CONDITION MONITORING SYSTEMS

NR674 – JULY 2024

RULE NOTE

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NR674 DT R02 July 2024 takes precedence over previous revision.

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These rules are provided within the scope of the Bureau Veritas Marine & Offshore General Conditions, enclosed at the end of Part A of NR467, Rules for the Classification of Steel Ships. The latest version of these General Conditions is available on the Bureau Veritas Marine & Offshore website.

NR674

CONDITION MONITORING SYSTEMS

July 2024

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Section 1   Approval of Condition Monitoring Systems

1   Scope

1.1   Application

1.1.1   This Rule Note applies to design, installation and testing of permanently installed Condition Monitoring Systems (CMS) where condition monitoring results are used in relation with the scope and/or frequency of Class surveys.

This Rule Note applies to:

- Permanently installed CMS of type A or B.

  The requirements for approval of such condition monitoring equipment and systems are provided in Sec 2.

- Predictive CMS.

  The requirements for approval of predictive CMS are provided in Sec 3.

Note 1: In addition to this Rule Note, for classification purpose, reference is made to NR467 "Rules for the classification of steel ships":

- The requirements for approval of Condition Based Maintenance (CBM) Scheme are given in NR467, Pt A, Ch 2 App 4. These requirements apply only to vessels operating on approved Planned Maintenance Survey (PMS) scheme.

- The requirements for a ship to be assigned one of the classification notations **CBM** and **CBM-P** as well as the requirements for the maintenance of these notations are given in NR467, Pt A, Ch 1, Sec 2 and NR467, Pt A, Ch 2, App 4.

See also NI684 "Guideline for Condition Based Maintenance" for further details on requirements and class workflow.

1.1.2   This Rule Note does not apply to tailshaft monitoring systems.

Note 1: For shaft monitoring, refer to **MON-SHAFT** notation as defined in Pt A, Ch 1, Sec 2, [6.6.3].

1.2   Condition monitoring systems (CMS) and predictive CMS

1.2.1   As a Rule, the terminology used in this Rule Note is defined in NI684 "Guidelines for Condition Based Maintenance".

1.2.2   This document differenciates CMS of predictive type from other types of CMS based on their complexity and the solutions implemented to support prognostic and diagnostic (D & P) functions:

- When CMS use rule base logic (e.g. threshold between monitored values and limiting parameters / baseline value) to provide a diagnostic they will be named "CMS". Moreover, CMS are categorized into three categories:

  - Type A: On-line, permanently installed systems.

  - Type B: On-site testing and detection. It involves the operation of a qualified person on-site with portable measurement equipment and usually the installation of a portable sensor, but the sensor can also be permanently installed.

  - Type C: Sampling systems which involve off-site analysis (e.g. oil sampling and analysis).

- When CMS software systems use complex algorithms, machine learning and knowledge of global equipment populations/ defect data in order to provide information on the health of a machinery (e.g. diagnostic or prognostic) and maintenance recommendations.

  Due to the high number of data required for their operation, predictive CMS are to be supported by dedicated data infrastructure, data quality framework and ad-hoc organization.

  As predictive CMS are using more refined and complex models than simple CMS techniques to perform health diagnostics and prognostics, they usually provide deeper insights on the state of machineries. However, those systems are still considered as new technologies and therefore, a risk analysis is to be carried out to ensure that the underlining risks are taken into consideration and mitigated, as necessary. Moreover, qualified personnel need to be involved in the development process, and predictive CMS are to be used as a tool by predictive CBM service suppliers.

Section 2   Condition Monitoring Systems

1   General

1.1   Application

1.1.1 Permanently installed CMS of type A or B, as defined in Sec 1, [1.2.1], are to comply with the requirements of this Section.

1.2   Documentation to be submitted

1.2.1 The documentation to be submitted for approval of CMS defined in [1.1.1] are listed in Tab 1.

The Society reserves the right to request the submission of additional documents in the case of non-conventional design or if it is deemed necessary for the evaluation of the systems or components.

Table 1 : General documentation to be submitted

No.	I / A **(1)**	Item	Reference
CMS DEFINITION			
1	I	CMS Definition **(2)**	[2.1]
2	A	List of sensors with specifications	[2.2]
CMS DESIGN ASSESSMENT			
3	A	List of computerized systems and corresponding documentation (see NR467, Pt C, Ch 3, Sec 3)	[3]
4	A	Requirements for Cyber Security and Safety	[3.5]
5	A	List of CMS data for traceability	[3.6]
TESTING			
6	A	Tests reports according to Pt C, Ch 3, Sec 6, [3] and [4]	[3.3]
(1) A = to be submitted for approval; I = to be submitted for information			
(2) For applicable items			

2   Condition Monitoring System Definition

2.1   Diagrams and functional schemes

2.1.1 Diagrams and functional schemes (e.g. bloc diagram) describing the CMS are to be provided, with general definition of the monitoring techniques and interfaces.

2.2   Sensors

2.2.1 Following information are to be provided regarding sensors definition:
- ID of sensors, along with the physical parameter monitored

Note 1: Representation of sensor location on the equipment, with spatial orientation should be provided.
- Sensors characteristics (e.g. sensitivity, range...) and calibration.

Note 2: Description of sensor attachment method should be provided.

3   Requirements for Condition Monitoring System

3.1   General

3.1.1 A Human Machine Interface (integrated or stand alone) is to be provided on-board to enables CM data visualization, follow-up of CMS breakdown and log display.

Note 1: The Chief Engineer is the responsible person on board in charge of CMS, and therefore sufficient information and instrumentation are to be made available on-board for his use.

3.1.2 CMS are to be capable, through their own interface or integrated in another system, to produce a condition report and maintenance recommendation.

3.1.3 CMS are to include a method for backing up data at regular interval, to prevent loss of data in case of CMS failure (e.g. CMS data, software...).

3.1.4 The operation or the installation of a CMS shall not have any impact on the equipment, or on the availability or functionality, of Computer Based Systems already installed on board. A risk assessment report may, upon request, be requested by the Society.

3.2 Components

3.2.1 The Condition Monitoring System and components, as indicated in NR467, Pt C, Ch 2, Sec 15, [2], are to be of a type approved by the Society. They are to be approved on the basis of the applicable requirements of these Rules and in particular the ones defined in NR467, Part C, Chapter 3.

Note 1: All sensors, transmitters and data processing equipment already used within the scope of notations **AUT-UMS**, **AUT-CCS**, **AUT-PORT** or **AUT-IMS** may be used as an input for CMS.

3.2.2 Installation of sensors are to be performed by a personal qualified for condition monitoring. Sensors are to be permanently marked or labelled.

Installation of cables must follow approved cable tray path. Cable installation is to comply with requirements of NR467, Pt C, Ch 2, Sec 12.

Note 1: Where it may not be possible/suitable for permanent markings or labels, exact location could be shown in schematic drawings, machinery information diagrams or photos.

3.3 Computer based systems

3.3.1 CMS of Type A for which functions are performed through computer based systems are to comply with requirements of NR467, Pt C, Ch 3, Sec 3, as Category I system:

- software functional description and associated hardware description is to be submitted for information
- test program for on board tests, including wireless network testing, are to be submitted for information
- acceptance testing and on board tests, as described in NR467, Pt C, Ch 3, Sec 6, [3] and [4], are to be witnessed by the Surveyor.

3.3.2 Pre-integrated systems are to comply with requirements stated in NR467, Pt C, Ch 3, Sec 3, [8].

3.4 Alarms and failures

3.4.1 CMS are to be self-checking and able to detect faults, malfunctions or interruptions of its different parts: data acquisition (DA), data processing (DP), diagnostic and prognostic assessment (D & P) and health management (HM), as defined in NI684. Especially, it is to be able to detect the following when applicable:

- loss of main source of power or low battery
- sensor faults (e.g. missing value, calibration expired, value outside range, slope excess, constant value…). The list of detected faults is to be specified
- loss of communication or network failures
- failure of storage device
- storage capacity nearly complete (e.g. 90% storage warning)
- software abnormal operation
- processor failure (e.g. overheating)
- loss of UTC synchronization.

Detected failures are to initiate an alarm and are to be logged in the system. A no-fault condition shall be positively indicated (e.g. green light).

Note 1: For data quality concerns, it is recommended that a system is implemented on board to ensure that, data recorded during an identified fault or malfunction event, are flagged appropriately as untrustworthy data. The list of flag definitions is the responsibility of the designer.

3.5 Cybersecurity

3.5.1 Access to computerized systems for modification of CMS parameters are to be secured (e.g. username/password).

Note 1: Access is to be restraint to the Chief Engineer or other authorized person.

3.5.2 Where CMS use remote monitoring or diagnosis (i.e. data is transferred from the vessel and analyzed remotely), the system is to be capable to maintain continuous on-board operation in the event of loss of the communication function. In addition, the system is to comply with the applicable requirements for cyber security of equipment in accordance with Chapter 5 of NR659 "Rules on cyber security for the classification of marine units".

3.6 Traceability

3.6.1 CMS parameters

A system is to be provided to identify where CMS parameters (e.g. baseline, limiting parameters, data collection task interval, sampling time...) are modified during the operation. Parameters and user performing the modification are to be logged in the system.

3.6.2 CMS operation data

CMS are to have the ability to store, or to communicate to external storage, the CMS operation data according to NR467, Pt A, Ch 2, App 4.

Note 1: Refer to NI684, Sec 2, [5.3].

Section 3   Predictive Condition Monitoring Systems

1   General

1.1   Application

1.1.1 Predictive CMS, as defined in Sec 1, [1.2] are to comply with the requirements of this Section.

1.1.2   Predictive CMS service supplier
The company operating the predictive CMS, and involved in Condition Based Maintenance based on the results of predictive CMS, is to be approved as predictive CMS service supplier and comply with the applicable requirements given in NR533 "Approval of Service Suppliers".

1.1.3   Predictive CMS manufacturer recognition
Predictive CMS are generally to be developed by Original Equipment Manufacturers (OEM) for the condition monitoring of their own equipment.

When the predictive CMS manufacturer is not the OEM, the manufacturer is to submit a written statement from the OEM recognizing that the predictive CMS may be an alternative to the OEM maintenance recommendations for the concerned equipment.

1.2   Workflow

1.2.1 The following workflow is to be followed for approval of predictive CMS (see Fig.1):

a) Predictive CMS manufacturer recognition

b) Predictive CMS definition, with:
- scope (e.g. machinery, equipment item)
- system (e.g. data infrastructure, software modules)
- operational organization (e.g. shore support).

c) Risk assessment

d) Predictive CMS design approval

e) Predictive CBM service supplier approval.

1.3   Documentation to be submitted

1.3.1 The documentation to be submitted to the Society is listed in Tab 1.

Figure 1 : Predictive CMS and predictive CBM service supplier approval workflow
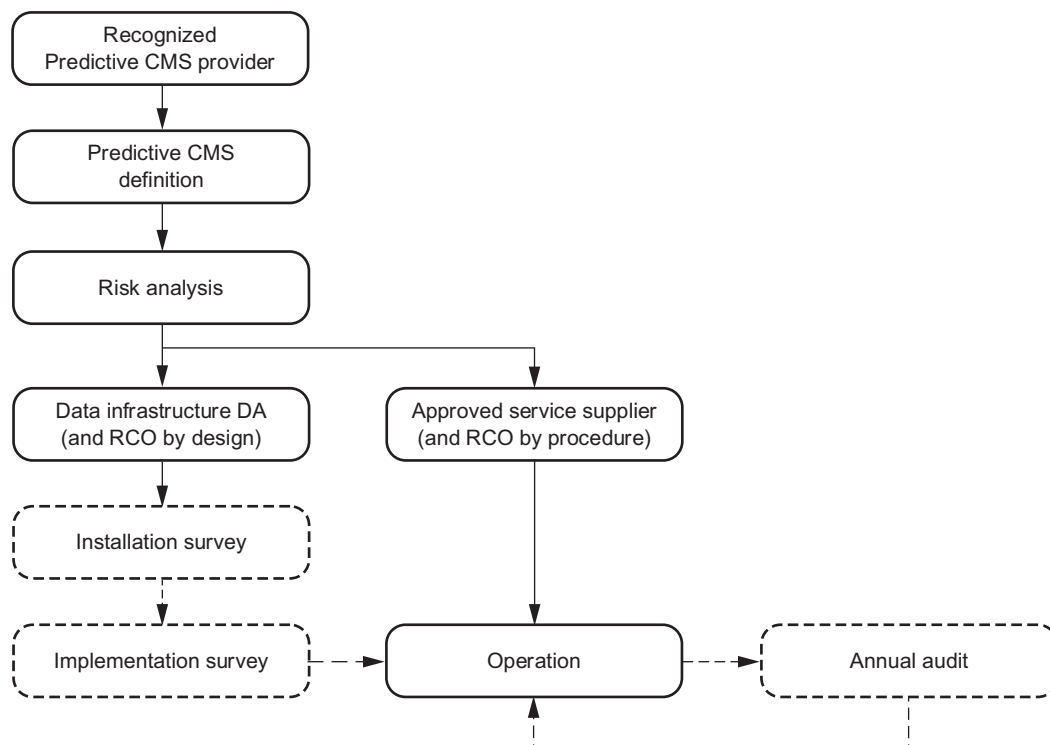
Table 1 : Documentation to be submitted

No.	I / A **(1)**	Item	Reference
		PREDICTIVE CMS DEFINITION	
1	A	Written statement from the OEM, as applicable	[1.1.3]
2	I	List of equipment and equipment items covered	[2.1.2]
3	I	Predictive CMS definition	[2.1.1]
		RISK ANALYSIS	
4	I	Risk analysis and Risk Control Options (RCO) **(2)**	[3.2]
5	A	List of sensors with specifications	[3.5]
6	A	Design assessment of the supporting data infrastructure **(3)**	[3.3]
7	I	Model definition for anomaly detection, diagnostic or prognostic	[3.7]
8	A	Health assessment	[3.8]
9	I	Data quality	[3.9]
10	A	Requirement for cyber security and safety	[3.4]
		ORGANIZATION	
11	A	Service supplier approval	[1.1.2]
12	I	Predictive CMS handbook	[4.1.2]
		OPERATION AND AUDITABILITY	
13	A	Traceability	[3.10]
(1)	A = to be submitted for approval, I = to be submitted for information		
(2)	Upon request by the Society		
(3)	See NR467, Pt F, Ch 4, Sec 4		

2 Predictive CMS definition

2.1 General

2.1.1 The following diagrams and functional schemes (e.g. bloc diagram) describing the predictive CMS are to be provided:
- System definition, with boundaries between systems and organizations
- Technology and tools for CMS anomaly detection, diagnostic or prognostic

Note 1: Definition of supporting data infrastructure is in the scope of NR467, Pt F, Ch 4, Sec 4.

- Health assessment:
  - General description of how the predictive CMS handle the outputs of anomaly detection, diagnostic, prognostic modules or of other knowledge, to perform health assessment and maintenance recommendation is to be provided.
  - Dedicated process to support health assessment (e.g. shore expert support, experienced personnel support) is to be documented
  - Outputs are to be described (e.g. alerts, emails, reports, human intervention...)
- Operational organization supporting and operating the predictive CMS.

2.1.2 List of equipment items

List of equipment items in the scope of predictive CMS is to be provided along with the failure modes covered (e.g. bearing wear).

Note 1: For the failure mode covered, a high level FMEA Failure Mode and Effect Analysis (FMEA) should be provided with:
- effect and criticality of the failure mode for the equipment. Risk on the machinery is to be specified
- consequence for the ship along with the corresponding risk.

3 Predictive CMS requirements

3.1 General

3.1.1 The Chief Engineer is the responsible person on board in charge of predictive CMS, and therefore sufficient information and instrumentation are to be made available on-board for his use.

A human machine interface (integrated or stand alone) is to be provided on-board to enable access to predictive CMS health assessment output, follow-up of CMS breakdown and log display.

3.1.2 Predictive CMS are to be developed, or integrated, so that users have access to equipment item running hours (or calendar date), along with the acceptable limit conditions based on the manufacturers' recommendations or recognized standard.

3.2 Risk Assessment

3.2.1 The operation or the installation of the CMS is not to have any impact on the equipment, on the ship or on the availability or functionality, of computer based systems already installed on board.

A risk assessment report may be requested by the Society.

3.2.2 When a risk assessment is requested by the Society, Risk Control Options (RCO) are to be specified.

Note 1: The RCO can be preventive (reduce the occurrence by reducing the frequency of an event) or mitigate the consequence of an event. The RCO can be:

- by design: when safety features are integrated within design (e.g. sensor redundancies, additional power supply...)
- by procedures: when specific actions are performed by the crew or operator to control the risk. In that case, they are in the scope of the CMS Handbook as defined in NI684, Sec 2, [4].

3.3 Data Infrastructure

3.3.1 The data infrastructure supporting the predictive CMS is to be approved with regards to the applicable requirements of NR467, Pt F, Ch 4, Sec 4.

3.3.2 Software supporting predictive CMS function is to be approved in accordance with the requirements of NR467, Pt C, Ch 3, Sec 3 for Category I systems.

3.3.3 In the event of CMS failure, predictive CMS are to be capable of continuous on board operation, and to provide sufficient information on the state of the machine to perform maintenance. Especially where predictive CMS use remote support (e.g. remote diagnosis), the system is to be capable of continuous on board operation in the loss of the communication function.

3.4 Cybersecurity

3.4.1 Predictive CMS are to comply with the requirements of Sec 2, [3.5].

3.5 Data producer

3.5.1 In addition to the requirements in the scope of NR467, Pt F, Ch 4, Sec 4, the following information are to be provided for sensors:

- Sensors characteristics (e.g. sensitivity, range, accuracy, reliability)
- Representation of sensor location on the equipment, with description of sensor attachment method. Spatial orientation should be provided.

Note 1: For data producers, refer to NI684, Sec 2, [2.2].

3.6 Data processing

3.6.1 Data processing related to processing of sensors signal (e.g. noise filter, interference filters...) are to be specified.

3.7 Anomaly detection, diagnostic and prognostic models

3.7.1 General

Predictive CMS software use complex algorithms, machine learning and knowledge of global equipment populations/defect data in order to identify acceptability for continued service or the requirement for maintenance.

These systems may be independent of the recommended maintenance and standard condition monitoring suggested limits stated by OEM recommendations or international standards.

3.7.2 Model specifications and development

General description of the model used for anomaly detection, diagnostic or prognostic is to be provided.

3.7.3 Additional requirements for anomaly detection

Anomaly detection system enables an early detection of equipment failure, but they do not provide enough information to provide maintenance recommendation.

The anomaly detection system is to be supported by CMS of type A, B or C to provide complete diagnostics or prognostics. These CMS of type A, B or C are part of the anomaly detection system and therefore:

- They are to be documented, refer to NR674 and NI684 as applicable.
- The predictive CMS approved service suppliers are to be approved for those CMS.

3.7.4 Model retraining

Models may be periodically refined and retrained on new data (e.g. accumulation of in service data) to refine model performance or adequacy to operational conditions. In that case, the full model development process is to be carried out. Continuous learning are to be avoided. This is part of the sustainment process that is to be documented in model development.

3.8 Health assessment

3.8.1 The health assessment function integrates the output of anomaly detection, diagnostic, prognostic or other knowledge, to set up information on the health status of the machinery (e.g. visualization, analytics) and, when supported by appropriate organisation and maintenance recommendation.

3.8.2 The predictive CMS is able to produce the annual report as specified in NR467, Pt A, Ch 2, App 4.

Note 1: Refer also to in NI684, Sec 2, [5.4].

3.8.3 The health assessment function is to enable data visualization of:

- current data and historical data with ID/Tag and timestamps,
- equipment running hours,
- metadata (e.g. sensors characteristics, sampling time).

3.8.4 The health assessment function is to enable access to analytics and output of the diagnostic (or anomaly detection) module:

- Diagnostic of the asset health is to be presented in a format and a level of details suitable for the end user

Note 1: To be used in the scope of a CBM Scheme, the health assessment is to be used by approved service supplier's qualified personnel.

- Baseline data (e.g. value representative of the correct machinery behaviour) is to be available.
- Acceptance criteria, with confidence interval, is to be available. A traffic light system is to be used (minimum of 3 categories)

Note 2: Refer to NI684 "Guidelines for Condition Based Maintenance".

- In case of an anomaly detection system, the additional CM tasks that are to be scheduled to conclude on the condition of assets are to be indicated.
- Information on processes for false alert mitigation are to be provided.
- When applicable, descriptions of associated failure modes are to be available.
- When applicable, maintenance actions are to be accessible.

3.8.5 The health assessment function is to enable access to prognostic module:

- prediction of degradation is to be presented in a format and with a level of details suitable for the end user,
- time to failure is to be indicated, with trend representation,
- associated confidence interval of the prediction is to be accessible.

3.9 Data Quality

3.9.1 General

Data quality framework is to be implemented (refer to NR467, Pt F, Ch 4, Sec 4, [10.3]).

3.9.2 Sensor characteristics

Sensors characteristics (e.g. range, precision...) are to be appropriate with regards to the models developed.

3.9.3 Sensor metadata

Sensors metadata are to be available in the predictive CMS database and accessible in a documented information model. The minimum data listed in [3.5.1] are to be available.

Note 1: Refer to NR467, Pt F, Ch 4, Sec 4, [10].

3.9.4 Model performance indicator

Predictive CMS are to be developed with performance indicators to monitor model performances with regards to the true condition of the machinery.

The following indicators are to be monitored and targets for each performance indicator are to be specified:

- true positive and true negative,
- false alarms (false positive),
- false negative (errors that were not prevented by predictive CMS),
- alarm per asset time,
- reactive maintenance per asset time,
- percent downtime per asset time,
- asset time (or maintenance action) outside OEM recommended values.

3.10 Auditability

3.10.1 Predictive CMS operation data

Predictive CMS is to have the ability to store, or to communicate to external storage, the CMS data according to NR467, Pt A, Ch 2, App 4.

In addition, the following data are to be stored:

- anomaly detection, diagnostic and prognostic models at initial condition (e.g. at implementation),

- models performance indicators, as defined in [6.8.3],

- data used during sustainment process,

- any other parameter that have been modified during the operation (e.g. data collection task interval, sampling time),

Note 1: Refer to NI684, Sec 2, [5.3].

3.10.2 Anomaly detection, diagnostic and prognostic model are to be backup regularly, with reference of the versions, to ensure proper traceability,

3.10.3 Data are to remain available for a period of 5 years.

4 Organization

4.1 General

4.1.1 Service supplier

In accordance with the requirement of [1.1.2], a approved service supplier is to:

- support the predictive CMS

- be able to perform Condition Based Maintenance of the equipment.

4.1.2 Predictive CMS Handbook

The predictive CMS Handbook describing procedures in the scope of predictive CMS is to be submitted, including:

- alarm validation process (false positive mitigation), with qualified human in the loop

- procedures for action support (e.g. additional condition monitoring task, maintenance)

- RCO by procedures, when they are output of the risk assessment

- procedures for continuous improvement.

Note 1: Refer to NI684, Sec 2, [4].

5 Testing

5.1 General

5.1.1 In addition to the tests described in NR467, Pt F, Ch 4, Sec 4, and in NR467, Pt A, Ch 2, App 4, the following tests are to be carried out:

- general testing of the predictive CMS:
  - check generation of health reports and maintenance recommendations
  - check data, time series, status of the sensors calibration
  - generate a condition report in a test mode with simulation of incipient failures and compare the results to the corresponding test case

- testing of functionalities described in [3.8]

- check production of the annual report as described in [3.8.2]

- check availability of audit data listed in [3.10].

Shaping a World of Trust