detailed in Appendix A. The process flow map provides a comprehensive overview, although there may be a few exceptions that require further clarification.

- What precisely constitutes a baseline inspection/assessment.
- What precisely defines the CBM process.

4.2 Baseline Inspection/Assessment

4.2.1 The purpose of the baseline inspection/assessment is to intuitively determine the current condition of the equipment, as well as its suitability for service.

4.2.2 For equipment that is new or unused since manufacture or repair/remanufacture, see 5.3.3. This provides the minimum requirements for the unused product baseline.

4.2.3 In cases where equipment has been in service since its manufacture or repair/remanufacture, the baseline condition may be established through maintenance records, product history files, and proxy inspections. However, if relevant data is unavailable, a major inspection in line with the applicable equipment specification must be used as an alternative or additional method to establish the equipment's baseline condition before considering CBM.

- If the equipment has been in service for less than 5 years, the maintenance records, product history file, and a proxy inspection may be sufficient to establish its baseline condition.
- If the equipment has been in service for 5 years or more, a major inspection in accordance with the applicable equipment specification shall be required before considering CBM.

4.3 CBM process definition

4.3.1 Document (Identify and Quantify) via FMECA.

- Failure Modes
- Damage mechanisms
- Effects
- Criticality
- Causes

4.3.2 When conducting the FMECA, it is recommended that the probability of failure (POF) and consequence of failure (COF) be considered in the analysis. API Recommended Practice 580, *Risk-Based Inspection*, 3rd edition 2016 sections 9 and 10 will be useful in determination of the overall Risk Assessment.

4.3.3 FMECA report, to be filed as part of the technical records created for the product.

4.3.4 Create a ledger that documents the critical damage mechanisms and critical measurements that directly relates to the data sources that might be available to those failure modes.

This ledger should be a summary of the failure modes that have exceeded the RPNmin value for the project.

4.3.5 Develop means to gather data from viable sources. Section 5.0 provides an extensive list of suitable sources. Some examples are as follows:

- Product History File
- Operational History
- Failure data
- Reliability data
- External studies/analysis
- Testing data
- Etc

4.3.6 **Analysis of Data, see section 6.0**

4.3.7 **Documented equipment reliability study**

- To establish the maintenance/inspection frequency
- To establish the reassessment frequency

New rig/equipment maintenance process and schedule to be documented. This process shall provide all necessary documentation for the new inspection frequency, critical features to be monitored, other areas of interest, monitoring method(s), data collection, specific tools or analysis to be performed at each interval etc.

4.3.8 Performance verification and monitoring

4.3.8.1 Section 6.4 provides basic guidance for performance verification and validation.

4.3.9 CBM reassessments

4.3.9.1 The CBM (Condition-Based Maintenance) process is expected to be a dynamic one, providing ongoing risk and reliability evaluations that take into account current and future conditions. The outcomes of the evaluation will rely on the data collected at the time of the assessment. Since the equipment's condition is likely to change over time, the frequency of data collection and reassessment is also expected to vary accordingly.

4.3.9.2 Keeping the CBM (Condition-Based Maintenance) program up to date and well-maintained is crucial to ensure that the latest inspection, process, and maintenance information is utilized. The outcomes of inspections, changes in process conditions, and the adoption of new maintenance practices can all have a significant impact on the program and may necessitate a reassessment. Annex A is included as an illustrative example of methodologies that could be used to assist in creating a reassessment program.

5 Data Collection

5.1 Minimum data to be collected for Analysis.

5.1.1 The following data sets are intended to provide guidance and facilitate the creation of a case to support alternative maintenance frequencies.

5.1.2 The type of data to be collected depends on the equipment under assessment and the failure modes identified in the FMECA (Failure Modes, Effects, and Criticality Analysis).

5.1.2.1 Depending on the actions taken to mitigate the potential causes of the identified failure mode, the equipment owner must choose one or more data types to collect and analyze.

5.1.2.2 Qualitative data refers to empirical data, such as the equipment's appearance, pictures of damaged areas, observations, and so on.

5.1.2.3 Quantitative data refers to physically measurable data from sources such as dimensional inspections, NDE (Non-Destructive Evaluation) results, etc.

5.1.3 A competent individual, typically an SME (Subject Matter Expert) or a recognized technical authority, should specify which data should be selected for analysis based on the equipment in question.

5.2 Product History File

5.2.1 To incorporate an alternate inspection frequency into a CBM program, the equipment must have a properly documented Product History File (PHF). A list of documents needed to compile the PHF can be found in API 16AR.

5.2.2 If a comprehensive Product History File is not available, a thorough major inspection and subsequent testing (such as functional and hydrostatic testing) must be conducted to verify that the equipment satisfies the requirements of the relevant standard and product definition.

5.2.3 Historical documentation related to repair and remanufacturing must be retained as part of the Product History File. This documentation often includes the last Certificate of Conformance/Specification (COC/COS), which provides the assessor with information on the date of the last overhaul and the RSL (Repair Specification Level) in accordance with the applicable repair specification.

5.2.4 The existence of undocumented repairs will prohibit the inclusion of the equipment in a Condition-Based Maintenance program.

5.2.5 Reviewing the repair/remanufacturing data should offer insight into how the equipment has performed over its lifetime.

5.3 Storage and Preservation Records

5.3.1 It is common for equipment to have a period of idle time between manufacture or subsequent repair/remanufacture activities before being placed into service. During this period, it is important to ensure that proper storage and preservation measures are taken to prevent damage or deterioration of the equipment.

Additionally, electronic or hard copy storage and preservation records should be collected and made available to support the analysis and justification of adopting a Condition Based Maintenance (CBM) approach. These records may include information such as the date of manufacture or repair, the type of maintenance performed, and any associated test results.

By analyzing this information, maintenance managers can determine the optimal maintenance strategy for the equipment based on its current condition and expected usage. CBM can help to reduce maintenance costs and downtime by allowing maintenance activities to be scheduled based on the actual condition of the equipment rather than on a predetermined schedule.

5.3.2 Well control equipment shall be stored in accordance with the equipment owner's or the manufacturer's preservation and storage recommendations.

5.3.3 Before returning to service, the components shall be inspected and tested in accordance with the equipment owner's requirements, with consideration of the manufacturer's recommendations.

5.3.4 The preservation and the maintenance of the preservation shall be documented.

5.3.5 Any elastomer seals found to be outside the manufacturer's recommended shelf-life expiration date shall not be installed in BOP systems.

Table 1

5.3.6 Equipment preservation and maintenance records & data shall include the original equipment serial number or unique identification.

5.4 Operational History

It is vitally important to gather operational history to help assess and ascertain equipment condition. The minimum data required for this section is dependent on the equipment being assessed and should include the following as applicable:

5.4.1 The documented date the equipment went into service.

When collecting and analyzing data to justify a different frequency for inspections its vitally important to understand the equipment in-service date. The in-service date shall be recorded electronically or have hard copy documentation that can demonstrated when the equipment was placed into service for example commission records/installation records, Ref API S53 section 5.4.2.2 or 6.5.2.2.

5.4.1.1 Wet Days/Usage Data. A method to track the usage (start/stop) shall be established and monitored.

5.4.2 Records of well control events or abnormal conditions for example:

a. Hang off
b. Drift off
c. Divert
d. Extreme & Survival (16F/Q)
e. Stripping or Milling
f. Jarring
g. H_2S Exposure

5.4.3 Pressure Cycle or flow meter counts if applicable to specific equipment.

Ram BOP bonnets, for example.

5.4.4 Record of Environmental Conditions, such as:

a. Wellbore Temperature
b. Water Depth
c. Wellbore Pressure
d. Wave/sea states
e. Ocean current
f. Mud/completion fluids exposure
g. Fluid Chemistry & Density

5.4.5 Physical Conditions

a. Elastomer age
b. Top Tension
c. Riser tally
d. Drill String tension or setting

5.4.6 All of the physical operational sources of data might be used to develop product specific fatigue, fracture mechanics or finite element models to aid in the prediction of the remaining life of the product.

5.5 Maintenance and Testing History

5.5.1 A maintenance and repair historical file shall be maintained by serial number or unique identification number for each major piece of equipment. Maintenance history & testing trends can give an indication of equipment condition. Where applicable collect the below data for analysis to support the justification

a. Hydraulic Chamber test records (already required annually in Standard 53)
b. Planned/preventive maintenance tasks specified in the equipment owner’s planned maintenance system.
c. Function test records (already required weekly in Standard 53)
d. Visual inspection records/photos (Equipment owners PM program)
e. Dimensional records
f. NDE records if applicable
g. Corrective work orders/repairs carried out during operations and in-between wells.

5.5.2 A lack of maintenance records/history, for equipment that has been in service, will prevent that equipment from being placed into a Condition Based maintenance scheme until such time that all necessary planned/preventive maintenance tasks have been performed and documented.

5.6 Performance Data

5.6.1 Function test records, can be used to assess changes over time, for example an increase in gallon counts and actuation times can indicate degradation.

5.6.2 Data from emergency system testing

5.6.3 Pressure Test Records, a review of historical pressure test records can give an indication of system performance and integrity over time

5.6.4 BOP Control System fluid sampling and reports, collecting historical fluid condition can support decision making. Poor fluid quality will can accelerate equipment degradation

5.6.5 If applicable/fitted Vibration monitoring and acoustic sensory data

5.7 Technology

5.7.1 There are varying forms of technology that might be used to support and simplify data collection and analysis, for example:

a. Equipment sensors
b. Laser Scanning
c. Varying non-intrusive NDT techniques
d. Software additions to control systems that have ability to digitally record cycle counts, record wellbore temperatures and trend overlay system pressures. Estimates of performance or condition from analytical algorithms.

5.8 Failure Data

5.8.1 It is the responsibility of the equipment owner to track equipment malfunctions or failures, whether that component is in use or not and whether there is non-productive time or not, shall be recorded and tracked and serve as a key source of information when developing the FMECA.

5.8.2 Details of the equipment, control system and essential test data shall be maintained from the beginning to the end of the maintenance cycle and considered for use during the CBM scheme development.

5.8.3 The failure data shall include, as a minimum:

a. A clear concise description of the event
b. A clear description of the equipment/component concerned, including part number, serial number, size and pressure ratings
c. The root cause if the equipment owner's SME can confidently state the root cause of the event.
d. The condition of the failed equipment
e. Frequency and quantity of failures

5.8.4 An RCFA (root cause failure analysis) shall be conducted when:

a. There is a loss of a well barrier
b. There is an unplanned BOP/LMRP recovery
c. The failure is classified as recurring
d. The equipment owner's SME is not able to confidently determine the cause of failure.

5.8.5 The failure data collected from actual field events shall be compared to the failure modes identified in the FMECA. In the event the failure mode was not predicted, the FMECA and subsequent risk assessment shall be re-evaluated.

5.8.6 Failure data from other sources (customers/rigs) for similar equipment may also serve as a valuable source.

5.9 Inspection Data

5.9.1 The results of a detailed physical inspection consisting of dimensional and non-destructive examination results, including but not limited to magnetic particle inspection, liquid penetrant inspection, ultrasonic inspection, radiographic examination and visual inspection.

5.9.2 To be considered as the primary source of quantitative data.

5.10 Proxy Inspection Data

5.10.1 Proxy inspection data is a secondary source of quantitative data and shall not be considered as a sole source of information when collecting quantitative data.

5.10.2 It is acceptable to use proxy data to support condition assessments but only on the premise that the data is sourced from the same system and rig and the equipment under assessment has been subjected to the same operational conditions. A good example of where proxy data can be used is the choke manifold or ram BOP body main connection ring grooves.

5.10.3 Proxy data should be selected from an area that has been subjected to the highest loading or usage.

6 Data Analysis

6.1 Design Inputs

6.1.1 This document is not intended to provide detailed descriptions of methods for analyzing data. This document will however provide some applicable requirements to be considered when selecting an appropriate method for the analysis.

6.1.2 To establish an alternative to a schedule-based-inspection program, any analysis method of condition-based data shall be developed and documented to sufficiently justify its intended application and ensure repeatability throughout the life of the relevant equipment.

6.1.3 Condition based data analysis methods shall document component failure modes and critical features as defined within an equipment FMECA.

Analysis methods of condition-based data should address observed and anticipated operational failure modes with potential to disrupt or curtail drilling operations.

6.1.4 The intended application of the analysis method shall be defined and include the following minimum requirements:

a) Equipment type.
b) Specific failure modes addressed as defined within the component level FMECA.
c) Any other equipment features that may limit the validity of the analysis method.

6.1.5 An analysis method shall have defined input requirements for collected data that include the following:

a) Minimum data population size
b) Allowable data types

c) Required data collection frequency
d) Collected data units of measure (as applicable)

All assumptions used as part of an analysis development or implementation shall be defined. Such assumptions may include how the analysis handles unknown historical data, data gaps, data cleaning, or any other empirical methods inherent to the analysis.

6.2 Design Outputs

6.2.1 Outputs or conclusions of an analysis methos should have the ability to compare against acceptance criteria, historical data, original design philosophy, accepted industry standards or other established baseline. It is recommended that the outputs be quantitative for easier historical trending purposes and to avoid varying interpretations.

6.2.2 Analysis of condition-based data shall define the following:

a. Generated output data type
b. Recommended actions for each potential outcome of the analysis
c. The frequency of when the analysis should be performed.
d. The frequency of when the outputs or conclusions are generated by the analysis
e. Any relevant definitions used within the analysis, as defined for its intended use. (Example Cycle)
f. Generated output units of measure (as applicable)

Analysis and generated output frequency requirements shall be established based on expected failure mode occurrence, such that the analysis provides sufficient mitigation. Analysis may be performed at the same frequency as data collection (“real time”) or performed periodically on historically collected data (“batch”).

6.2.3 The baseline assessment establishes the baseline condition which answer the question is the suitable to be placed into service, does it meet the class requirements/design requirements.

6.3 Quality Control

6.3.1 Quality control measures should be implemented to ensure analysis methods are accurate, relevant, and reliable from initial implementation to long term application.

6.3.2 Collected condition-based data used as an input to analysis shall be included in the maintenance records for the equipment and be included in the Product History File.

6.3.3 For analyses that use complex data science models, controlled versions of implemented code be archived to ensure an accurate understanding of the methods used.

6.4 Performance Monitoring

6.4.1 The use of key performance indicators (KPIs) should be used to better understand the performance, quality, and validity of an analysis method over time. Examples might include confidence intervals, % error, analysis sensitivity, and model accuracy.

Performance monitoring methods should periodically evaluate analysis assumptions, limits and input requirements to substantiate the analysis validity. The implementation of automated monitoring methods is recommended if possible.

6.4.2 The purpose of the KPIs is to indicate how well the equipment is performing as compared to the design intent or standards.

6.5 Records and Documentation

6.5.1 Methods used to analyze condition-based data shall be defined and documented and include the following minimum requirements:

a. Analysis summary/description
b. FMECA reference
c. Applicability
d. Assumptions/limitations
e. Data Inputs
f. Calculations/outputs
g. Validation process

Annex A

(informative)

A.1 Data Collection Frequency

A.1.1 Data collection frequency is dependent on failure modes of target equipment and condition monitoring technology employed

- Failure mode, Failure mechanism & Condition monitoring technology
- Ease of data access & condition assessment. Does data collection require:
  - Intrusion (disassembling of equipment),
  - Operational disruption (collection of samples) or
  - Physical access (mounting of non-standard sensors)
  - Significant Effort/Cost/Time involved in condition assessment
- Time to Failure Distribution of failure mode (Random or Gaussian)
- P-F interval: represents the second (middle) phase in a three-phase life cycle model and deterioration model of assets. The three phases are identified as follows:
  - Phase 1: Pre-P period (<P)
  - Phase 2: P-F interval (P-F)
  - Phase 3: Post-F Period (>F)

The pattern of the P-F Interval is reflected on a P-F curve, Figure 1, and is used to express the probability of failure (POF) of a piece of equipment within a given time frame, usually a calendar year. The P-F curve is likely the most useful tools in Reliability Centered Maintenance (RCM). When used properly, the data collection frequency/inspection interval must be less than the P-F interval.

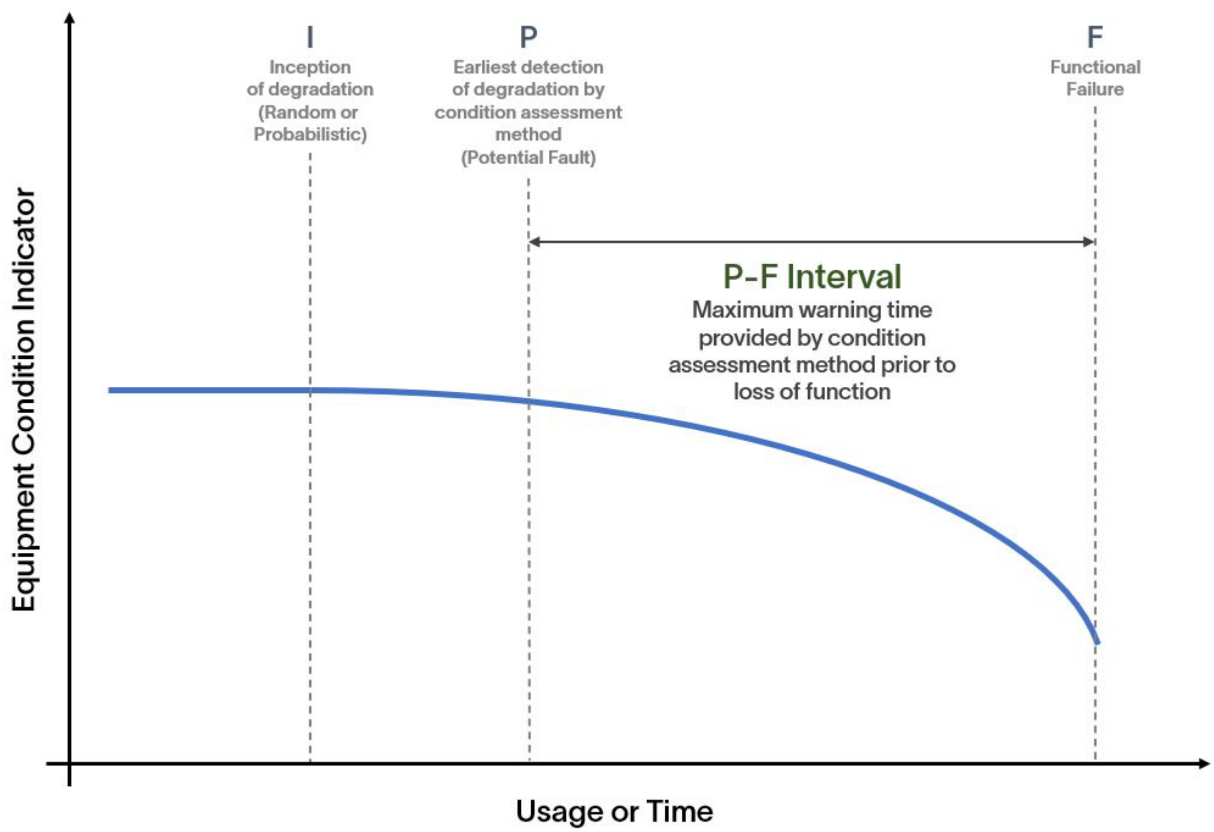

Figure 1: P-F curve

A.1.2 If condition data can be gathered with ease, without needing physical access to equipment, it should be collected and assessed as often as practicably possible.

A.1.3 If the target equipment failure mode is randomly distributed, data collection should be as often as practicably possible. The collection interval should not be more than 50% of P-F Interval.

A.1.4 If failure mode is wear-out related exhibiting gaussian/normal distribution, data collection should be triggered on an Unreliability threshold (specified by stakeholder) and then be driven by characteristics of the distribution (standard deviation/variance)

- E.g. Begin Data collection when Unreliability is 5%. Thereafter, data collection should be based on 50% of the P-F interval.

Appendix A

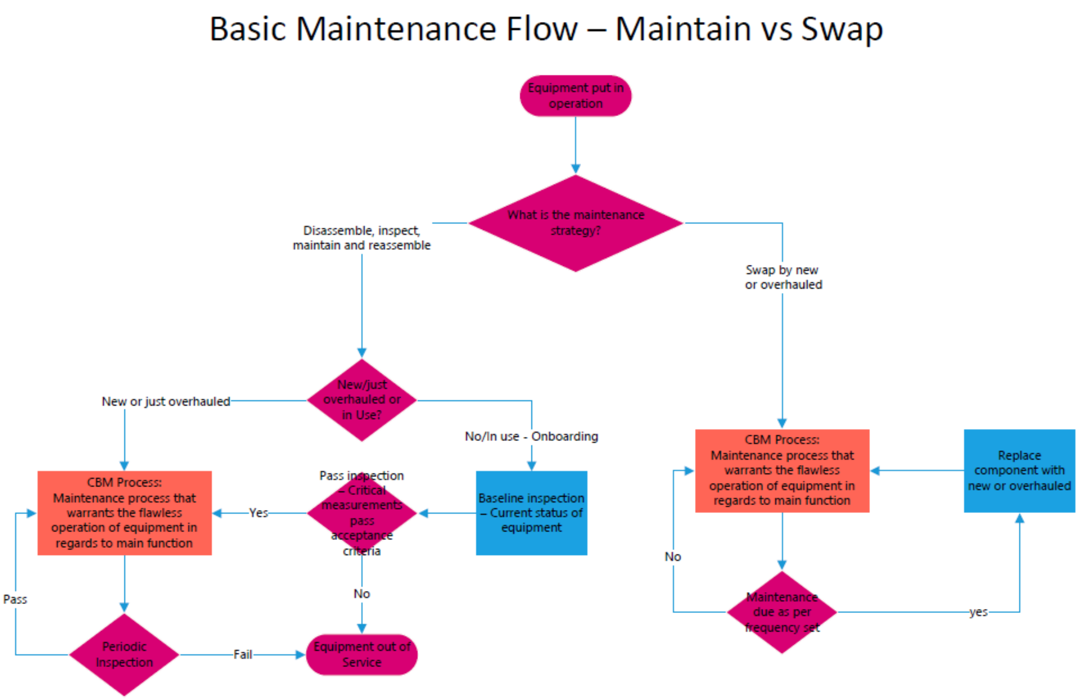

Figure 2 - Maintenance Flow

Appendix B

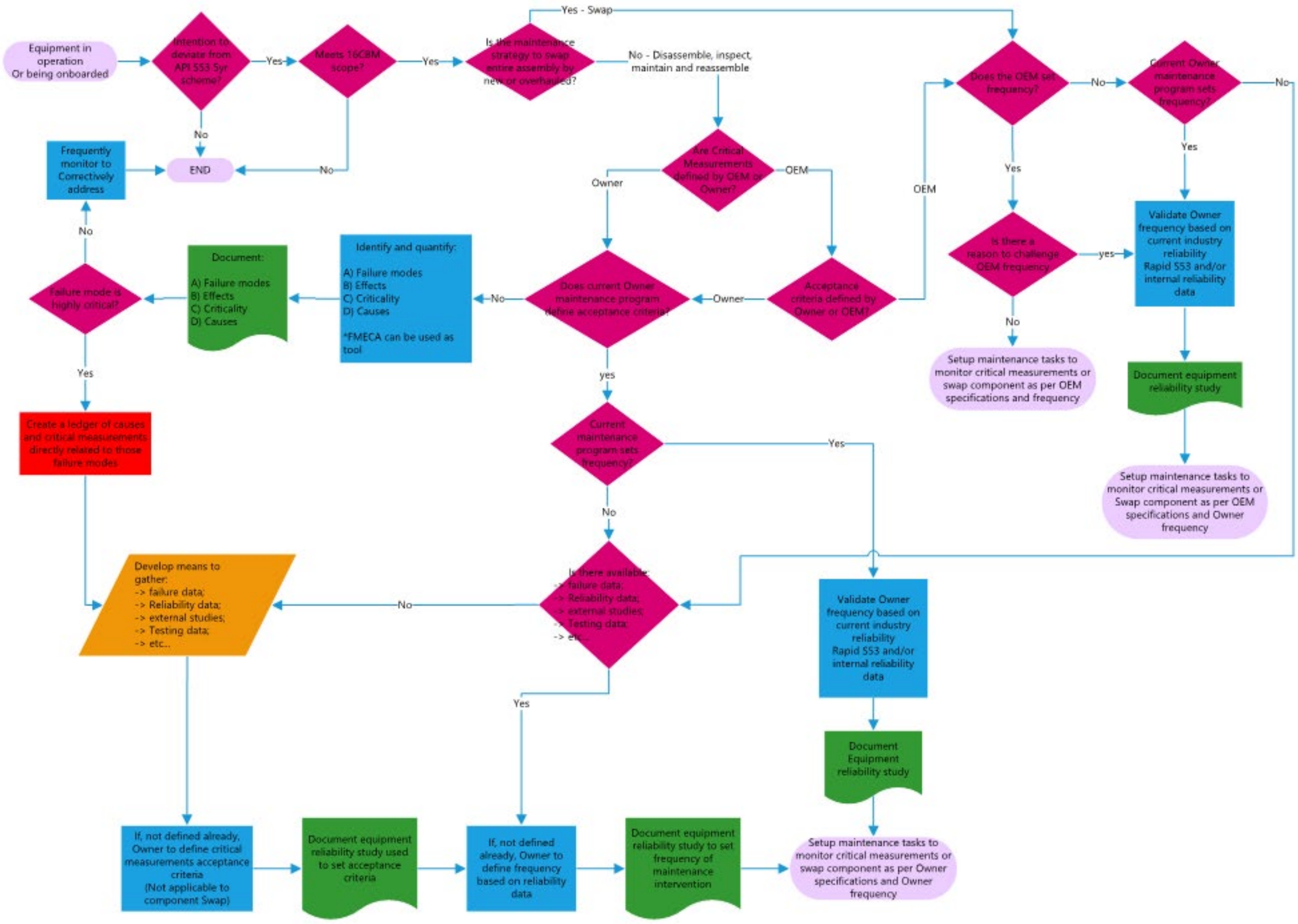

Figure 3 - CBM Process Flow