



GUIDE FOR

SURVEYS BASED ON MACHINERY RELIABILITY AND MAINTENANCE TECHNIQUES

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Foreword

The mission of the American Bureau of Shipping (ABS) is to serve the public interest, as well as the needs of its clients, by promoting the security of life, property, and the natural environment. This is primarily accomplished through the development and verification of standards for the design, construction and operational maintenance of marine and offshore facilities. These standards or Rules are established from principles of naval architecture, marine engineering and other engineering principles that have been proven satisfactory by service experience and systematic analysis.

Marine and offshore operators are striving towards improved operational effectiveness and efficiency. To achieve this end requires a focus on maximizing uptime, establishing quantitative condition assessment, and improving the overall safety, planning, operations, maintenance and repair processes. This is accomplished with a lifecycle process executing operations and maintenance in a continuous improvement cycle. This cycle aims at improving asset operations with a balanced criticality and risk-based approach.

The Guidelines presented herein offer ABS clients methodologies for achieving classification notations applied to machinery reliability and maintenance management programs. This Guide describes the process and responsibilities for ABS review of design submittals, analysis processes, and resulting maintenance plans as applicable throughout lifecycle stages. The methodology presented relies heavily on risk and reliability assessment techniques as a way to better understand and anticipate machinery and operational issues related to these concepts.

Since 1978, ABS has cooperated with Owners on developing and implementing preventative maintenance programs. In 1984, ABS issued its first *Guide for Survey Based on Preventative Maintenance Techniques* with subsequent updates in 1985, 1987, 1995 and then inclusion in the *ABS Rules for Survey After Construction (Part 7)* in mid 2002. Machinery systems continue to become larger and more complex, requiring skilled operators with specialized knowledge of the machinery and systems onboard.

This Guide supersedes the *ABS Guide for Surveys Based on Reliability-Centered Maintenance* (2014).

This Guide updates Reliability Centered Maintenance (RCM) and includes two new reliability processes:

- Design for Reliability (DFR) utilizes reliability/risk analyses to improve reliability-related performance to a predetermined value. It also provides a structure for applying these reliability/risk analysis tools throughout the design process to provide the information needed by the designer to make more informed design or procurement decisions.
- Reliability Based Maintenance (RBM) is an alternative reliability process to Reliability Centered Maintenance (RCM). RBM utilizes risk and criticality of systems and equipment to determine the level of analysis needed for maintenance development. A machinery system is selected for evaluation, then the criticality or risk ranking of the equipment and components is determined. The maintenance task selection processes are then chosen based on this criticality.

The final result is a suite of reliability processes that support a comprehensive preventative maintenance plan as defined in Appendix 7-A-14 of the *ABS Rules for Survey after Construction (Part 7)*.

This Guide becomes effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of these Guidance Notes is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.



GUIDE FOR

SURVEYS BASED ON MACHINERY RELIABILITY AND MAINTENANCE TECHNIQUES

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SECTION 1 General

1 Application

This Guide provides techniques for owners and operators to leverage reliability principles into machinery design, maintenance plan development, and sustainment activities. Owners and operators maintaining their marine or offshore assets with advanced machinery maintenance practices may increase their reliability and/or operational availability. Additionally, the processes found in this Guide and the resulting preventative maintenance plan may provide an alternative for crediting of Special Periodical Survey of Machinery.

Early in the lifecycle, the reliability of components, systems, or combinative processes can be improved by selecting appropriate reliability-enhancing design strategies. These strategies focus on:

- Improving equipment and configuration reliability through their arrangements,
- Designing to simplify manufacturing and assembly,
- Forecasting the design needs anticipated for operations, maintenance,
- Generating a testing and evaluation plan to confirm and validate the changes in design.

These processes enable optimized design, integrated features, and/or technology that will support minimizing operational disruption from component failure, maintenance, inspection, and survey of equipment. Design changes and critical components or machinery identified during design analysis steps may have additional construction tolerances and manufacturing hold points (testing and validation). These requirements support the construction and manufacturing plan thereby addressing reliability throughout the process up to and including commissioning.

To support operational activities, planning must take place to develop an in-service maintenance plan. A systematic process coupling risk and reliability principles should be followed for maintenance alignment and justification. This should take into consideration equipment criticality, functional definitions with applicable failure management analysis, equipment history of performance, OEM recommendations, and spare parts management.

As a means to credit Continuous Survey, clients may enroll their equipment in the ABS Preventative Maintenance Program (PMP). This allows the operator to execute planned maintenance and condition-monitoring activities through an ABS approved program. ABS Surveyors can then utilize the results of these programs to provide crediting toward Special Periodical Survey Machinery requirements. This can reduce disruptions and minimize impact to operations from ABS Survey activities. The ABS Preventative Maintenance Program requirements are contained in Appendix 7-A-14 of the *ABS Rules for Survey after Construction (Part 7)*.

The procedures and techniques described herein are applicable to maintained machinery and address multiple stages of equipment and asset lifecycle. No program for improved reliability supersedes the judgment of ABS during the design and approval process for certification of the machinery or systems as required by the applicable ABS Rules such as:

- *Rules for Building and Classing Steel Vessels (Steel Vessel Rules)*
- *Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*
- *Guide for Classification of Drilling Systems (CDS Guide)*

Nor does it waive ABS Surveyor attendance for damage, overhauls, operational tests, and verification of safety devices such as relief valves, over-speed trips, emergency shut-offs, low-oil pressure trips, etc., as required by the applicable Rules.

It is a prerequisite that the machinery enrolled in the programs outlined within this Guide be on a Special Continuous Survey of Machinery cycle.

2 Objective

The objectives of this Guide are to:

- Provide reliability based programs to address improved maintenance program performance. These efforts can provide increased asset value and result in improved asset safety and operational effectiveness. An additional benefit is a more clear definition of asset health so that unanticipated repairs are minimized and operations are less prone to delay.
- Provide requirements for improved reliability which seek to reduce the risk to personnel, vessels or marine structures, and the environment. This will potentially reduce the economic consequences due to a machinery failure which may otherwise occur more frequently without the application of a rational maintenance strategy, as provided for by this Guide.
- Foster effective asset management philosophies for new or existing assets and assist in providing credit toward the requirements of Special Periodical Survey of Machinery.

3 Definitions

The following definitions are applied to the terms used in this Guide.

ABS Recognized Condition Monitoring Company: The reference to this term refers to those companies whom ABS has identified as an External Specialist to carry out condition monitoring on designated machinery.

Baseline Data: Refers to *condition monitoring* indications (ex. vibration records, temperature/pressure readings, etc.) established with the *equipment item* or *component* operating in good order, when the unit first entered the Program; or the first condition-monitoring data collected following an overhaul or repair procedure that invalidated the previous baseline data. The baseline data is the initial condition-monitoring data to which subsequent periodical condition-monitoring data is compared.

Cause: See “*failure cause*”.

Component: The hierarchical level below *equipment items*. This is the lowest level for which the component can be identified for its contribution to the overall functions of the *functional group*; can be identified for its *failure modes*; is the most convenient physical unit for which the *preventative maintenance plan* can be specified.

Condition Based Maintenance (CBM): A maintenance plan, conducted on a frequent or real-time basis, which is based on the use of Condition Monitoring (CM) to determine when part replacement or other corrective action is required. This process involves establishing a baseline and operating parameters, then frequently monitoring the machine and comparing any changes in operating conditions to the baseline. Repairs or replacement of parts are carried out before the machinery fails based upon the use of the tools prescribed for CM.

Condition Monitoring (CM): Scheduled diagnostic technologies used to monitor machine condition to detect a potential failure.

Confidence: The analyst’s/team’s certainty of the risk evaluation.

Consequence: The way in which the effects of a *failure mode* matter. Consequence can be expressed as the number of people affected, property damaged, amount of oil spilled, area affected, outage time, mission delay, revenue lost, etc. Regardless of the measure chosen, the consequences are expressed “per event”.

Corrective Measures: Engineered or administrative procedures activated to reduce the *likelihood* of a *failure mode* and/or its *end effect*.

Criticality: A measure of risk associated with the *failure mode* and its *effects*. The *risk* can be measured qualitatively (e.g., high, medium, low) or quantitatively (e.g., \$15,000 per year).

Design for Maintenance and Inspection: A systematic design evaluation process used to improve maintenance efficiency and application in the design process. Incorporating future maintenance of the asset into the design is vital to maintaining the inherent reliability and capability of the process throughout its life.

Design for Manufacture and Assembly (DFMA): A systematic design evaluation process used to improve part design and part manufacture early in the design process. DFMA considers all aspects of the design, development, total parts, manufacturability, cost, assembly time and modularity to further enhance the overall design for manufacturability and quality.

Effects: See “failure effects”.

End Effects: See “failure effects”.

Environmental Standards: International, national and local laws and regulations or industry standards that must be complied with.

Equipment Items: The hierarchical level below *systems* comprised of various groups of machines or components.

Event: An occurrence that has an associated outcome. There are typically a number of potential outcomes from any one initial event ranging in *severity* from minor (trivial) to critical (catastrophic), depending upon other conditions and add-on events.

Evident Failure Mode: A *failure mode* whose *effects* become apparent to the operators under normal circumstances if the failure mode occurs on its own.

Failure Cause: The basic equipment failure that results in the *failure mode*. For example, pump bearing seizure is one failure cause of the failure mode where a pump fails.

Failure Characteristic: The failure pattern (i.e., wear-in, random, wear-out) exhibited by the *failure mode*.

Failure Effects: The *consequences* that can result from a *failure mode* and its *causes*.

- **Local Effect:** The initial change in the system operation that would occur if the postulated failure mode occurs.
- **Next Higher Effect:** The change in condition or operation of the next higher level of indenture caused by the postulated failure mode. This higher-level effect is typically related to the functional failure that could result.
- **End Effect:** The overall effect on the vessel that is typically related to the consequences of interest for the analysis (loss of propulsion, loss of maneuverability, etc.). For the purposes of this Guide, the term End Effects applies only to the total loss or degradation of the functions related to propulsion and directional control including the following consequences: loss of containment, explosion/fire, and/or safety occurring immediately after or a short time thereafter as a result of a failure mode. For offshore activities, these may be extended to include functions related to drilling operations, position mooring, hydrocarbon production and processing, and/or import and export functions.

Failure-finding Task: A scheduled task used to detect *hidden failures* when no *condition-monitoring* or *planned-maintenance* task is applicable. It is a scheduled function check to determine whether an item will perform its required function if called upon.

Failure Management Strategy: A proactive strategy to manage failures and their effects to an acceptable risk. It consists of proactive maintenance tasks and/or one-time changes.

Failure Mechanism: Describes how the *failure mode* may occur. One *failure mode* for a particular piece of equipment may have several failure mechanisms. The failure mechanism may vary during the life of the equipment as the failure rate pattern changes. See Subsection 2/2.

Failure Mode: Describes how equipment can fail and potentially result in a functional failure. Failure mode can be described in terms of an equipment failure cause (e.g., pump bearing seizes), but is typically described in terms of an observed effect of the equipment failure (e.g., pump fails off).

Failure Modes and Effects Analysis (FMEA): A systematic process to identify potential failures to fulfill the intended function, to identify possible failure causes so the causes can be eliminated, and to locate the failure impacts so the impacts can be reduced.

Failure Modes, Effects and Criticality Analysis (FMECA): A variation of the FMEA that includes an explicit estimation of the severity of the consequences of the failure or a combination of the likelihood of the failure and severity of the consequences.

Frequency: The potential of an undesirable *event* is expressed as events per unit time, usually per year. The frequency should be determined from historical data if a significant number of events have occurred in the past. Often, however, risk analyses focus on events with more severe *consequences* (and low frequencies) for which little historical data exist. In such cases, the event frequency is calculated using risk assessment models.

Function: What the *functional group, systems, equipment items* and *components* are designed to do. Each function should be documented as a function statement that contains a verb describing the function, an object on which the function acts, and performance standard(s).

- **Primary Function:** Directly related to producing the primary output or product from a functional group/system/equipment item/component.
- **Secondary Function:** Not directly related to producing the primary output or product, but nonetheless is needed for the functional group/system/equipment item/component.

Functional Failure: A description of how the equipment is unable to perform a specific *function* to a desired level of performance. Each functional failure should be documented in a functional failure statement that contains a verb, an object and the functional deviation.

Functional Group: A hierarchical level addressing propulsion, maneuvering, electrical, vessel service, and navigation and communications *functions*.

Hazard: Conditions that may potentially lead to an undesirable *event*.

Hidden Failure Mode: A *failure mode* whose *failure effects* do not become apparent to the operators under normal circumstances if the failure mode occurs on its own.

Indications (Failure Detection): Alarms or conditions that the operator would sense to detect the *failure mode*.

Level of Indenture: A relative position within a hierarchy of *functions* for which each level is related to the functions in the level above. For the purposes of this Guide, the levels of indenture in descending order are: *functional group, systems, subsystems, equipment items* and *components*.

Likelihood: See “frequency”.

Maintained Machinery: Machines or equipment are maintained where lifecycle decisions involve the repair, overhaul, or replacement of the machinery or its sub-components. These activities restore system function. Pumps, electrical motors, switchgears, gears, generators, compressors, internal combustion engines, turbines, hydraulic cylinders, winches, windlasses, and control and alarm systems are examples of maintained machinery.

Maintenance Task Analysis: Maintenance planning strategy that reviews all previous asset performance records as well as pertinent asset records that detail the best approach for maintenance. These results are used to tailor decision making on maintenance task selection.

One-time Change: Any action taken to change the physical configuration of a *component*, an *equipment item* or a *system* (redesign or modification), to change the method used by an operator or maintenance personnel to perform an operation or maintenance task, to change the manner in which the machinery is operated or to change the capability of an operator or maintenance personnel, such as by training.

Operating Context: The defined set of circumstances under which the *functional group* is expected to operate. The operating context may include the physical and operational environment as well as the specified performance criteria of the functional group.

Operating Mode: The operational state the vessel or marine structure is in. For example, cruising at sea, entering or departing a port.

Original Equipment Manufacturer (OEM): Company that manufactures equipment or components which are purchased and by others.

P-F (Potential Failure) Interval: The time interval between the point at which the onset of failure can be detected and the point at which functional failure occurs.

Parallel Redundancy: Applies to *systems/equipment items* operating simultaneously where each system/equipment has the capability to meet the total demand. In the event of a *functional failure* in one system/equipment item, the remaining system/equipment item will continue to operate, but at a higher capacity. For some arrangements, standby systems/equipment items may also be in reserve.

Performance and Quality Standards: The requirements *functional groups/systems/equipment items/components* are to operate at, such as minimum/maximum power or pressure, temperature range, fluid cleanliness, etc.

Planned Maintenance: For the purposes of this Guide, planned maintenance is a scheduled maintenance task that entails discarding a *component* at or before a specified age limit regardless of its condition at the time. It also refers to a scheduled maintenance task that restores the capability of an item at or before a specified age limit, regardless of its condition at the time, to a level that provides an acceptable probability of survival to the end of another specified interval. These maintenance tasks are also referred to as “scheduled discard” and “scheduled restoration”, respectively.

Potential Failure: An identifiable condition that indicates that a *functional failure* is either about to occur or is in the process of occurring.

Preventative Maintenance: Consists of all the maintenance tasks identified as necessary to provide an acceptable probability of survival to the end of a specified interval for the machinery systems. In IACS UR Z20, this is referred to as a “Planned Maintenance Scheme”. ABS Preventative Maintenance Program is defined in Appendix 7-A-14, “Surveys Based on Preventative Maintenance Techniques” of the *ABS Rules for Survey after Construction (Part 7)*

Proactive Maintenance Task: Implemented to prevent failures before they occur, detect the onset of failures or discover failures before they impact system performance.

Projected Likelihood: The *likelihood* (or *frequency*) of a *failure mode* occurring based on a maintenance task being performed or a *one-time change* implemented.

Projected Risk: The resulting *risk* that results from the combination of the *consequence* and the *projected likelihood*.

Random Failure: Chance failures caused by sudden stresses, extreme conditions, random human errors, etc. (i.e., failure is not predictable by time).

Reliability: The probability that an item will perform its intended function for a specified interval under stated conditions.

Reliability Centered Maintenance (RCM): A process that is used to determine the most effective approach to maintenance. It involves identifying actions that when taken will reduce the probability of failure and which actions are most cost effective. ABS has developed a maintenance program which uses RCM analysis of installed equipment to develop a Maintenance Program, a spare parts holdings list and includes a sustainment plan. For additional information on RCM, see also *ABS Guidance Notes on Reliability-Centered Maintenance*.

Reliability Based Maintenance (RBM): A maintenance strategy development model that will act as the foundation for applying selective reliability techniques, choosing and deploying a maintenance plan, and creating an effective reliability strategy to support an efficient maintenance environment

Risk: Composed of two elements, *frequency* and *consequence*. Risk is defined as the product of the frequency with which an event is anticipated to occur and the *severity* of the consequence of the event’s outcome.

Risk Matrix: A table indicating the *risk* for an associated *frequency* and *consequence severity*.

Root Cause Analysis: An analysis that identifies the causal factors, intermediate causes and root causes of an incident and develops recommendations to address each level of the analysis.

Run-to-failure: A failure management strategy that allows an *equipment item/component* to run until failure occurs, and then a repair is made.

Safeguards: See “*corrective measures*”.

Safety Standards: Methods that address the *hazards* that may be present in an *operating context* and specify the *safeguards* (*corrective measures*) that must be in place for the protection of the crew and vessel.

Servicing and Routine Inspection: These are simple tasks intended to (1) assess the failure rate and failure pattern by performing routine servicing (e.g., lubrication) and (2) spot accidental damage and/or problems resulting from ignorance or negligence. They provide the opportunity to confirm that the general standards of maintenance are satisfactory. These tasks are not based on any explicit potential failure condition. Servicing and routine inspection may also be applied to items that have relatively insignificant failure *consequences*, yet should not be ignored (minor leaks, drips, etc.).

Severity: When used with the term *consequence*, indicates the magnitude of the consequence.

Special Continuous Survey of Machinery (CMS): The requirements for Special Continuous Survey of Machinery are listed in the following Rules and Guides. Special Periodical Survey requirements are carried out in regular rotation to complete all of the requirements of the particular Special Periodical Survey within a five-year period. The proposed arrangements are to provide for survey of approximately 20% of the total number of survey items during each year of the five-year period, as referenced in:

- 7-2-1/7 “Continuous Surveys” (Vessels in Unrestricted Service) and 7-2-2/9 “Continuous Surveys” (Vessels in Great Lakes Service) of the *ABS Rules for Survey After Construction (Part 7)*.
- 7-2-2/1.5 “Continuous Surveys” (MODU) of the *ABS Rules for Building and Classing Mobile Offshore Drilling Units*
- 9/7.1 “Continuous Survey Program” of the *ABS Guide for the Classification of Drilling Systems*

Special Periodical Survey – Machinery: The requirements for a conventional ABS Special Periodical Survey – Machinery are listed in the following portions of the ABS Rules and Guides. Generally, this is considered 100% equipment crediting at Special Survey. There are Special Periodical Survey requirements in ABS Rules and Guides for specific vessel types, services, marine and offshore structures, such as:

- *ABS Rules for Survey After Construction (Part 7)*:
 - 7-2-2/7 “Special Periodical Surveys” (Vessels in Great Lakes Service)
 - 7-2-3/5 “Special Periodical Surveys” (Vessels in Rivers and Intracoastal Waterway Service)
 - 7-6-2/3 “Special Periodical Surveys – Machinery” (7-6-2/3.1, All Vessels, 7-6-2/3.3, Tankers)
- *ABS Rules for Building and Classing Mobile Offshore Drilling Units*:
 - 7-2-2/1.3 “Special Periodical Surveys”
- *ABS Guide for Classification of Drilling Systems*:
 - 9/5.3 “Special Periodical Surveys”

Subsystems: An additional hierarchical level below *system*, comprised of various groups of *equipment items* for modeling complex *functional groups*.

Systems: The hierarchical level below *functional group*, comprised of various groups of *equipment items*.

Wear-in Failure: Failure method that is dominated by “weak” members related to problems such as manufacturing defects and installation/maintenance/startup errors. It is also known as “burn in” or “infant mortality”.

Wear-out Failure: Failure method that is dominated by end-of-useful life issues for equipment.

4 Program Conditions and Administration

For enrollment in any of the maintenance and reliability programs, 7-A-14/3 of the *ABS Rules for Survey After Construction (Part 7)* are to be complied with including the following additional requirements:

4.1 Engineering Review

Where enrollment of machinery in any reliability program (Design for Reliability, Reliability Based Maintenance, or Reliability Centered Maintenance) is requested, the documented analyses and resulting in-service maintenance plan are to be submitted to the responsible ABS Engineering Office for approval. After implementation, if additional equipment is to be added to the programs, the analyses are to be submitted to the responsible ABS Engineering Office which performed the initial review. The requirements for the documentation to be submitted are listed in each Section of this Guide.

4.2 Implementation Survey

Implementation survey is to be carried out by the attending Surveyor within one year from the date of the approval letter approving the reliability analysis and resulting maintenance plan, as issued by the responsible ABS Engineering Office. The requirements for the implementation survey are listed in Section 6. This requirement is in addition to the Implementation Survey for ABS Preventative Maintenance Program per 7-A-14/5.3 and 7-A-14/17.5 as applicable in *ABS Rules for Survey After Construction (Part 7)*.

When this survey is carried out and the implementation found to be in order, a report confirming the implementation of the program is to be submitted by the attending ABS Surveyor. A class notation and survey status indicator will be assigned and distinguished in the *Record*, if appropriate, in accordance with Subsection 1/8.

4.3 Spares Holding

For assets enrolled in any reliability program, the Surveyor is to verify that an effective, computerized spares holding inventory and ordering system is established onboard at the Implementation Survey and at subsequent Annual Confirmation Surveys.

4.4 Sustainment

An effective sustainment program will collect, analyze, review and respond to in-service data throughout the life of the vessel so as to continually improve the maintenance plan. The results of the sustainment process are to be submitted to the attending Surveyor at the Annual Confirmation Survey and validated as part of survey process.

If the reliability analysis or resulting maintenance plans are revised as a result of the sustainment process, the attending Surveyor must be notified. The ABS Surveyor may require the analyses to be submitted to the responsible ABS Engineering Office that performed the initial review.

Reliability Based Maintenance (RBM) and Reliability Centered Maintenance (RCM) programs require an office audit be completed within five years after the date of enrollment of a vessel or after the crediting date of the previous special sustainment audit. The Surveyor will audit the shore office management plan to verify that the vessel's maintenance sustainment and continuous improvement activities are occurring and such activities are documented.

4.5 Annual Confirmation Survey

Simultaneously with each Annual Survey of Machinery for vessels on these programs, an Annual Confirmation Survey is to be performed by the attending Surveyor. This is to verify that the reliability program is being effectively implemented and is supporting execution of an approved maintenance program.

4.6 Cancellation of Program

The survey arrangement for machinery under this program may be cancelled by ABS if the program is not being satisfactorily carried out, either from the maintenance records or the general condition of the machinery, or when the agreed intervals between overhauls are exceeded.

Sale, change of management of the vessel, or transfer of class is to be cause for reconsideration of the approval.

The Owner may at any time cancel the survey arrangement for machinery under this program by informing ABS in writing. For this case, items which have been inspected under the program since the last Annual Survey may be credited for class at the discretion of the Surveyor. However, ABS will determine future survey requirements for machinery formerly enrolled as determined applicable by the Rules.

4.7 Overhauls and Damage Repairs

Damage, failure, deterioration or repair to machinery or equipment, which affects or may affect classification, is to be submitted by the Owners or their representatives for examination by a Surveyor at first opportunity. All repairs found necessary by the Surveyor are to be carried out to the Surveyor's satisfaction in accordance with 7-1-1/7.1 of the *ABS Rules for Survey After Construction (Part 7)*.

In the case of overdue outstanding recommendations or a record of unrepaired damage which would affect the Machinery Reliability and Maintenance Program, the relevant items are to be surveyed to the requirements of Special Periodical Survey until the recommendation is fulfilled or the repair is carried out.

5 Application of Risk and Criticality in Decision Making

The purpose of a criticality analysis is to rank items with respect to risk. The risk can be measured qualitatively (e.g., high, medium, low) or quantitatively (e.g., \$15,000 per year). Risk can be considered as the product of two factors: how often a loss event occurs (frequency) and how severe the effects are (consequence).

Frequency of a loss is usually expressed in loss events per year. The frequency can either be determined from past data (if a large number of events have occurred) or calculated using risk analysis tools (if few data records exist).

Consequence can be expressed in terms of a combination of a loss event's impact on the following example consequences:

- *Capital Investment.* Damage to and cost of repair of equipment
- *Community.* Effect on the public
- *Directional Control.* Complete loss or reduction of maneuverability
- *Explosion or Fire.* Damage to equipment and/or the vessel
- *Loss of Containment.* Amount of harmful substances released to the environment (cost of substance loss, the cleanup cost)
- *Operations.* Loss of hire, outage time of functions such as drilling, position mooring (station keeping), hydrocarbon production and processing, loading or unloading functions
- *Propulsion.* Complete loss or reduction of propulsive capability
- *Safety.* The number of people affected (injured or fatalities)

A sample risk matrix is shown in Section 1, Table 1 below. A risk matrix is an efficient way to characterize the risk of loss events. A risk matrix is simply a grid of cells that corresponds to defined consequence (High to Low) and frequency categories into which the loss events can be placed. The consequence and frequency categories are defined broadly enough to help one easily determine an appropriate risk cell for a loss event, but narrow enough to provide varying degrees of resolution for decision making. In many cases, frequency and consequence levels on a risk matrix are graduated by an order of magnitude (e.g., multiples of 5 or 10).

TABLE 1
Risk Matrix Example Format

Consequence Level	Likelihood of Failure				
	Improbable	Remote	Occasional	Probable	Frequent
High	Medium	Medium	High	High	High
Medium High	Low	Medium	Medium	High	High
Medium Low	Low	Low	Medium	Medium	High
Low	Low	Low	Low	Medium	Medium

6 Reliability Assessment Team Requirements

The analysis processes supporting reliability are best performed by a multi-disciplinary team to bring together varying perspectives and technical strengths. A team approach verifies that all required information that is available within the vessel or marine structure and/or organization is considered in the analysis, as well as providing a thorough analysis of the risks of failure and effective maintenance tasks.

The specific composition of the team depends on the vessel or marine structure complexity, program scope and any applicable regulations. Some of the technical disciplines may require outside assistance (from within or outside the organization) as advisors, but a core team is essential for continuity.

The team should have the expertise to identify and analyze all of the factors and their implications to machinery function including explosion/fire, loss of containment and safety. If during the risk and criticality prioritization, failure scenarios are inaccurately characterized, the analysis could potentially affect maintenance efforts of related components, thus resulting in a hazardous situation or inefficient maintenance. Personnel with technical and risk analysis knowledge are essential for the program to function effectively.

The team will typically consist of individuals with experience and technical knowledge in the maintenance and inspection of machinery with the following disciplines:

- i) Degradation and failure mechanisms of machinery
- ii) Reliability
- iii) Operations
- iv) Risk analyses
- v) System process hazards
- vi) Safety and health
- vii) Materials of construction

The team members may also be tasked to:

- viii) Participate and actively contribute in all risk analyses and reliability meetings and share their knowledge and experience for the analyses
- ix) Validate the quality and veracity of the information available
- x) Perform their specific tasks, keeping in mind the end goals of the reliability program

6.1 Client Activities and ABS Participation

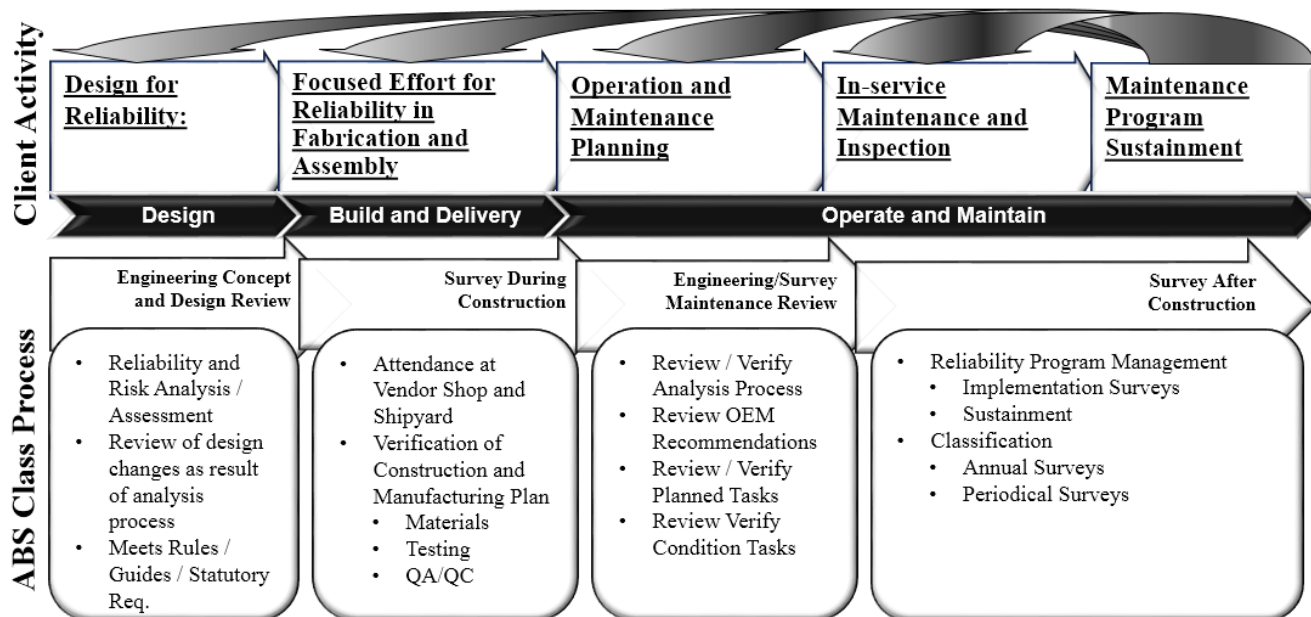
Conducting a reliability and risk assessment involves a team brainstorming session that provides a unique forum for designers, operational and safety personnel to discuss the design in a structured manner.

While ABS does not mandate that ABS personnel be part of this assessment team, as a participant, the ABS representative will be able to point out the issues that ABS considers to be relevant for the classification of the proposed design and thus should be discussed.

7 Coordination with Lifecycle Activities

The classification processes (engineering review, survey during construction, and survey after construction) coordinate with the lifecycle approaches as illustrated in Section 1, Figure 1. The objective is to align operator's in-service maintenance plan with the applicable survey requirements. For additional details on lifecycle activities, see Appendix 1.

FIGURE 1
Class Alignment with Client Programs



8 Classification Notations

The programs in this Guide are to be approved by an ABS Engineering Office. Upon completion of a satisfactory Implementation Survey, a “Certificate of Approval” is to be issued by the attending Surveyor. An optional notation, if appropriate, will be entered in the *Record*. In order to qualify for a notation assigned under this Guide requirements, a vessel is required to be assigned with a **PMP** notation in accordance with the Preventative Maintenance Program in Appendix 7-A-14 of the *ABS Rules for Survey After Construction (Part 7)*.

Details on each phase of an asset lifecycle and the associated ABS processes are explained in the following Sections of this Guide. The lifecycle program must be aligned to the applicable lifecycle phases and activities that are summarized herein. Where the requirements of this guide are met and the Owner request, a vessel may be assigned with one of the following optional notations:

- i) An approved program in accordance with Section 2, “Design for Reliability” will be assigned and distinguished in the *Record* with the class notation **RBMD** with an approved program in accordance with Section 3, or **RCMD** with an approved program in accordance with Section 4.
- ii) An approved program in accordance with Section 3 “Reliability Based Maintenance” will be assigned and distinguished in the *Record* with the class notation **RBM**.
- iii) An approved program in accordance with Section 4 “Reliability Centered Maintenance” will be assigned and distinguished in the *Record* with the class notation **RCM**.

8.1 Program Enrollment Options for Asset, System, or Equipment

The processes associated with the programs described in this Guide can be applied holistically to the asset (comprised of multiple systems), specific systems or specific equipment(s) of a system(s) at the Owner’s option.

TABLE 2
Program Definitions and Notations

Program	Definition	ABS Notation	Applicable Guide Section								
			ABS Engineering Submittal			Operational Documentation				ABS Surveys	
			DFR	RBM	RCM	Onboard Req.	PMP	Sustain	Annual Report	Implement	Annual Confirmation
			2/2	3/2	4/2	5/2	5/3	5/4	5/5	6/1	6/2
Design for Reliability	Design for reliability (DFR) utilizes reliability/ risk analysis tools so that future reliability-related performance meet expectations. It also provides a structure for applying these reliability/ risk analysis tools throughout the design process to provide the information needed by the operator to make more informed design decisions.	RBMD	✓	✓		✓	✓	✓	✓	✓	✓
	** DFR requires the addition of a reliability based or reliability centered maintenance program.	RCMD	✓		✓	✓	✓	✓	✓	✓	✓
Reliability Based Maintenance	A maintenance development process that will act as the foundation for applying selective reliability techniques, choosing and deploying a maintenance plan, and creating an effective reliability strategy to support an efficient maintenance environment	RBM		✓		✓	✓	✓	✓	✓	✓
Reliability Centered Maintenance	A systematic process coupling risk and reliability principles to create a maintenance plan by taking into consideration equipment criticality, functional definitions with applicable failure management analysis, OEM recommendations. To support the resulting maintenance plan, RCM also deploys a risk based analysis of spare parts and a sustainment plan.	RCM			✓	✓	✓	✓	✓	✓	✓
In order to qualify for a notation assigned under this Guide requirements, a vessel is required to be assigned with a PMP notation in accordance with the Preventative Maintenance Program in Appendix 7-A-14 of the <i>ABS Rules for Survey After Construction (Part 7)</i> . The below is for comparison with above reliability programs.											
Preventative Maintenance Program (see 7-A-14)	A program that consists of planned maintenance and/or condition-monitoring activities. Maintenance intervals and tasks follow OEM recommendations or documented operator experience.	PMP				✓	✓		✓	✓	✓

8.2 Machinery Status Indicators

Upon satisfactory completion of the Implementation Survey, the attending Surveyor shall advise Classification Documentation Center (CDC) to update the items covered by a Planned Maintenance plan are to be shown by a “PM” indicator, and the items covered by a Condition Monitoring plan are to be shown by a “CM” indicator. When equipment is covered by both PM and CM plans, items are shown by a “PM/CM” indicator. The owner is to confirm with the attending Surveyor that the vessel shows the correct indicators for the listed equipment.

TABLE 3
Machinery Status Indicators

<i>Maintenance Task Type Selection</i>	<i>Notations</i>
	<i>All</i>
Combination Planned and Condition Monitoring	PM/CM
Planned Maintenance	PM
Condition Monitoring	CM

8.3 Equipment Certification

Equipment suppliers can also pursue equipment certification independently. This certification requires enrollment in ABS Type Approval Program while also achieving the requirements of Section 2. Type Approval for Reliability in Design:

- i) *ABS Type Approval Program.* For ABS Type Approval Program, see 1-1-4/7.7 of the *ABS Rules for Conditions of Classification (Part 1)*.
- ii) *Design for Reliability Procedure.* Submittal requirements per Subsection 2/3 of this Guide.

9 Sample Program Workflows

Section 1, Figures 2 through 5 provide example workflows for each of the reference programs in this Guide.

FIGURE 2
Design for Reliability Process Workflow

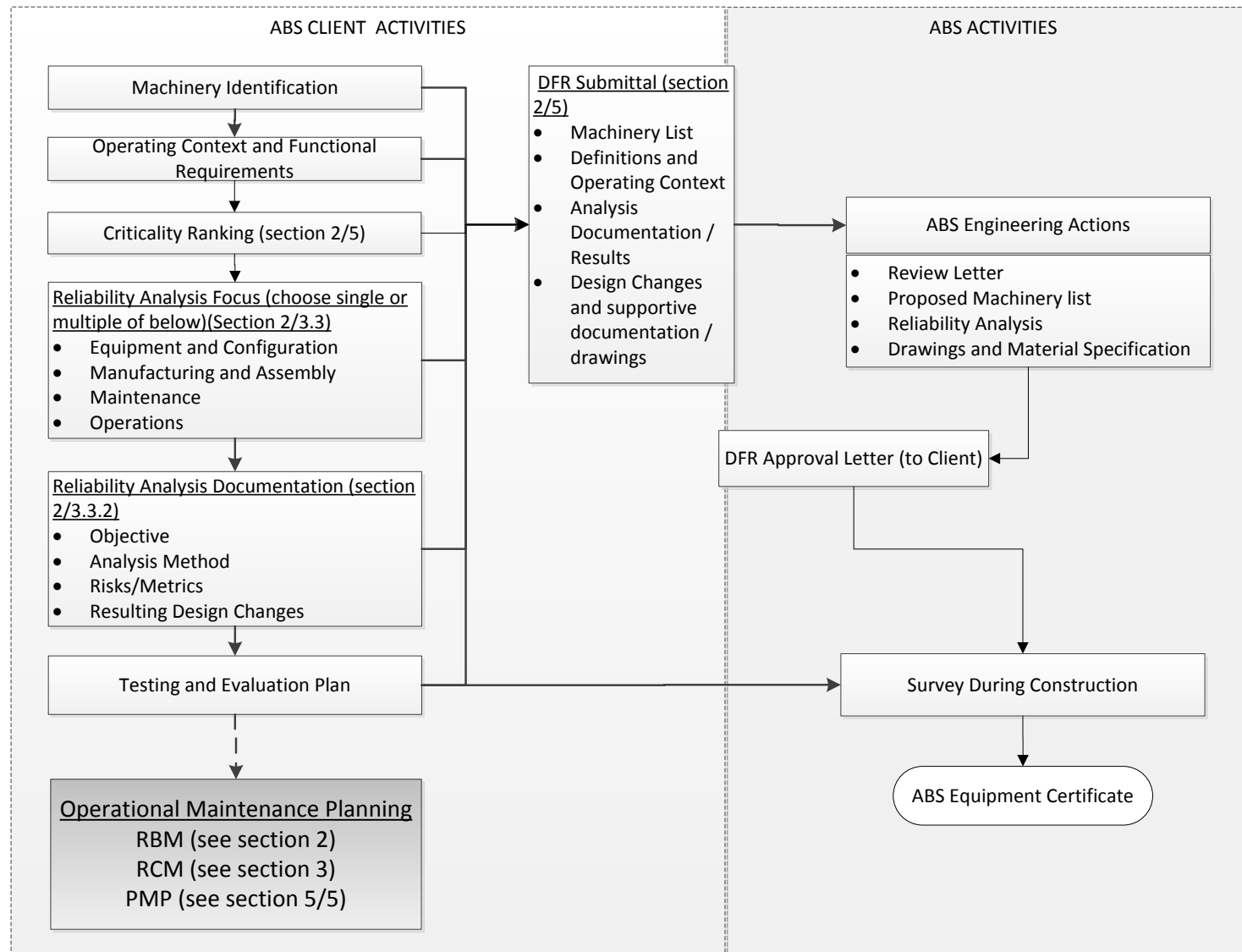


FIGURE 3
Reliability Based Maintenance Process Workflow

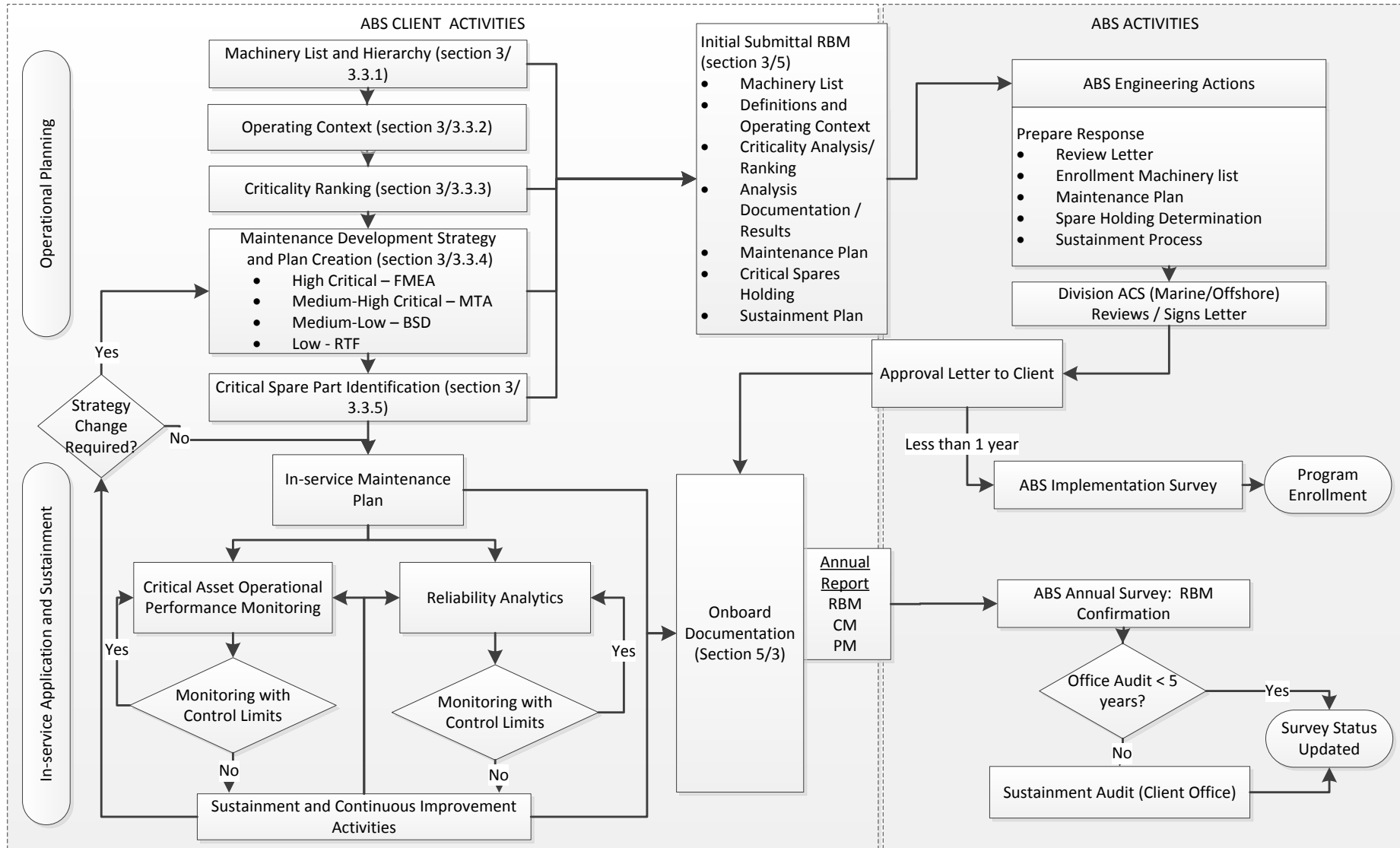


FIGURE 4
RCM Process Workflow

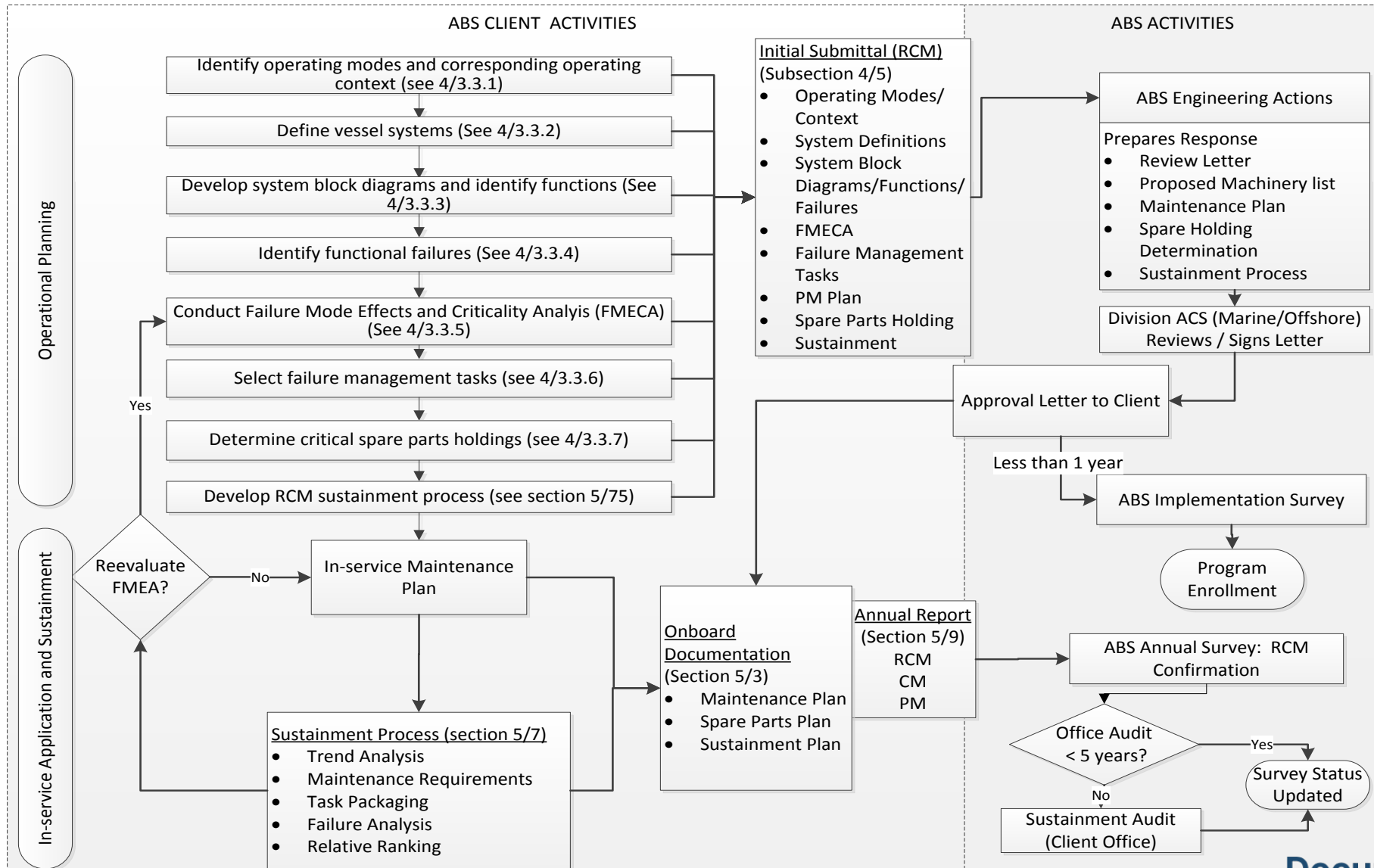
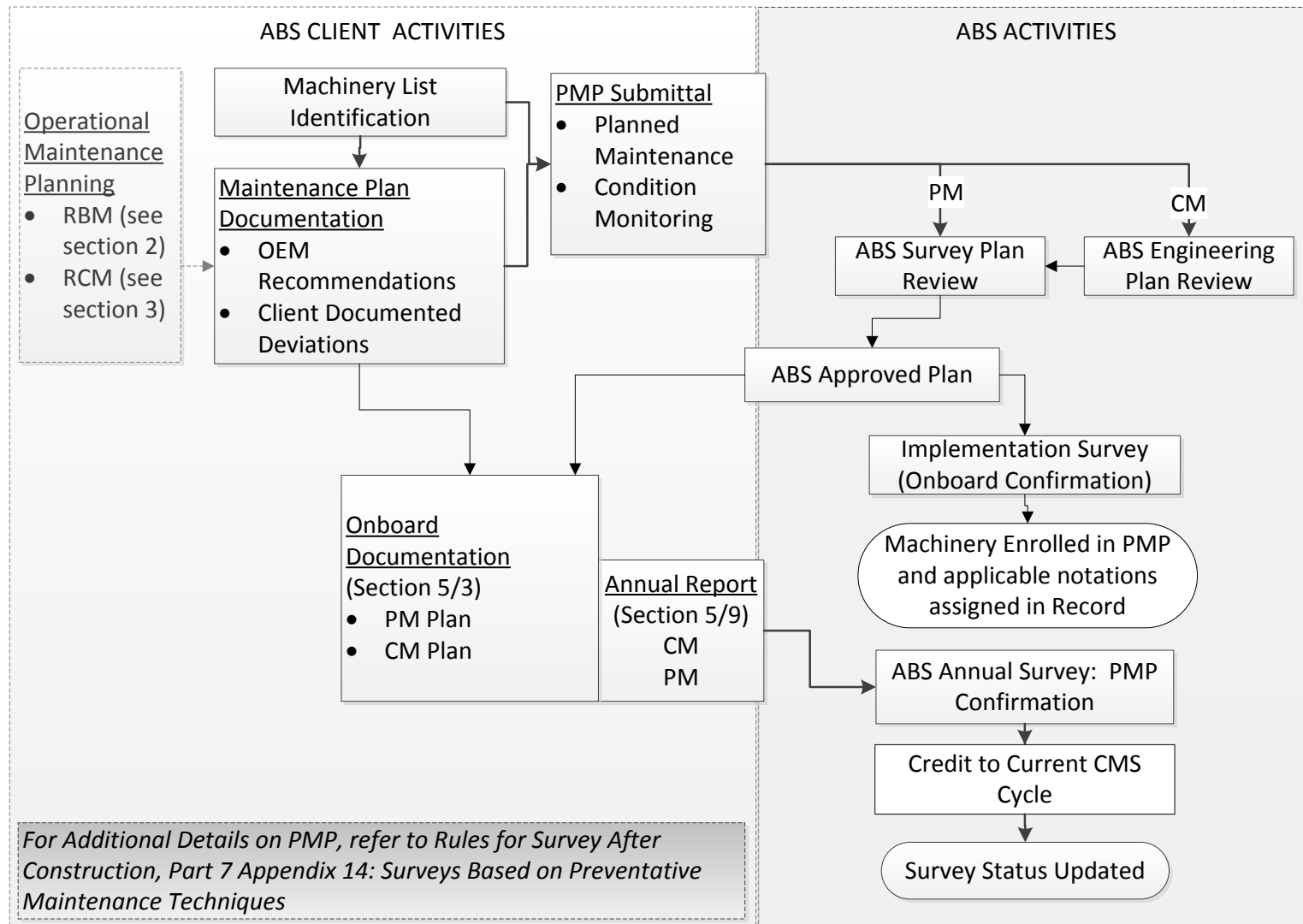


FIGURE 5
PMP Process Workflow



SECTION 2 Design for Reliability

1 Principles of Design for Reliability

Design for reliability (DFR) refers to the incorporation of reliability-enhancing strategies and practices into the design, manufacture and capital equipment procurement procedures. An engineering evaluation is used to verify the design is in accordance with applicable Rules, Guides and statutory regulations and the design reliability analysis is in accordance with the requirements of this Section.

The reliability criteria may be based on design, manufacture, material composition or phases of operation (transit, installation, commissioning and in-service) as selected by the submitter. Upon successful completion of the requirements of this Section, an appropriate notation per Subsection 1/8 may be assigned. Equipment suppliers can also pursue equipment certification independently as referenced in 1/8.3.

1.1 Age Requirements for DFR

Enrollment in Design for Reliability requires either:

- The equipment is manufactured and certified as part of new construction, or
- The equipment or components are manufactured and certified as part of a redesign and modification.

1.2 Limitations

1.2.1 Non-OEM supplied parts

Parts supplied by vendors other than the OEM are to be in accordance with 2/2 and 2/3.

1.2.2 Changes to Design or Procedures

Change in the design or procedures as submitted in 2/3, requires the manufacturer to notify ABS of those changes for re-assessment and resulting effect on configuration, design, and validity of notation.

2 Analysis Requirements

2.1 Design for Reliability Overview

DFR utilizes reliability/risk analysis tools to verify improved reliability-related performance to a predetermined value provided by the designer. DFR also provides a process for applying these reliability/risk analysis tools throughout the design process and the information needed to make more informed design or procurement decisions. When chosen, a DFR is required to be performed at an appropriate level of analysis necessary at each design stage to support the decision-making needs.

2.2 Reliability Team

The team that supports the DFR process is to be documented in accordance with Reliability Team Requirements (see Subsection 1/6).

2.3 Procedures

2.3.1 Defining Design for Reliability Objectives

The key activities of DFR are initiated based on establishing the key objectives for improving reliability. The objectives for improving reliability via design changes are shown in Section 2, Table 1. The chosen path can employ one or a combination of the objectives described (A-D). All design for reliability activities are to establish a testing and evaluation plan which will validate function and reliability requirements.

TABLE 1
Reliability Objectives in Design

<i>A: Equipment and Configuration</i>	<i>B: Manufacturing and Assembly</i>	<i>C: Efficient Maintenance</i>	<i>D: Efficient Operations</i>
The inherent potential of an asset to perform reliably is referenced by the technology of the equipment employed and the degree of redundancy. The design processes are to evaluate the level of redundancy required to achieve targeted process availability.	Designing to help reliable manufacturing and assembly of the asset that helps lead to reliable performance. Equipment and process specifications are to anticipate sources of variability and try to minimize process sensitivity to such variability.	Incorporating future maintenance of the asset into the design is vital to maintaining the inherent reliability and capability of the process throughout its life.	Designers should consider the interaction between the operator and equipment with focus on designing systems that reduce likely human error. The designers must consider the environment in which the process is being operated to minimize equipment vulnerabilities. The environment includes location, maintenance envelope, and accessibility of the equipment.

2.3.2 Design for Reliability Analysis

The design phase analysis and any resulting changes help establish a baseline for inherent reliability of a system/machinery/component. The designer is to document the reasoning behind the selected method/tool used for reviewing and analyzing the design for reliability improvements. For additional details on design for reliability methods see Appendix 1. Documentation of the objective, method, references, and results should be submitted to ABS Engineering Office for review.

3 Plans and Data to be Submitted

The following information is to be submitted to ABS Engineering Office for review

3.1 For All Machinery Items to be Included

- i) A list and description of machinery/items for analysis
- ii) Design for Reliability statement of intent documenting the reason(s) for DFR analysis
- iii) Item definition and operating context:
 - a) Design basis documents that include the “operating envelope”, working environment, design life, etc.
 - b) Process or functional description
 - c) General arrangement/layout drawings (post any design changes)
 - d) Details of material specification to be utilized
- iv) Criticality ranking:
 - a) Components for assessment
 - b) Factors for each component
- v) *Analysis Process Documentation.* Design for Reliability can focus on multiple paths for improvement. Many industry methods exist for reliability and performance analysis (see Appendix 3). The submittal must include an explanation of the process and justification.
 - a) Reliability objective definition
 - 1) Reference path objective(s) from Section 2, Table 1
 - 2) End state reliability goal (Probability, Interval, Stated Conditions)
 - b) *Definition of Analysis Method.* If multiple methods utilized, submittal shall include items 2/3.1v)c) and 2/3.1v)d) for each method deployed.

- c) Risks or metrics analyzed (Quantitative or Qualitative)
 - d) Reference showing justification for application
- vi) Results of analysis
 - a) Specified design changes
 - b) Required maintenance to support reliability goal
 - c) Estimate of design reliability improvement

To support survey activity in the shipyard and at vendor facilities, the following items are required for submittal:

- vii) Material Specifications
- viii) Inspection and Test Plan
- ix) Quality Assurance Programs
- x) Project assembly and construction “hold-points”

3.2 As Applicable for Each Item

- i) Process flow diagrams (PFDs)
- ii) Piping and instrumentation diagrams (P&IDs)
- iii) Electrical one-line drawings and Electrical loads
- iv) Instrumentation details and accompanying logic diagrams
- v) System interface requirements
- vi) Mechanical design drawings

SECTION 3 Reliability Based Maintenance

1 Principles of Reliability Analysis

1.1 Definition

Reliability Based Maintenance (RBM) is a process to develop a preventative maintenance plan. A machinery system is selected for evaluation, then the criticality or risk ranking of the equipment and components is determined. The maintenance task selection processes are then chosen based on this criticality.

Effective asset management can help achieve best in class maintenance and asset performance. Reliability based maintenance analysis can be applied to create the in-service maintenance plan and sustainment processes. This Guide provides the requirements for a process that can be created and managed by the client or executed in collaboration with ABS.

1.2 Tools and Expertise Employed to Perform RBM Analyses

- i) Design, engineering and operational knowledge of the system
- ii) Failure modes, effects and criticality analysis (FMECA), or similar reliability process
- iii) Condition-monitoring techniques with the understanding of their application
- iv) Risk-based decision making (i.e., the frequency and the consequence of a failure in terms of its impact on safety, the environment and commercial operations)

1.3 Process Documentation and Implementation

- i) The analyses and the decisions taken
- ii) Progressive improvements based on operational and maintenance experience
- iii) Clear audit trails of maintenance actions taken and improvements made

2 RBM Process Requirements

The analysis is to be conducted for all equipment and systems proposed for enrollment in the RBM Program. The Initial RBM Analysis is to be submitted to the responsible ABS Engineering Office for approval. Subsequently, Annual RBM reports are to be prepared for review by the attending Surveyor at the Annual Confirmation Survey.

2.1 Overview

An analysis of the systems proposed for enrollment applying RBM utilizes the system drawings; equipment item drawings; preventative maintenance instructions for systems, equipment items or components; and operator experience. The final result of the analysis is a preventative maintenance plan for the selected systems and equipment items.

2.2 Reliability Team

The team members supporting the Reliability Based Maintenance process is to be documented in accordance with Subsection 1/6, "Reliability Team Requirements".

2.3 Procedures

The requirements for the RBM procedure are shown in a process flow diagram in Section 1, Figure 4 and described further as follows. Additional support information on RBM is in Appendix 1.

2.3.1 System Selection and Machinery List Development

As the primary step of effective asset management in support of RBM, it is important to develop a formal process to clearly define the difference between assets and spare parts.

Each system selected for RBM analysis is to be defined. The system definition involves (1) partitioning the vessel's functional groups into systems, subsystems (as necessary due to complexity), equipment items and components, and (2) further development of the narrative description for each functional group, system, equipment item and component.

2.3.2 Operating Context

To properly define operating characteristics, the various operating modes for the asset or equipment are to be identified. Operating contexts are to be developed for each level of the machinery hierarchy. An example of an operating mode, along with its operating context, is provided in Appendix 1, Table 2.

2.3.3 Criticality Ranking

The process chosen is to be capable of prioritizing or ranking assets to optimize the utilization of maintenance resources based on factors such as: safety, quality, environmental impact, operational throughput, operational cost, and/or current system or equipment reliability.

2.3.4 Maintenance Development Strategy

Developing an effective maintenance strategy assists in improved reliability of an asset at the planned operational cost and coordinates the utilization of maintenance resources by dedicating them to the execution of high value maintenance activities. The criticality ranking drives which maintenance strategies should be applied to an asset, and results in a complete maintenance plan for later execution. The varying levels of maintenance plan development are determined from criticality analysis and ranking (see Section 3, Figure 1):

- *Failure Modes Effects and Criticality Analysis (FMECA)*. This process analyzes asset sub-assemblies and components to identify failure modes and their accompanying causes and system effects. Each failure mode has a risk calculation performed to prioritize and quantify the level of mitigation required. Condition-monitoring or planned maintenance tasks are identified with a preference to apply non-disruptive predictive technologies as the primary option.
- *Maintenance Task Analysis (MTA)*. This process reviews all previous asset maintenance and performance records with the objective to reaffirm or select replacement value added maintenance tasks. The approach analyzes maintenance tasks and their alignment and coverage of failure modes in an effort to enhance their application.
- *Basic Strategy Development (BSD)*. This is a review of the current maintenance tasks and the affiliated job plans that are presently in place to develop a standard to be followed based on utilizing the current content. If no current content exists, Original Equipment Manufacturer (OEM) recommendations will be the baseline for standard development.
- *Run to Failure (RTF)*. This strategy allows the asset to operate until a failure occurs followed by replacement of the failed component(s). (See Note in Section 3, Table 1)

TABLE 1
Criticality Based Maintenance Alignment

Equipment Criticality Tiers	Maintenance Development Alignment			
	FMECA	MTA	BSD	RTF*
Top 25%	X			
Upper Middle 25%	O	X		
Lower Middle 25%		O	X	
Bottom 25%			O	X*

Legend: X – Recommended, O – Optional

* Note: Class items where RTF strategy is deployed require compliance with Special Periodical Survey

2.3.5 Critical Spare Part Identification

For the proposed maintenance schedules to be viable, it is essential that the spares that support the identified maintenance tasks in 3/3.2.3 are available at the appropriate time. There are procurement factors which can also drive classification of a spare part, deeming it more or less important. The primary factors that determine if a spare part is identified as critical are as follows:

- The component is directly linked to a failure mode that has a high risk calculation or failure consequence.
- The component failure causes the asset to cease operation or operate at an unsatisfactory level of performance.

2.3.6 In-service Application and Sustainment

Once assets are in operation, their performance is to be monitored. Critical assets are to be selected so that overall operation is satisfactory based on individual asset performance. The primary method to determine if the asset is operating or function efficiently is to monitor operational performance parameters with designated control limits. Similarly, a method to determine if the maintenance strategy is effective and appropriate is to monitor reliability analytics with designated control limits.

In the event it is determined that the asset is operating unsatisfactorily, functioning inefficiently, or the maintenance strategy is ineffective based on monitoring operational performance, a root cause analysis (RCA) should be performed to identify the corrective and preventative actions required to restore the asset to a functional condition.

3 Plans and Data to be Submitted

The following information is to be submitted to an ABS Engineering Office for review:

3.1 Items Selected for Analysis

- i) Criticality Analysis and Ranking
- ii) Design basis documents that include the “operating envelope“, working environment, design life, etc.
- iii) Process or functional description
- iv) General arrangement/layout drawings

3.2 Risk and Reliability Analysis

The Owner is to document the analysis tools used as part of each assessment. Submittals for the program are to provide results and descriptions of the analysis. The submittal is to include an explanation of the process and justification. Refer to Appendix 2, “Risk and Reliability Tools and Techniques”, for suggested analyses.

3.2.1 Analysis Objective Definition

- i) Analysis team members
- ii) Analysis/method utilized
- iii) Risks or metrics analyzed (quantitative or qualitative)
- iv) Reference showing justification for application
- v) Documented results of analysis

3.2.2 Analysis Results and Documentation

- i) Criticality Assessment
- ii) Identify components
- iii) Factors for each component
- iv) Criteria and scoring for each factor (with weighting)
- v) Scoring calculation for each component

- vi) Scoring calculation for assessment
- vii) Determine score groupings for bulk analysis

3.2.3 Failure Modes Effects Analysis (where applicable)

- ix) Identification of failure modes and their causes
- x) Evaluate the effects on the system of each failure mode
- xi) Identification of failure detection methods
- xii) Identification of corrective measures for failure modes

3.2.3 Maintenance Task Analysis (where applicable)

- i) Identification of maintenance tasks reviewed
- ii) Failure modes addressed by each task
- iii) Documentation on decision process for modification (trade-off study, FMEA, etc.)
- iv) Resulting maintenance changes

3.3 Maintenance Plan**3.3.1 List and Description of the Machinery**

A table listing the owner's equipment item name and the equivalent ABS Survey Manager name is to be provided for reference.

3.3.2 For Items to be enrolled in ABS Preventative Maintenance Program

- *Planned Maintenance:* Refer to 7-A-14/13.5.1 of the *ABS Rules for Survey After Construction (Part 7)*
- *Condition Monitoring:* Refer to 7-A-14/15.5.1 of the *ABS Rules for Survey After Construction (Part 7)*

3.4 Critical Spares Holding

For the proposed maintenance schedules to be viable, the spares that support the identified maintenance tasks are available at the appropriate time. The spares holding requirement is to be developed based on the following considerations:

- i) Parts necessary to perform tasks to correct each failure mode identified in the reliability analysis,
- ii) Parts required as a result of work to correct "condition monitoring", "planned maintenance", "failure finding", "any applicable and effective" and "run-to-failure" tasks.
- iii) An evaluation of the effects on the functional group or system's operational availability if an out-of-stock condition occurs.
- iv) Assessment for those parts whose use can be preplanned. For those parts whose use cannot be preplanned, determine the quantity necessary to achieve the desired operational availability.
- v) Lead time required for ordering a part out of stock.

3.5 Sustainment Plan

The plan for continued improvement shall be submitted to the ABS Engineering Office. The results of the sustainment activities must be maintained onboard for verification at annual surveys. See Subsection 5/4.

SECTION 4 Reliability Centered Maintenance

1 Principles of Reliability Centered Maintenance

1.1 Definition

Reliability centered maintenance is a process of systematically analyzing an engineered system or maintained machinery to understand:

- i) Its functions
- ii) The failure modes of its equipment that support these functions
- iii) How then to choose an optimal course of maintenance to prevent the failure mode from occurring or to detect the failure mode before a failure occurs
- iv) How to determine spare holding requirements
- v) How to periodically refine and modify existing maintenance over time

1.2 Objective

The objective of RCM is to achieve reliability for all of the operating modes of a system. An RCM analysis, when properly conducted, should answer the following seven questions:

- i) What are the system functions and associated performance standards?
- ii) How can the system fail to fulfill these functions?
- iii) What can cause a functional failure?
- iv) What happens when a failure occurs?
- v) What might the consequence be when the failure occurs?
- vi) What can be done to detect and prevent the failure?
- vii) What should be done if a maintenance task cannot be found?

1.3 Tools and Expertise

Typically, the following tools and expertise are employed to perform RCM analyses:

- i) Failure modes, effects and criticality analysis (FMECA).
- ii) RCM decision flow diagram.
- iii) Design, engineering and operational knowledge of the system
- iv) Condition-monitoring techniques
- v) Risk-based decision making (e.g., the frequency and the consequence of a failure in terms of its impact on safety, the environment and commercial operations)

1.4 Reliability Centered Maintenance Overview

By using RCM principles, maintenance is evaluated and applied in a rational manner. Functional failures with the highest risk are identified and then focused on. Equipment items and their failure modes that will cause high-risk functional failures are identified for further analyses. Maintenance tasks and maintenance strategies that will reduce risk to acceptable levels are determined. Spare parts inventories are determined based on the maintenance tasks developed and a risk assessment. An RCM sustainment procedure is instituted to continually monitor and optimize maintenance. Accordingly, improved equipment and system reliability can be expected.

The primary objective of RCM analysis is to provide a comprehensive, systematic and documented investigation which establishes important failure conditions of the machinery system(s), maintenance tasks or system/equipment redesigns chosen to reduce the frequency of such occurrences, and the rationale for spares inventory. There may be special conditions for steam turbines, internal combustion engines, electrical switchgear and power distribution panels and permanently installed monitoring equipment.

Additional benefits for the Owner/Operator of the vessel or marine structure which are beyond the scope of this Guide are:

- To provide data to generate comprehensive training, operational and maintenance programs and documentation; and
- To provide the results of the study into the asset's failure characteristics so as to assist in an assessment of levels of risk proposed for the asset operations.

2 Process Requirements

The analysis is to be conducted for all equipment and systems proposed for enrollment in the RCM Program. The Initial RCM Analysis is to be submitted to the responsible ABS Engineering Office for approval. Subsequently, Annual RCM reports are to be prepared for review by the attending Surveyor at the Annual Confirmation Survey.

2.1 Overview

A detailed study of the system(s) or machine(s) subject to RCM analysis is to be made through the use of system drawings; equipment item drawings; documents containing maintenance requirements for systems, equipment items or components; and operator experience.

2.2 Reliability Team

A list of team members supporting the Reliability-Centered Maintenance process is to be documented in accordance with Reliability Team Requirements (see Subsection 1/6).

2.3 Procedures

2.3.1 Operating Modes and Context

To properly define operating characteristics, the various operating modes for the asset or equipment are to be identified. Operating contexts are to be developed for each level of the machinery hierarchy. An example of an operating mode, along with its operating context, is provided in Appendix 1, Table 2.

2.3.2 System Definition

Each system selected for RCM analysis is to be defined. The system definition involves (1) partitioning the asset's functional groups into systems, subsystems (as necessary due to complexity), equipment items and components, and (2) further development of the narrative description for each functional group, system, equipment item and component.

2.3.3 System Block Diagrams and Functions

The functions for the functional groups, systems, equipment items and components are to be identified. When identifying functions, the applicable operating modes and the operating context is to be listed. All functions are to be identified.

Block diagrams are to be developed showing the functional flow sequence of the functional group, both for technical understanding of the functions and operation of the system and for subsequent analysis. As a minimum, the block diagram is to contain:

- i) The partitioning of the functional group into systems, equipment items and components
- ii) All appropriate labeled inputs and outputs and identification numbers by which each system is consistently referenced
- iii) All redundancies, alternative signal paths and other engineering features that provide “fail-safe” measures

2.3.4 Identification of Functional Failures

A list of functional failures for each function identified in 4/2.3.3 is to be identified for each functional group, system, equipment item and component.

Each functional failure is to be documented in a functional failure statement that contains a verb, object and the functional deviation. Example Functions and Functional Failures are given in Appendix 1, Table 3.

2.3.5 Failure Mode Effects and Criticality Analysis (FMECA)

The FMECA is to be considered using the bottom-up approach, starting from the lowest level of detail identified during the system partitioning. A sample bottom-up FMECA format is shown in Appendix 1, Table 4.

2.3.6 Selection of the Failure Management Tasks

All causes of each failure mode are to be evaluated. Appropriate failure management tasks are to be selected for all corrective measures. All manufacturers’ maintenance recommendations are to be considered during the selection of the failure management tasks. If changes or deletions to the manufacturers’ recommendations are made, these are to be documented in the analysis.

The Task Type is to be identified as follows: Condition Monitoring (CM), Planned Maintenance (PM), Combination of CM and PM (CM/PM), Failure Finding (FF), One-time Change (OTC), Run-to-Failure (RTF), Any Applicable and Effective Task (AAET).

2.3.7 Critical Spares Holding Determination

For the proposed maintenance schedules to be viable, it is essential the spares that support the identified maintenance tasks are available at the appropriate time.

2.3.8 Sustainment Plan

For the sustainment planning, the plan for continued improvement shall be submitted to the ABS Engineering Office. The results of the sustainment activities must be maintained onboard for verification at annual surveys. See Subsection 5/4.

3 Plans and Data to be Submitted**3.1 RCM Analysis Documentation**

For each step, the following topics are to be documented:

- i) The results of the analysis step
- ii) The decision tools used
- iii) Any other pertinent information related to the step (e.g., assumptions, equipment excluded from the analysis)

Based on the maintenance tasks identified in the RCM analysis, a maintenance plan is to be developed and documented in accordance with Subsection 5/3.

The documentation for the FMECA analysis, maintenance and spares holding plans and sustainment process are to be preferably in an electronic format, although paper copies will be accepted.

The following information is to be submitted to an ABS Engineering Office for review.

3.1.1 Operating Modes/Context

Operating modes, as applicable, within normal design environmental conditions (see 4/2.3.1).

3.1.2 System Definitions

A narrative description for each level of indenture and the corresponding functional requirements is to be documented (see 4/2.3.2).

3.1.3 System Block Diagrams/Functions/Failures

The functions for the functional groups, systems, equipment items and components are to be identified (see 4/2.3.3).

A list of functional failures for each function identified is to be identified for each functional group, system, equipment item and component (see 4/2.3.4).

3.1.4 FMECA

The failure modes effects and criticality analysis shall be conducted as specified in 4/2.3.5 and following documentation submitted:

- i) Identification of failure modes and their causes
- ii) Evaluate the effects on the system of each failure mode
- iii) Identification of failure detection methods
- iv) Identification of corrective measures for failure modes
- v) Criticality analysis

3.1.5 Failure Management Tasks

Appropriate failure management tasks are to be selected for all corrective measures (see 4/2.3.6). A maintenance task summary with the information indicated in Appendix 1, Table 10 is to be submitted.

3.1.6 Critical Spare Parts Holding

A spare parts holding determination summary with the information indicated in Appendix 1, Table 11 is to be submitted. For the proposed maintenance schedules to be viable, it is essential that the spares that support the identified maintenance tasks are available at the appropriate time. The spares holding requirement is to be developed based on parts necessary to perform tasks to correct each failure mode identified in the reliability analysis as follows:

- i) Parts necessary to perform tasks to correct each failure mode identified in the reliability analysis.
- ii) Parts required as a result of remedial work to correct “condition monitoring”, “planned maintenance”, “failure finding”, “any applicable and effective” and “run-to-failure” tasks.
- iii) An evaluation of the effects on the functional group or system’s operational availability if an out-of-stock condition occurs.
- iv) Assessment for those parts whose use can be preplanned. For those parts whose use cannot be preplanned, determine the quantity necessary to achieve the desired operational availability.
- v) Lead time required for ordering a part out of stock

3.1.7 Sustainment Plan

The procedures and processes used by the operator to sustain the preventative maintenance plan are to be developed and submitted (see 4/2.3.8).

3.2 Maintenance Plan

3.2.1 List and Description of the Machinery

A table listing the owner's equipment item name and the equivalent ABS Survey Manager name is to be provided for reference.

3.2.2 For Items to be Enrolled in ABS Preventative Maintenance Program

- *Planned Maintenance:* Refer to 7-A-14/13.5.1 of the *ABS Rules for Survey After Construction (Part 7)*
- *Condition Monitoring:* Refer to 7-A-14/15.5.1 of the *ABS Rules for Survey After Construction (Part 7)*

3.2.3 For Items on Alternate Applicable Maintenance Tasking

The applicable items from 4/3.2 and the maintenance sheet(s) for each machine/system considered.



SECTION 5 In-Service Application and Operations

1 Principles of Maintenance and Sustainment

Owners and operators are to maintain their vessels and marine structures with updated machinery maintenance practices, which may increase the reliability and/or operational availability. Proper documentation is to be maintained and available onboard with an effective sustainment program in place.

In some cases, the chosen maintenance practices may include equipment and/or system firmware or software updates via cyber-enabled systems. Refer to the *ABS Guidance Notes on the Application of Cybersecurity Principles to Marine and Offshore Operations – Volume 1: Cybersecurity* for information on this topic.

2 Onboard Documentation

The Chief Engineer or maintenance supervisor shall be the responsible person onboard the vessel or offshore floating unit in charge of the Maintenance Program. If a computerized system is used for storing the maintenance documentation and maintenance program, access is to be controlled with user authorizations as directed by the Chief Engineer or Maintenance Supervisor. The following information is to be available onboard.

2.1 All Programs

- i) A copy of the ABS approval letter for program enrollment (RBM, RCM, PMP).
- ii) A copy of the reviewed maintenance plan (PM and CM)
- iii) All records showing compliance with the program, including a copy of the most recent Owner's annual report are to be made available for review by the Surveyor at the Annual Survey – Machinery.

2.2 Condition Monitoring

The latest up-to-date information required in 7-A-14/15.7.1 of the *ABS Rules for Survey After Construction (Part 7)*.

2.3 Planned Maintenance

The latest up-to-date information required in 7-A-14/13.7.1 of the *ABS Rules for Survey After Construction (Part 7)*.

2.4 Any Other Applicable and Effective Tasks

The applicable items listed in 5/2.1, 5/2.2 and 5/2.3.

2.5 Spares Holding

If enrolled in RCM or RBM, records for required critical spare parts, inventory on hand and ordering procedures to procure additional spare parts are to be readily available.

2.6 Sustainment

If enrolled in RCM or RBM, records of sustainment activities in accordance with Subsection 5/4 are to be readily available.

3 Preventative Maintenance Program

A properly conducted preventative maintenance plan may allow enrolled equipment to be credited as satisfying the requirements of Special Continuous Survey of Machinery. Increased operational testing may be required to satisfy Survey requirements.

This plan must be in accordance with Appendix 7-A-14 “Surveys Based on Preventative Maintenance Techniques” of the *ABS Rules for Survey After Construction (Part 7)*.

4 Sustainment Activities

The RBM and RCM Programs require ABS Engineering Office review of sustainment planning. The results of the sustainment activities must be maintained onboard for verification by the attending Surveyor at annual surveys.

4.1 Sustainment Documentation Requirements

For sustainment plans applying the following items, the item must include at a minimum:

- i) *Trend Analysis.* Condition and Performance monitoring tasks are specified for trend analysis.
 - Equipment identification;
 - Data to be collected; and,
 - Pre-determined limits identified for the data when the condition-monitoring tasks are developed indicating those maintenance actions to be taken when data are outside of the limits.
- ii) *Maintenance Plan Review*
 - *Maintenance Requirement Document Reviews.* Documents containing maintenance requirements for systems, equipment items or components are to be reviewed at least annually to identify outdated maintenance processes, techniques or technologies, or to bring attention to obsolete tools and outdated spare parts.
 - *Task-packaging Reviews.* When maintenance tasks are modified and updated, they continue to be placed back into the same packaged intervals. However, over time, the original packaged interval may no longer be optimal. Task packaging reviews should be conducted periodically to evaluate the intervals to verify that as maintenance tasks are added, deleted or modified, optimum packaged intervals are maintained
 - *Age-exploration Tasks.* When insufficient age-to-failure data is available or assumed data is used during the initial RCM or RBM analysis, age exploration tasks are to be designed and implemented.
- iii) *Failures.* A record is to be maintained of failure analyses conducted, and any changes to the affected maintenance task(s) or one-time changes to the equipment item/component.
- iv) *Relative Ranking Analysis.* A relative ranking analysis can be developed for those items having the highest operational cost or cost impact.
- v) *Sustainment Result Implementation*
 - A record is to be maintained of the results of other activities conducted that result in changes to the reliability analysis and/or maintenance tasks. The attending ABS Surveyor must be notified of these changes. The ABS Surveyor may require the analysis or task changes be submitted to the responsible ABS Engineering Office that performed the initial review.
 - It may be determined that an existing maintenance task is not being performed at its most effective interval. By collecting information through sustaining efforts, the data necessary to refine the assumptions used to establish the interval during the initial RCM or RBM analysis can be used to adjust the task interval and thereby improve the interval's effectiveness.