Guide for

Smart Functions for Marine Vessels and Offshore Units

June 2022

GUIDE FOR

SMART FUNCTIONS FOR MARINE VESSELS AND OFFSHORE UNITS
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American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

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Foreword *(1 June 2022)*

Smart Functions, which provide crew and support personnel with key information to aid in decision-making, are becoming increasingly common on board marine vessels and offshore units. Common Smart Functions include structural and machinery health monitoring, asset efficiency monitoring, operational performance management, and crew assistance and augmentation to support vessel operations.

Smart Functions are enabled via a data infrastructure and supported by robust software integrity and cybersecurity that facilitate the use of aggregated data from sensors and other sources, data analytics, and data synthesis for reporting, decision making and actions.

ABS is introducing this *Guide for Smart Functions for Marine Vessels and Offshore Units* to provide the industry with technical and survey requirements for vessels fitted with Smart Functions. Compliance with the requirements given in this Guide may result in the granting of optional class notations **SMART (INF)** covering the data infrastructure, as well as **SMART (SHM)** and/or **SMART (MHM)** covering the Smart Functions for health monitoring of structures or machinery of marine vessels or offshore units.

This Guide further describes the ABS process to approve technology and services offered in support of Smart Function implementation. Recognition by ABS of external service suppliers includes third party organizations that support Smart Function implementation, Original Equipment Manufacturers (OEMs), shipyards, owners, and operators. The Product Design Assessment (PDA) option may also be offered to any party providing hardware and software meeting the requirements within this Guide.

This Guide allows for the use of the data and decision-making support provided by the Smart Functions to assist Surveyors in performing onboard activities. Onboard equipment or systems having Smart Function capability can be considered for implementation of alternate means to credit survey requirements.

This Guide is meant to be used together with the ABS *Guidance Notes on Smart Function Implementation*, which provides ABS clients with the procedures for setting goals and deciding on the Smart Functions needed to achieve these goals, as well as the Rules and Guides issued by ABS and other recognized International, National, and Industry Regulations and Standards.

The July 2020 edition included requirements related to notification of ABS on damage, failure, and repair, similar to 1-1-8/1 of the ABS *Rules for Conditions of Classification (Part 1)*.

The October 2021 edition adds a reference to the ABS *Guide for Autonomous and Remote Control Functions* and replaces the requirements for surveys after construction with references to Section 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)*.

The June 2022 edition of the Guide replaces "Service Provider" with "Service Supplier" to match IACS terminology and expands the acceptance of the Service Suppliers to AEM, OPM and CAA functions, in addition to the existing SHM and MHM functions.

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 the Guide is the most current.

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

GUIDE FOR

SMART FUNCTIONS FOR MARINE VESSELS AND OFFSHORE UNITS

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SECTION 1
General

1 Introduction

1.1 Purpose *(1 June 2022)*

The purpose of this Guide is to:

i) Establish a goal-based framework for Smart Function (SF) implementation;

ii) Establish a risk informed approach and requirements for Smart Function assessment;

iii) Offer optional Smart Function class notations;

iv) Provide recognition to Service Suppliers (SSs) offering Smart Function services;

v) Issue Product Design Assessments (PDAs) to Smart Function system hardware and software;

vi) Extend equipment PDA documents with attachment for manufacturers equipment to recognize Smart Functions for alternative survey approach;

vii) Establish alternate means to credit survey after construction requirements.

1.2 Audience *(1 June 2022)*

This Guide is intended for use by marine vessel and offshore unit owners, operators, designers, shipyards, equipment and system manufacturers, as well as Smart Function product and service suppliers, vendors, and integrators.

2 Smart-to-Autonomy Levels *(1 June 2022)*

Smart is defined in this Guide on the scale of Smart-to-Autonomy levels based on the human-system level of interaction in the processes of data handling, decision-making and execution.

The Smart-to-Autonomy levels are defined as follows:

i) *Manual*: No system augmentation of human functions. The system offers no or limited assistance, and a human must make all decisions and take all actions.

ii) *Smart*: System augmentation of human functions. The system provides passive decision support, in the form of health and condition anomaly detection, diagnostics, prognostics, decision/action alternatives, and/or recommendations.

iii) *Semi-Autonomy*: Human augmentation of system functions. The system takes a decision-making role and performs action selection. A human is in the loop for approval and possible override of system-selected actions.

iv) *Full Autonomy*: No human involvement in system functions. The system makes decisions and takes actions autonomously. Humans are out of the loop and the system may provide notifications.

The role of human and system for the levels described above is summarized and detailed in 1/2 TABLE 1.

TABLE 1
Smart-to-Autonomy Levels

Level	*Features*	*Data Handling*	*Decision Making*	*Execution of Action*
Manual	No system augmentation	System and Human	Human	Human
Smart	System augmentation of human functions	System and Human	Human with System support	Human
Semi-Autonomy	Human augmentation of system functions	System	System with Human supervision	System with Human supervision
Full Autonomy	No human augmentation	System	System	System

3 Smart Function

3.1 Definition

The Smart Function described in this Guide refers to systems installed and services deployed to continuously collect, transmit, manage, analyze, and report data for enhanced health and condition awareness, operational assistance, operational optimization, and decision-making support.

3.2 Features *(1 June 2022)*

The Smart Functions described in this Guide has the following features:

i) Is categorized at the Smart level as defined in Subsection 1/2

ii) Can be implemented for individual onboard equipment, across functional systems, or holistically across the entire vessel

iii) Can be implemented as a standalone system or through integration/interaction with other onboard systems

iv) Can be centralized at one physical location or decentralized across several onboard locations, with or without onshore support facilities that are interlinked for continuous or periodic data exchange

v) Provides passive decision support and typically requires services from SSs to close the decision-making loop

3.3 Smart Function Categories *(1 June 2022)*

The following Smart Function (SF) categories are typically implemented:

i) *Structural Health Monitoring (SHM)*: Monitors structural loads, responses, and health conditions to assess the structural integrity, provide structural health awareness, and help reduce the potential for structural damage.

ii) *Machinery Health Monitoring (MHM)*: Monitors the health state and operational conditions of onboard machinery and systems to detect anomalies that assist to predict the onset of condition degradation or improper operation which may lead to functional failure.

iii) *Asset Efficiency Monitoring (AEM)*: Assesses equipment, system, or vessel efficiency and provides maintenance and tune-up activity triggers to maintain or improve efficiency levels. Asset efficiency refers to the efficacy and proficiency of equipment, a system, or a vessel to perform its functions or missions. Asset efficiency is an inherent design characteristic and typically degrades with operation time. This can be due to factors such as hardware wear and tear, corrosion, material degradation, biofouling and contaminant deposition. Asset efficiency levels can be maintained through efficiency monitoring and proper maintenance. Examples of asset efficiency include hull resistance and engine efficiency. AEM is often used in tandem with a health monitoring function, as it usually monitors efficiency. AEM functions are typically implemented through continuous onboard data collection and onshore data analysis, efficiency assessment, and inspection / maintenance planning by subject matter experts.

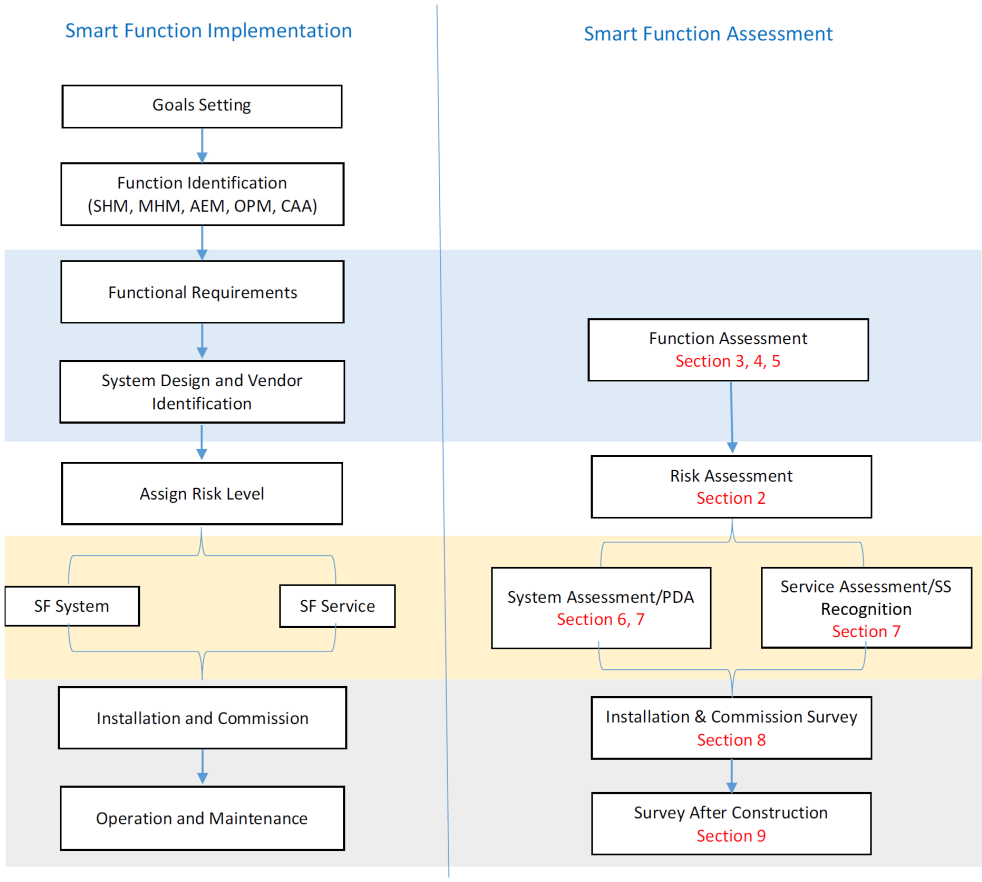
iv) *Operational Performance Management (OPM)*: Monitors, manages, and analyzes equipment, systems, or vessel operational parameters and performance data. The results provide guidance and recommendations for operators and onboard crew to optimize the way the equipment, system, or vessel is operated and managed. In contrast to asset efficiency monitoring that focuses on managing performance within the bounds of the asset's inherent efficiency, operational performance management targets operational parameters and the ability to operate the onboard systems and vessel to achieve optimum performance under the current asset efficiency level. Operational performance management focuses on the human's interaction with the physical asset (i.e., "behavioral" aspects). Examples of OPM functions include voyage optimization, route planning and power plant balancing.

v) *Crew Assistance and Augmentation (CAA)*: Assists crew reporting and other onboard activities through automatic data collection, electronic logging, data processing, analysis, and report generation. CAA-related Smart Functions can be either a standalone function or integrated with the health monitoring and performance management functions. For example, auto-logging and reporting are a common feature often incorporated within an OPM function. Enhanced situational awareness can also come from increased sensing and analytics capacity that augments the crew in vessel operations, such as night vision, obstacle detection, and collision avoidance. The objectives of CAA functions are to reduce crew workload and human error, enhance crew situational awareness and help minimize the risk of potential human oversights.

4 Goal-Based Framework

1/4 FIGURE 1 shows the goal-based framework for Smart Function implementation in the left-hand column outlined in the ABS *Guidance Notes for Smart Function Implementation* with parallel requirements for assessment as described in the indicated Sections of this Guide shown in the right-hand column.

FIGURE 1
Smart Function Implementation and Assessment *(1 June 2022)*



4.1 Smart Function Implementation

This paragraph provides guidance on the general process that the SF implementation is to cover. The ABS *Guidance Notes for Smart Function Implementation* may be used as a reference. This general process is to be assessed by ABS following the methodology of 1/4.2.

4.1.1 Goal Setting

Smart Function implementation may achieve the following goals:

i) Increase health state awareness in order to enhance safety and asset integrity and to minimize downtime associated with failures and maintenance;

ii) Improve asset efficiency and operational performance in order to reduce fuel consumption, emissions and Operational Expenses (OPEX);

iii) Assist and augment crew with vessel operations related to navigation bridge management, practices, and compliance reporting in order to enhance vessel situational awareness and navigation safety, reduce crew workload, and minimize potential human error.

As classification requirements incorporate more vessel-specific and condition-based approaches, properly implemented Smart Functions may augment the Surveyor's understanding of the vessel's health state for more condition-based and less intrusive survey scopes.

4.1.2 Smart Function Identification

To achieve the goals described in 1/4.1.1, the appropriate SF categories as defined in 1/3.3 are to be identified.

The following table aligns SF categories with common vessel functions, structures, and systems, as applicable to marine vessels and offshore units. Similar categorization may apply to systems for other vessel types, not explicitly referenced in 1/4.1.2 TABLE 2.

TABLE 2
Map of Smart Function Category to Vessel Function, Structure and System

Vessel Function/Structure/System	*Health State Awareness*		*Asset Efficiency & Operational Performance*		*Crew Assistance & Augmentation*
	SHM	*MHM*	*AEM*	*OPM*	*CAA*
Propulsion System		X	X	X	
Steering/Maneuvering System	X	X	X		
Power Generation/Distribution		X	X	X	
Firefighting System/Equipment		X			
Auxiliary Machinery		X	X	X	
Drilling and Production		X	X	X	
Cargo/Ballast Handling System		X	X	X	X
Hotel/Accommodation/HVAC		X	X	X	
Global Hull	X				
Local Structures	X				
Shafting/Propeller		X			
Navigation		X		X	X
Station Keeping/Mooring	X	X		X	X
Hull & Propeller Performance			X	X	X
Compliance Reporting					X

4.1.3 Functional Requirement

Functional requirements define a set of Smart Function tasks necessary to accomplish the specified goals.

Functional requirements for individual SF categories eligible for notations are listed in Sections 3, 4, and 5 of this Guide.

4.1.4 System Design and Vendor identification

To realize the functional requirements set per 1/4.1.3, the SF system design and vendor(s) are to be identified.

4.1.5 Risk Level Assignment

A risk level is to be assigned based on the procedure outlined in Section 2 by evaluating the various risk factors associated with the Smart Function implementation.

The system technical requirements presented in Section 6 of this Guide are based on the assigned risk level.

4.1.6 Smart Function System

The Smart Function system (or SF system in this Guide) is a combination of hardware and software, including data source, data analytics algorithms, and models that realize the identified Smart Functions and satisfy the functional requirements.

The hardware and software of the SF system can be centralized at one physical location or decentralized across several locations onboard the vessel with or without onshore facility support.

4.1.7 Smart Function Service

The Smart Function service (or SF service in this Guide) is a human-in-the-loop process that facilitates decision making for the SF system including actions related to anomaly detection, structural and machinery health diagnostics and/or prognostics.

SF service delivery is to follow established and quality-controlled procedures by qualified and competent staff. The SF service typically involves interaction and data exchanges with SF systems.

The service delivery component of SF implementation is covered under Section 7.

4.2 Smart Function Assessment

The Smart Function implementation described in 1/4.1 and 1/4 FIGURE 1, is to be independently assessed by ABS as outlined in 1/4.2.1 to 4.2.3 and summarized in 1/4.2.3 TABLE 3.

4.2.1 Function Assessment

Function assessment is the verification and validation procedure to confirm the capability and scope of the Smart Function satisfy the implementation goals.

The function assessment requires verification through engineering review and Surveyor validation through representative witnessing of functional achievement either at vendor site or on board the vessel and is covered by the technical requirements of Subsections 3/6, 4/6 and 5/7.

4.2.2 System Assessment

System assessment is the verification and validation procedure to confirm that the SF system hardware and software and its interaction and integration with onboard system(s) satisfies the system technical requirements of the appropriate risk level. The system assessment covers the following system properties:

i) Suitability for marine environment

ii) System integration and potential error propagation

iii) System reliability, maintenance, integrity and security

iv) Algorithm and model accuracy, system response time and capacity

The system assessment requires verification through engineering review and Surveyor validation via onboard installation survey and onsite manufacture survey.

Detailed technical requirements for system assessment on hardware, software, data, data analytics and model are summarized in Section 6 of this Guide.

4.2.3 Service Assessment

Service assessment is the verification and validation procedure to confirm the SF service supported by Quality Assurance/Quality Control (QA/QC) procedures and practices, personnel qualifications and competencies, to confirm that the service can be delivered consistently and reliably for its intended purpose.

Service assessment requires verification through engineering review and Surveyor validation via onsite audit. Detailed service assessment procedures and requirements are defined in Section 7 of this Guide.

TABLE 3
Smart Function Assessment

	Intention	*Applicable to*	*Assessment Method*	
			Verification	*Validation*
Function Assessment	Smart Function capability is defined and understood	SF capability and scope	Engineering review	Representative demonstration and/or functional test
System Assessment	System satisfies the technical requirements	SF system hardware, software (platform), algorithm, model, and data source	Engineering review	Onboard (onsite) Survey
Service Assessment	Service can be delivered consistently and reliably	Procedure, process, staff qualification and competency, QA/QC	Engineering review	Onsite audit, site/vessel validation by Surveyor

5 Guide Scope *(1 June 2022)*

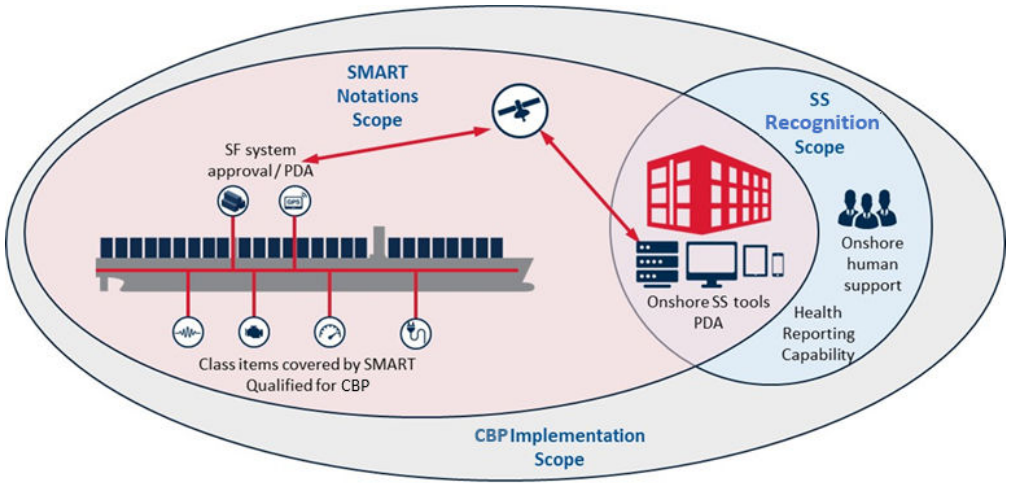
This Guide is applicable to all marine vessels and offshore units, herein referred to as vessels.

This Guide covers the SF categories SHM and MHM as defined in 1/3.3, within the scope of optional Smart Function class notations, **SMART (INF)**, **SMART (SHM)** and/or **SMART (MHM)**, SS recognition, and PDA as described in Subsections 1/6, and 1/8.

In order to keep this Guide concise, references in this Guide are made to requirements in the ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)* and ABS *Rules for Building and Classing Mobile Offshore Units (MOU Rules)*. Where the requirements are not stated for other vessel types, similar requirements will be applied. We recommend contacting ABS for clarification on applying these requirements to vessels not covered by the *Marine Vessel Rules* and the *MOU Rules*.

1/5 FIGURE 2 demonstrates the relationship of hardware and software approval to notation achievement as well as the recognition scope for Service Suppliers, and further illustrates the relationship of both these scopes to implementation of alternate means to support Survey after construction.

FIGURE 2
Class Scope for Smart Functions *(1 June 2022)*



5.1 AEM, OPM and CAA Functions

Smart Functions for AEM, OPM, and CAA as defined in 1/3.3 may be enabled by the optional Smart Function Notation **SMART (INF)**.

ABS may recognize these Smart Functions via the verification and validation process defined in the ABS *Guidance Notes for Qualifying New Technologies* while also considering the applicable requirements of this Guide, the ABS *Guidance Notes on Smart Function Implementation*, and other relevant ABS and industry standards.

Class Record Comments may be recorded as SMART (AEM), SMART (OPM), and/or SMART (CAA) to recognize that the corresponding function has been reviewed by ABS, approved for "System Integration" maturity, and installed on an ABS Classed vessel.

5.2 Semi-Autonomy and Full Autonomy *(1 October 2021)*

Functions operating at semi-autonomous or fully autonomous levels as defined in Subsection 1/2 are outside of the scope of this Guide. For such applications, refer to the ABS *Guide for Autonomous and Remote Control Functions*.

6 Class Notations

6.1 Smart Function Notations

The optional class notation **SMART (xx, yy, etc.)** is to be assigned to a vessel possessing a permanently installed SF system. The implementation is to satisfy the function assessment and system assessment as described in 1/6.1 TABLE 4.

The SF system can be installed during vessel construction or by retrofit.

The descriptive notation "**xx, yy, etc.**" can be any of the single notation, or a combination of the notations listed here.

INF: Data **INF**rastructure for Smart Function implementation

SHM: Structural **H**ealth **M**onitoring

MHM: **M**achinery **H**ealth **M**onitoring

For example, **SMART (INF, MHM)** indicates a vessel with pre-installed data infrastructure and a machinery health monitoring Smart Function system.

The SF covered vessel structure/system/equipment (see 1/4.1.2 TABLE 2 for examples) and their corresponding Tiers (see Sections 4 and 5) are to be recorded in the vessel record notes.

TABLE 4
Requirements for Obtaining Smart Function Notations

Notation	*Applicable to*	*Task*	*Function Assessment*	*System Assessment*
INF, **SHM**, **MHM**	Smart Function system(s)	Verification	Functional requirements (Sections 3, 4, 5)	Technical requirements (Section 6)
		Validation	Onboard function test (Sections 8, 9)	Installation survey and Surveys after Construction (SAC) (Sections 8, 9)

6.2 Maintenance of Smart Function Notations

To maintain the optional Smart Function notations of 1/6.1:

i) The SF system is to be kept properly maintained and operational. The survey after construction requirements described in Section 9 are to be met and the survey is to be conducted to the satisfaction of the attending Surveyor;

ii) Records of modifications, upgrades, and retrofits to the SF system, including both hardware and software, are to be kept onboard and made available to the attending Surveyor.

6.3 Change of Vessel Ownership

Sale, change of vessel management, or transfer of class will result in reconsideration by ABS of SF system approval, notations and class survey use.

7 Service Suppliers *(1 June 2022)*

7.1 Service Supplier Recognition *(1 June 2022)*

ABS is to issue a certificate to recognized Service Suppliers (SSs). SSs recognized by ABS are listed on the ABS website so that the information is verifiable and available to the industry.

The SS recognition covers SHM, MHM, AEM, OPM or CAA functions**.** The requirements for obtaining a SS recognition are summarized in Section 1, Table 5. Refer to Section 7 of this Guide for the detailed procedure and requirements for SS recognition.

Service suppliers are recognized as having established procedures, adequate capacity, and qualified and competent staff to provide services indicated in compliance with recognized QC/QA standards as defined in Section 7 of this Guide. ABS is not approving or certifying the specific service delivered.

TABLE 5
Requirements for Obtaining SS Recognition *(1 June 2022)*

SS Recognition	*Applicability*	*Task*	*Function Assessment*	*System Assessment*	*Service Assessment*
SHM, MHM	OEM, Third Party Service Companies, Shipyard, Owners and Operators that conduct Smart Function Operations	Verification	Functional requirements (Sections 4, 5)	PDA for hardware and software tools (Section 7)	Procedure/staff/ quality requirements (Section 7)
		Validation	Representative service demonstration (Section 7)	Tool deployment onsite survey (Section 7)	Onsite audit (Section 7)
AEM, OPM and CAA	OEM, Third Party Service Companies, Shipyard, Owners and Operators that conduct Smart Function Operations	Verification	N/A	PDA for hardware and software tools (Section 7)	Procedure/staff/ quality requirements (Section 7)
		Validation	Representative service demonstration excluding stated quantitative performance benefits. (Section 7)	Tool deployment onsite survey (Section 7)	Onsite audit (Section 7)

7.2 AEM, OPM and CAA Functions *(1 June 2022)*

Service Suppliers for AEM, OPM and CAA functions are recognized as having established procedures, and qualified and competent staff to provide the services indicated in compliance with recognized QC/QA standards as defined in Section 7.

8 Type Approval Program

8.1 Product Design Assessment *(1 June 2022)*

ABS may issue a Product Design Assessment (PDA) for the below systems reviewed under the Type Approval program:

- System/equipment to deliver the Smart Function;
- Hardware and software that the SS uses for data handling, data analytics, and service delivery. The tool and platform can be designed and developed by the SS or by a third-party.

The PDA is to follow the ABS Type Approval Program; refer to Appendices 1-1-A3 and 1-1-A4 of the ABS *Rules for Conditions of Classification (Part 1)*.

8.2 Product Design Assessment Attachment

When the Smart Function product is provided by OEMs as part of their system/equipment, ABS may issue a PDA as an attachment to the approved system/equipment PDA. The approved Smart Function capability, scope, applicable risk level, and alternate survey approach are to be recorded in the PDA Attachment.

The PDA attachment to be issued is unique for individual system/equipment types.

9 Alternate Means to Credit Survey Requirements *(1 October 2020)*

New technologies may enable less intrusive surveys of hull and machinery systems through alternative means of verification of compliance to specific survey requirements. Alternative means of verification involves determining the vessel's health and maintenance status by leveraging data and digital capabilities such as but not limited to, Smart Functions, system automated and self-verification testing, remote inspection technologies, and remote verification and attendance through the ABS Remote Survey program.

Class items covered by Smart Function SHM and MHM may qualify for alternate means to credit survey requirements. Machinery items are also to be enrolled in a Preventative Maintenance Program (PMP) in accordance with the requirements of 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)* in order to be considered for implementation of alternate means to credit survey requirements. Refer also to Sections 4, 5, 7, 8 and 9 of this Guide.

10 Submittal Requirements *(1 June 2022)*

Section 1, Table 6 below summarizes the documents to be submitted to ABS for the optional Smart Function class notations, Service Suppliers Recognition as well as PDA. Detailed description and requirements on these submittals are listed in Appendix 3. ABS may request additional submittals.

TABLE 6
Submittal Requirements *(1 June 2022)*

Submittal Requirements	*For SF Notation*	*For SS Recognition*	*For PDA*	*Assessment Requirements*
For Function Assessment				
1. Concept of Operations	X	X	X	Sec. 3/4, INF Function Assessment Sec. 4/6, SHM Function Assessment Sec. 5/7, MHM Function Assessment Sec. 7/7, SS recognition
2. Smart Function Risk Level	X	X		
3. Smart Function Description	X	X	X	
4. Stakeholder Role Matrix for Implementation	X	X		
For System Assessment				
5. SF System Architecture	X	X*	X	Sec. 6, System Assessment (*) submittals to include system specification to cover applicable requirements of Sec 6
6. SF System Specification	X	X*	X	
7. Additional Specification for Medium and High Risk Levels	X	X*	X	
8. Installation and Commissioning Plan	X			Sec. 8, Installation and Commissioning Survey
For Service Assessment				
9. Organizational Capability		X		Sec. 7/7, SS recognition Sec. 8, Installation and deployment
10. Tool Development and Deployment Process		X		
11. Data Center Support		X		

11 Application of New Technologies

Smart Functions in marine and offshore applications are built upon information technology, data science, software, and cybersecurity. It is foreseen that as these evolve, new and alternative capabilities and technologies not yet described within this Guide may be implemented on board ABS Classed vessels.

ABS will accept new capabilities and technologies on a case-by-case basis following the goal-based framework and risk-informed approach established in this Guide, the ABS *Guidance Notes on Smart*

Function Implementation, the ABS *Guidance Notes on Review and Approval of Novel Concepts* and the ABS *Guidance Notes on Qualifying New Technologies*.

12 Damage, Failure and Repair *(1 July 2020)*

Damage, failure, or deterioration detected by the implemented SHM or MHM Smart Function to hull, 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. Refer to 1-1-8/1 of ABS *Rules for Conditions of Classification (Part 1)*.

1 General *(1 June 2022)*

This Guide uses a risk-informed approach to set the prescriptive requirements for ABS verification and validation activities. The risk level is to be assigned by the submitter with consideration of the safety related risk factors and the potential consequences of the Smart Function failure or under-performance on the vessel's safety and operations.

Consideration of commercial risk is an important concept during a Smart Function implementation. However, a commercial risk assessment is not required to obtain optional Smart Function notations, SS recognition, or PDA attachment, and thus is not within the scope of this Guide.

The requirements for system assessment as described in Section 6, are based on the Smart Function's risk level assigned by the process described in Subsection 2/2.

2 Assignment of Risk Level

Each Smart Function submitted to ABS for approval is to be assigned a risk level by the submitter based on the approach described below.

2.1 Likelihood of Failure

The likelihood of a Smart Function failure or under-performance is to be determined by:

i) The complexity level of Smart Function system, service, and their integration and interaction (denoted as *SFN*)

ii) The highest sophistication level of the data analytics and model employed (denoted as *SDA*)

The characteristics levels for the complexity level of Smart Function Network (*SFN*) and highest Sophistication level of Data Analysis method employed (*SDA*) are defined in Section 2, Table 1.

TABLE 1
Smart Function Likelihood Characteristics Levels

Complexity Level of Smart Function System and Service (SFN)	
0	Simple (Standalone system)
1	Simple Network (Partial integration with other systems, not all systems networked)
2	Complex Network (All networked and fully integrated, onboard access only)
3	Multi-Attribute Connected (Remote and onshore accesses, onboard function relies on onshore support and continuous and reliable vessel-onshore communication)

Highest Sophistication Level of Data Analysis Employed (SDA)	
0	Basic (Parameter monitoring, statistics and trending)
1	Physics Based Models and Traditional Condition Monitoring Techniques with Analytics Support
2	Data Driven Models (Machine learning and Artificial Intelligence (AI) models, with or without use of physics-based models)

The likelihood of Smart Function under-performance or failure is defined as the summation of the assigned levels of above key likelihood characteristics (SFN + SDA) and is represented by the three likelihood levels defined in Section 2, Table 2.

TABLE 2
Likelihood Levels of Failure or Under-Performance

Likelihood Level	*SFN+SDA*	*Example*
L (Low)	0, 1	Hull girder bending moment and slamming monitoring with strain gauges and accelerometers
M (Medium)	2, 3	Engine cylinder temperature and pressure monitoring with integrated thermal and pressure sensors
H (High)	4, 5	Voyage optimization (periodical weather forecast feeding, operational parameters collected from relevant onboard systems, data-driven fuel consumption model)

2.2 Consequence of Failure

The consequence level denotes the potential impact of the Smart Function failure or underperformance on the vessel safety and operation. The consequence level is influenced by the following three factors:

i) The Smart Function level of Decision-making support (denoted as *SFD*)

ii) The Smart Function Integration level with the onboard systems (denoted as *SFI*)

iii) The System Category that the Smart Function integrates with (denoted as *SC*)

The decision-making support (*SFD*) and integration level (*SFI*) are defined in Section 2, Table 3.

TABLE 3
Smart Function Decision-Making Support and Integration Level

Smart Function Level of Decision-Making (SFD)	
0	Dashboard and Auto Reporting of Health, Performance, and Situational Awareness State
1	Decision Recommendations (Human take action)
2	Auto-Initiated Actions with Human's Supervision (Human in-the-loop)
Smart Function Integration Level (SFI)	
0	Standalone (Isolated from other systems, or passive listening only for data collection when integrated with onboard systems. No potential impact on the integrated system's safety and performance)
1	Partial (one-way data communication to the Smart Function with active data request. May cause performance degradation but there is no safety impact on the integrated onboard system)
2*	Fully Integrated (two-way communication with onboard systems with the potential sending commands to the systems for operational adjustment or optimization)

Note: Auto-initiated actions (*SFD* = 2) typically require full integration level (*SFI* = 2).

When Smart Functions are integrated with vessel systems (usually via an interface to the computer-based systems for control and alarming), a failure of the Smart Function may propagate to the integrated computer-based system and therefore expose the vessel to risk.

System Category (SC) is defined in 4-9-3/Table 1 of the *Marine Vessel Rules* according to the potential extent of the damage that may be caused by a single failure within the computer-based system. This categorization, implemented in this Guide for marine vessels and offshore units, is shown in Section 2, Table 4.

TABLE 4
System Categories (SC)

System Category	*Effects of Failure*	*Typical System Functionality*
I	Failure will not lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment	Monitoring function for informational/ administrative tasks
II	Failure could eventually lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment.	Alarm and monitoring functions Control functions which are necessary to maintain the ship in its normal operational and habitable conditions
III	Failure could immediately lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment.	Control functions for maintaining the vessel's propulsion and steering Vessel safety functions

Examples of assignment to system categories are shown in 4-9-3A2/5 of the *Marine Vessel Rules* and listed below. For similar system categories for other vessel types not listed below, refer to the applicable ABS Rules and Guides

i) *Systems Typically Belonging to Category I:*

- Maintenance support systems
- Information systems

ii) *Systems Typically Belonging to Category II:*

- Liquid cargo transfer control system
- Bilge level detection and associated control of pumps
- Fuel oil treatment system
- Ballast transfer valve remote control system
- Stabilization and ride control systems
- Alarm and monitoring systems for propulsion systems

iii) *Systems Typically Belonging to Category III:*

- Propulsion system of a ship, meaning the means to generate and control mechanical thrust in order to move the ship (devices used only during maneuvering, such as bow tunnel thrusters, are not in this scope)
- Steering system control system
- Electric power system (including power management system)

- Ship safety systems covering fire detection and fighting, flooding detection and fighting, internal communication systems involved in evacuation phases, and ship systems involved in operating lifesaving appliances
- Dynamic positioning system of equipment classes 2 and 3 according to IMO MSC/Circ.645 or MSC.1/Circ.1580
- Drilling systems

The consequence of a Smart Function failure or under-performance is defined by the below formula and represented by the three levels defined in Section 2, Table 5.

$SFD + (SFI \times SC)$

TABLE 5
Smart Function Failure – Consequence Levels

Consequence Level	*SFD + (SFI x SC)*	*Example*
L (Low)	0, 1	Hull girder condition monitoring (dashboard with installed strain gauges)
M (Medium)	2, 3, 4	Weather routing (route recommendations and passive data collection from relevant systems)
H (High)	5 and above	Power management and optimization (auto-adjusting engine operational parameters with certain range for best performance)

2.3 Risk Matrix

A risk matrix is to be utilized based on the level of likelihood and consequence described in 2/2.1 and 2/2.2, respectively, and as shown in Section 2, Table 6.

The risk matrix is to be utilized to assign a risk level (L: Low, M: Medium, H: High) to each of the Smart Functions implemented on each vessel.

TABLE 6
Risk Matrix

Consequence Level	*Likelihood Level*		
	L	*M*	*H*
L	L	L	M
M	M	M	H
H	M	H	H

3 Risk Assessment

For the Smart Functions that are assigned a high-risk level, a Functional Failure Modes, Effects and Criticality Analysis (FMECA) approach and Management of Change (MoC) process to address potential new risks to the vessel or unit are to be performed by the submitter. Based on the results of the functional FMECA, a component level FMECA is to be conducted when deemed necessary by ABS when:

i) A particularly critical subsystem, hardware and software component, data source, algorithm and analytics model are identified during the functional FMECA;

ii) Critical functions with a risk level high are identified during the functional FMECA;

Standard engineering evaluation can be used to demonstrate compliance with the stated design philosophy in lieu of the component FEMCA assessment for simple system and physics-based models. Use of a Standard engineering evaluation to replace the component FMECA assessment may be accepted upon approval by ABS.

3.1 Functional FMECA for Smart Functions

A Functional FMECA can be used to systematically identify and assess the potential risks to the vessel's safety and operation relevant to the Smart Function implementation.

3.1.1 Scope

The scope of the Functional FMECA is to include the risks associated with the Smart Function, including its hardware, software, data analytics and models, data integrity, cybersecurity, communication and interaction as well as its integration with onboard control and automation systems.

3.1.2 Objective

The objectives of the risk assessment are to at least include the following:

i) Assess the impact of functional failure of the Smart Functions to the vessel's safety and operability by conducting criticality analyses;

ii) Identify the failure modes and fail-safe state for the Smart Function system and actions required to reach the state under various operational modes;

iii) Identify any hazardous situations originating from the Smart Function and the potential impact on other vessel systems through integration or interactions;

iv) Evaluate if the existing safeguards are adequate and identify if additional safeguards are required to mitigate the risks for the design and operation of the Smart Function, when necessary.

3.1.3 Risk Factor

During the risk assessment, the following Smart Function risk factors are to be considered, as a minimum:

i) The role of the Smart Function, in terms of decision support and decision making;

ii) The complexity of the hardware, software, data analytics, algorithm and model;

iii) The reliability of the hardware, software, network and data communication;

iv) The redundancy of the onboard automation and control systems;

v) Loss of power supply;

vi) The uncertainty of analytics models, data, and data quality;

vii) The accuracy and robustness of the algorithm and analytics models;

viii) Data integrity, software quality and cybersecurity;

ix) Operation errors and human factors;

x) Potential integrity impacts on data;

xi) Potential corruption from integration and interoperability issues (i.e., from software and system interface incompatibilities).

3.1.4 Risk Assessment Plan

A risk assessment plan is to be developed and submitted to ABS prior to conducting the Functional FMECA study. The risk assessment criteria for evaluation (i.e., risk matrix) is to be included within the risk assessment plan. ABS will review the risk assessment plan and confirm if the proposed study approach is satisfactory. Further guidance on the development of risk assessment plan can be found in the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*.

3.2 Component Level FMECA

When required, the component level FMECA is to demonstrate that the Smart Function subsystems, hardware and software component, data source, algorithm and analytics model are designed so that no single failure will lead to an unsafe situation for the vessel and the vessel's primary functions in operation will not be lost or degraded.

A component level FMECA is to be conducted following the approach described below.

It is recognized that Smart Function systems (by virtue of being a new technology) are unique in terms of design, operating environment, and application, therefore, the risk assessment techniques (e.g., fault tree) other than the one described below can be adopted as well. In addition, more than one risk assessment technique can be applied.

The selection of risk assessment technique is to be discussed with, and approved by, ABS prior to performing the assessment.

3.2.1 Objective

The component level FMECA is to, as a minimum:

i) Identify the local effects of the component failure mode and "global" effects of the failure of the Smart Function system and its integrated/interconnected onboard systems.

ii) Identify the failure causes, failure mechanisms and the safeguards that can reduce the likelihood of failure or mitigate the consequence of failure.

iii) Identify and provide recommendations to eliminate or mitigate the effects of all single fault failures and common cause failures in the component which, if one occurs, would cause loss of capability.

3.2.2 Validation Program and Test Procedure

A FMECA validation program and test procedures are to be developed and submitted to ABS for review.

The purpose of the FMECA validation program is to verify the critical and selected results from the FMECA assessment.

The FMECA test program is to be developed based on the risk assessment and assumptions. Validation tests are to be carried out during factory acceptance testing and/or as part of the onboard commissioning of the Smart Function and verified by the attending Surveyor.

The ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification* provide detailed steps for the FMECA assessment and FMECA validation program.

FMECA reports and the FEMCA test program are to be kept onboard the vessel, and they are to be updated to address subsequent alterations and/or upgrades to the Smart Function system, its hardware, software, data analytics algorithm and models.

3.3 Management of Change

An effective MoC program is required for high risk Smart Functions and is to be reviewed by ABS.

A MoC program is to include the policies and procedures used to evaluate the potential impacts of a proposed change (temporary or permanent) so that they do not result in unacceptable risks.

Change includes the hardware modification and replacement, software patching and version upgrading, data analytics model revision, data source or data structure change, environment and operation changes, etc.

Once risk assessment acceptance is obtained from ABS and the proposed Smart Function system design proceeds into construction phase, the knowledge gained by the risk assessments is to be fed into the quality control process during construction and in-service stage once the Smart Function system is commissioned.

Whenever a change is made, the potential consequences of that change is to be assessed before implementation. Risk Assessments are to be re-executed if the change may alter the scope and objectives of the risk assessment.

The ABS *Guidance Notes on Management of Change for the Marine and Offshore Industries* provides detailed information on the development of an MoC program.

SECTION 3
Data Infrastructure for Smart Functions

1 General

The objective of a data infrastructure is to establish data handling functions with pre-installed hardware and software that support the current and potentially future Smart Function implementations.

The data infrastructure can be installed during construction or through a retrofit of a vessel.

2 Data Handling Functions

For a Smart Function implementation, the following data handling functions are typically involved to cover its data flow:

- Purposely Installed Sensor Interface
- Interface to Onboard System
- Data Network and Communication
- Data Management
- Data Processing and Analytics
- Human-Machine Interface

The capabilities of Data Processing and Analytics and Human-Machine Interface functions are typically specific to certain Smart Functions (e.g., SHM and MHM) and therefore are not considered as part of data infrastructure.

When a data handling function is not included in the above list, approval of the function is to be discussed and assessed by ABS in case-by-case basis.

3 SMART (INF)Notation

The **SMART (INF)** optional class notation can be assigned to an ABS Classed vessel, on board which the hardware and software are installed for accomplishing certain data handling functions.

The data handling function capability is to be assessed following Subsection 3/6 and the hardware and software are to be assessed following Subsection 3/7.

SMART (INF) can be assigned as a standalone notation or as together with one or multiple functional Smart Function notations, such as **SHM** or **MHM**.

The approved data handling functions as defined in Subsection 3/2, and the risk-level that the hardware and software can support are to be recorded in the vessel records.

The following example Class notation and vessel records indicate an installed data infrastructure in a Classed vessel, which supports Data Network and Communication and Data Management. The hardware and software have been approved for a medium risk Smart Function implementation:

- Notation: **SMART (INF)**
- Vessel Records: **Data Network and Communication (risk level medium), Data Management (risk level medium)**

4 Functional Requirements

To obtain the **SMART (INF)** optional notation, the following capabilities are required as a minimum for each corresponding data handling function, either individually or collectively.

4.1 Purposely Installed Sensor Interface

The interface is to receive data from the external environment and physical process/structures through sensors and measurement instruments installed for the Smart Function purpose.

The following capabilities are to be presented and supported by the installed hardware and software:

i) Predefined data interface to support certain number and type of input/output (I/O) channels

ii) Configurable and expandable I/O channels, in terms of number and type of channels

iii) Connection to the Data Network and Communication function when such function is implemented

iv) Time stamping and time synchronization for the data collected through the interface

v) Monitoring and alarming for signal/data stream interruption and lost

4.2 Interface to Onboard System

The interface to onboard system is to access and retrieve data from other onboard systems, such as automation, control and monitoring systems, in passive or active means for the Smart Function.

The following capabilities are to be presented and supported by the install hardware and software:

i) Predefined data interface to support certain number and type of I/O channels

ii) Configurable and expandable I/O channels, in terms of number and type of channels

iii) Connection to the Onboard Network and Communication function when such function is implemented

iv) Time stamping and time synchronization for the received data from various sources through the interface

v) Monitoring and alarming for signal and data stream interruption and loss

vi) Safeguard for potential error propagation to the interfaced onboard systems

4.3 Data Network and Communication

The network is to provide data transfer among data handling functions.

The following capabilities are to be presented and supported by the installed hardware and software:

i) Prewired or wireless onboard data network to access specific data interface locations, such as navigation bridge, engine control room, and cargo control room

ii) Two-way communication channels between the vessel and onshore facilities when applicable

iii) Managed data communication through recognized data communication protocols *iv)* Centralized communication volume and network load monitoring

v) Established cybersecurity and data integrity control for the communication

4.4 Data Management

The data management is to manage the collected data by providing data governance, data storage, and data synchronization.

The following capabilities are to be presented and supported by the installed hardware, software and proper documentation:

i) Expandable and scalable data storage capacity

ii) Data backup and data recovery capacity

iii) Data storage capacity and usage monitoring and alarming

iv) Connected to the Data Network and Communication function when such function is implemented

v) Standardized and documented data definition for the Purposely Installed Sensor Interface and Interface to Onboard System when applicable

vi) Time synchronization among all connected data sources

vii) Established cybersecurity and data integrity controls for data governance, storage, and backup

5 Configurability and Flexibility

Configurability and flexibility are to be considered and documented for the data infrastructure and kept on board the vessel.

6 Function Assessment

ABS is to verify and validate that:

i) The Smart Function description and system design satisfy the functional requirements listed in Subsection 3/4 for the corresponding data handing function.

ii) The system design and its hardware and software specifications are adequate to accomplish the defined functionalities.

iii) Representative demonstration and/or functional test of the data handling functions are to be conducted and witnessed to the satisfaction of the attending Surveyor.

7 System Assessment

ABS is to verify and validate that:

i) The hardware and software specifications meet the applicable technical requirements defined in Section 6 to the applicable risk level.

ii) The hardware and software are installed and commissioned according to the installation and commissioning plan to the satisfaction of attending Surveyors.

In lieu of *i*, the hardware and software specification review may be accompanied by a PDA. In this case, the PDA is to be reviewed by ABS to identify potential gaps between the provided capabilities and applicable technical requirements of Section 6.

8 Smart Function Integration

When Smart Functions are integrated with an ABS Classed vessel having the **SMART (INF)** notation, ABS can waive the corresponding submittal, review and survey requirements relevant to the approved data handling functions and their hardware and software; depending on the following conditions.

i) The approved risk level for the data handling function hardware and software is to be equal or higher than the risk level of the integrated Smart Function.

ii) The capabilities and scope of the data handling functions are to be reviewed against the integrated Smart Function's data handling needs. Any gaps identified between the provided INF capability and those required to meet the integrated Smart Function's functional needs are to be addressed prior to implementation.

iii) The approved data handling function hardware and software specifications are to be reviewed against the integrated Smart Function's specification needs. Any gaps identified between the provided INF capability and those required to meet the integrated Smart Function's specification needs are to be addressed prior to implementation.

iv) The hardware and software of the data infrastructure are to be properly configured to satisfy the integrated Smart Function's specification.

SECTION 4
Structural Health Monitoring

1 General *(1 July 2020)*

The objective of Structural Health Monitoring (SHM) for marine vessels and offshore units is to provide the vessel owner with structural health awareness, assess and predict structural damage and provide decision-making support on safer and more optimal vessel operation, inspection and repairs, and asset integrity management.

When damage, failure, or deterioration is detected by the implemented SHM Smart Function, refer to 1/12.

1.1 SHM Features

SHM discussed in this Guide, as a Smart Function, has the following features:

i) Using vessel-specific data for environmental and operational loads, operations, and up-to-date structural conditions;

ii) Integrating with data analytics, structural analysis and simulations to derive structural health state and to predict potential structural damages.

1.2 SHM Implementation

The SHM Smart Function discussed in this Guide is typically implemented with the following considerations:

i) The SHM function is implemented in various scope and capability tiers, in terms of covered structures, structural/failure modes, assessment/prediction accuracy, and the function's reliability levels;

ii) The SHM function and its tier are determined by balancing the potential benefits and return with technical complexity, required resource and effort, initial and operational/maintenance cost;

iii) The SHM function typically relies on human-in-the-loop SF services (e.g., data analytics, engineering analysis and simulation, assessment interpretation, etc.) to achieve a holistic coverage and reliable results;

1.3 Traditional Hull Condition Monitoring

Hull Condition Monitoring (HCM) is to monitor, visualize, and trend parameters relevant to environment, structural loads and responses through sensor-based measurements. HCM typically involves onboard and/or onshore reporting and threshold-based alarms for operational guidance and post-voyage analysis.

The difference between SHM, as a Smart Function, and the traditional HCM is primarily:

i) SHM provides structural health diagnostics and prognostics through correlation of various parameters and integration with analysis and simulation;

ii) HCM handles parameter-based monitoring and covers the loads, responses, and identifiable damages from direct sensor measurements at certain sensor installed locations;

When SHM is incorporated on a vessel having HCM, the HCM function may feed SHM with sensor-based data. In addition, the optional Class notation **HM1**, **HM2**, and **HM3** may be assigned when the requirements as described in the ABS *Guide for Hull Condition Monitoring Systems* are met.

2 SHM Tiers

SHM Tiers are defined based on the accuracy and reliability levels of the employed approach for structural health assessment and prediction as below:

- *Tier 1*: Vessel-specific load and operation monitoring based approach for structural health assessment.
- *Tier 2*: Tier 1 approach enhanced with continuous/periodic update on structural conditions (scantling, repairs and modifications) and data-driven and/or physics-based analysis and simulation for a holistic structural health assessment and prediction.
- *Tier 3*: Tier 2 approach calibrated and verified using high fidelity data, such as sensor-based measurements, for improved accuracy and reliability.
- *Tier 4*: Tier 3 approach integrated into a risk-based framework to support risk-based asset management decisions.

The functional requirements for the above SHM Tiers are listed in Subsection 4/5.

ABS may accept a variation from the above SHM Tier definition and their corresponding functional requirements on a case-by-case basis. Prior discussion with and approval from ABS are encouraged for an optional **SMART (SHM)** notation based on the Tier definition variation.

3 SMART (SHM) Notation

The **SMART (SHM)** optional class notation can be assigned to an ABS Classed vessel, on which the SF system is installed for performing SHM functions.

The SHM function capability is to be assessed following Subsection 4/6 and the SF system is to be assessed following Subsection 4/7.

The SHM Tier and scope are recorded in the vessel records.

The following notation example indicates a vessel with the SHM function capable of assessing structural health state using a Tier 3 approach:

- Notation: **SMART (SHM)**
- Vessel Records: **Global Hull (Tier 3), Local Structures (Tier 3)**

4 SHM Service Supplier Recognition *(1 June 2022)*

SS recognition for SHM can be issued to a service supplier who provides SHM SF services, in terms of conducting analysis and simulation, providing human-in-the-loop domain support, and assessing and predicting structural health state.

SS recognition for SHM can be issued to OEMs, independent third-party vendors, shipyards, and operators themselves who provide SHM SF services for various SHM Tiers.

The SS recognition is to follow the procedure and satisfy the requirements defined in Section 7.

The SHM scope and its corresponding SHM Tier are to be recorded in the certificate of recognition of the service supplier.

5 Functional Requirements *(1 June 2022)*

Capabilities necessary to obtain the optional **SMART (SHM)** notation and SS recognition for SHM SF services are listed in 4/5.1 to 4/5.4 and summarized in Section 4, Table 1.

Variations from the functional requirements defined in 4/5.1 to 4/5.4 may be accepted by ABS on a case-by-case basis. Discussion with ABS for possible acceptance of the capability variance is encouraged.

5.1 Tier 1

To conduct a vessel-specific load and operation based structural health estimation, the following data and analysis are to be employed:

i) Vessel-specific environmental and sea loads and loading history. The wave loads can be either obtained through direct onboard measurements or derived from hindcast data with the assistance of vessel routing or position history.

ii) Vessel-specific operational data such as history of cargo and other payload and loading pattern, vessel speed, heading, draft, and trim.

iii) Structural strength assessment and damage prediction using the vessel-specific load and operation data.

iv) Accumulated fatigue damage and damage rate estimation using the vessel-specific load and operation history.

5.2 Tier 2

To conduct a structural health monitoring and assessment, the vessel-specific load and operational data as required in Tier 1 is to be integrated with a comprehensive structural analysis method. The following data and analysis are to be employed:

i) The data collected in *i)* and *ii)* of Tier 1.

ii) Up-to-date structural condition data such as scantling and gauging, structural degradation, repair and modification.

iii) Finite Element (FE) based or other physics-based or data-driven analytics and simulations using the vessel-specific loads, operations, and up-to-date structural conditions.

iv) Strength assessment and damage prediction using the analysis and simulations in *iii)* covering deformation, yielding and buckling as a minimum.

v) Fatigue damage assessment and remaining useful life estimation using the analysis and simulation in *iii)*.

5.3 Tier 3

To conduct a structural health monitoring and assessment with enhanced accuracy and reliability, high-fidelity data, such as sensor-based measurements, are to be incorporated into the method. The following data and analysis are to be employed:

i) The data collected in *i)* and *ii)* of Tier 1.

ii) The data collected in *ii)* of Tier 2.

iii) Structural sensor package installed and commissioned on board the vessel. The sensor package is to be used for model and analysis calibration as well as direct monitoring of loads and structural responses.

iv) Finite Element (FE) based or other physics-based or data-driven analytics and simulations using the vessel-specific loads, operation, and structural conditions. The analysis and model prediction are to be calibrated and verified with high fidelity sensor data.

v) Strength assessment and damage prediction using the analysis and simulations in *iv)* for global and local structures covering deformation, yielding and buckling as a minimum.

vi) Fatigue damage assessment and remaining useful life estimation using the analysis and simulations in *iv)*.

vii) Onboard and/or onshore monitoring and alarming on extreme environmental, sea or operational events and overloading, as well as the potential structural damages triggered directly by the sensor data and the assessment and prediction outcomes of *v)*.

5.4 Tier 4

Integrating the SHM into a risk-based framework requires quantifying or qualifying uncertainties and risk factors relevant to data collection, data quality, analysis and simulation, construction, and operation. The following data and analysis are to be employed:

i) All data and analysis required in Tier 3.

ii) Structural health assessment and damage prediction with probability of failure.

iii) A risk-based framework with the dual consideration of potential consequence to structural integrity and probability of structural damage for asset management decision support.

TABLE 1
Structural Health Monitoring Tiers

SHM Tier	*SHM Tier Feature*	*Coverage*	*Employed Analytics*	*Notation*
1	Vessel-specific loads and operations	Global hull	Empirical analysis	**SMART (SHM)** Tier 1
2	Comprehensive structural health assessment	Global hull Local structures	FE-based (or equivalent) analysis	**SMART (SHM)** Tier 2
3	Comprehensive and calibrated structural health assessment Sensor package installed for direct monitoring and analysis calibration	Global hull Local structures Direct sensor-based monitoring on loads and responses for global and identified local structures.	FE-based (or equivalent), analysis Analysis and model calibration	**SMART (SHM)** Tier 3
4	Comprehensive, calibrated, and risk-based structural health assessment Sensor package installed for direct monitoring and analysis calibration Risk-based decision support	Global hull Local structures Direct sensor-based monitoring on loads and responses for global and identified local structures	FE-based (or equivalent), analysis Analysis and model calibration Uncertainty and risk assessment	**SMART (SHM)** Tier 4

6 Function Assessment

ABS is to verify and validate:

i) The SHM function and its function description are to meet the minimum functional requirements listed in Subsection 4/5 for the corresponding SHM Tier.

ii) The data flow from data source, data processing to analysis and recommendation/actions is to be covered by the function.

iii) The data collected from purposely installed sensors, onboard system interface and other data sources are adequate and suitable for the corresponding SHM Tier.

iv) The capability of the analytics employed are to be verified for the SHM function:

a) SHM capability and its coverage on structures, and mapping to failure modes are to be documented and submitted to ABS, including recommended actions (i.e., operational corrective action, inspection, and/or maintenance task initiation, etc.) based on the SHM assessment and prediction.

b) The analysis and model employed are to be verified:

- For physics-based models, the description of the model's capabilities and the applicable scope are to be reviewed by ABS.
- For historical data-driven models, the model's capabilities, description on the approaches employed, model development, deployment, and sustainment process are to be documented and verified and validated, including
  - Model development process, assumptions, and limitations
  - The model evaluation metrics, acceptance criteria, and testing procedure
  - The documented prediction capability upon deployment
  - Continuous improvement and sustainment plan for prediction capability
- Where a combination of physics-based and data-driven models are employed, the SHM function is to meet the requirements of both.

v) The SHM function's capability and the health assessment results are to be demonstrated to the satisfaction of the ABS Surveyor.

vi) When employing approach of SHM Tier 3, the calibration approach utilizing data from structural sensors is to be reviewed by ABS.

vii) When employing approaches of SHM Tier 4, the risk framework, approach, and risk assessment are to be reviewed by ABS.

7 System Assessment *(1 June 2022)*

ABS is to verify and validate:

i) The SF system hardware and software are to meet the applicable system requirements defined in Section 6.

ii) In lieu of *i)*, the hardware and software may be accompanied by a Product Design Assessment (PDA) issued by ABS. The PDA is subject to review by ABS for potential gaps between the provided capabilities in the PDA and the applicable technical requirements of Section 6.

iii) The hardware and software are to be verified during installation and commissioning to the satisfaction of the attending Surveyor following Section 8.

8 Service Assessment *(1 June 2022)*

ABS is to verify and validate:

i) The service suppliers have established procedures, adequate capacity, and qualified and competent staff to provide the services with compliance to recognized QC/QA standards as defined in Section 7.

ii) In lieu of *i)*, the service suppliers are to be SS recognized by ABS at the "Recognition" stage. The recognized scope is to be adequate for the corresponding SHM function.

iii) The services are to be audited by ABS at the facility and during deployment per the requirements in Section 7 to the satisfaction of the attending Surveyor.

9 Alternative Approach to Credit Survey Requirements *(1 June 2022)*

With SHM functions onboard an ABS Classed vessel and engagement of recognized SS for SHM, ABS hull survey can be more informed and targeted with proper survey preparation and review of the structural health reports, in advance of the onboard survey. The health reports are to be made available as part of survey preparation requirements.

Alternative survey requirements are based on implementation of SHM functions, continuous/periodical structural health assessment, and may be considered by ABS on a case by case basis. The management of findings associated with structural health condition and anomalies as supported by the SHM functions, may be accomplished via the use of appropriate condition management tools such as ABS Nautical Systems Hull Manager and Hull Manager 3D.

Periodical structural health assessment and reporting are to be conducted by a recognized SS for SHM functions.

SECTION 5

Machinery Health Monitoring

1 General *(1 July 2020)*

The objective of a Machinery Health Monitoring (MHM) Smart Function for marine vessels and offshore units is to provide the vessel owner with improved awareness of the health state and operational conditions of the onboard machinery and systems. MHM is used to support the vessel owner's decision making for safer and more reliable operation, maintenance planning, and integrity management. Depending on the capability of the MHM function, this decision-making support may range from basic trending and anomaly detection, to failure mode diagnostics, up to and including health prognostics.

When damage, failure, or deterioration is detected by the implemented MHM Smart Function to machinery, or equipment, refer to 1/12.

1.1 MHM Features

The MHM Smart Function discussed in this Guide has the following features:

i) The MHM function is specific to a particular machine type or system and may extend to supporting and ancillary systems depending on the level of data collection and MHM function capability.

ii) The MHM function employs operational data obtained from existing or purposely installed sensors on the machine or system. Health state can be monitored real-time or near real-time via data collection, data streaming, and assessment.

iii) Contextual data such as ambient environment and metocean conditions are often utilized by the MHM function to support the operational data analytics. Equipment utilization may be included in the operational data analytics.

iv) The operational data is analyzed by use of physics-based or historical data-driven algorithms and models that may be coupled with traditional condition monitoring techniques to better support the decision making process.

1.2 MHM Implementation

The MHM Smart Function discussed in this Guide is typically implemented with the following considerations:

i) The MHM function can be of various capability tiers.

ii) The health and condition awareness and decision support provided by MHM is reported either continuously or periodically to both the onboard crew and ashore personnel, depending on the type of decision support provided.

iii) The MHM hardware and software can be installed and commissioned during new construction or through retrofit of an existing vessel; either on top of a shared data infrastructure or by its standalone hardware and software modules.

1.3 Traditional Machinery Condition Monitoring Techniques

Condition monitoring (CM) involves the acquisition and processing of information and data that indicates the health state of a machine over time. When machine health state deteriorates, the condition parameters being monitored will exceed prescribed thresholds, envelope, or pattern and warrant further investigation through additional examination and diagnostics typically performed by a human. Often, actions by crew and maintenance staff are prescribed to restore the measurements to acceptable levels, typically specified by an OEM or recognized international standards. Traditional condition monitoring techniques for onboard machinery can be organized into the following categories:

- Temperature measurements
- Dynamic Measurement (Vibration, Ultrasonic)
- Oil analysis
- NDT and Corrosion Monitoring
- Electrical testing
- Observation and surveillance via Operational Variable Trending

The ABS *Guidance Notes on Equipment Condition Monitoring Techniques* provides information related to the above listed traditional condition monitoring techniques.

Condition monitoring may be used to provide a greater understanding of equipment condition, and a Condition Based Maintenance (CBM) scheme may be adopted for maintenance efficiency. The application of machinery condition monitoring techniques either visit-based or in real-time and continuous mode via permanently installed sensors, are outside the scope of this Guide. Approval by ABS of such techniques is covered under Appendix 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)*.

The use of CM and CM in conjunction with a CBM maintenance strategy is to follow Appendix 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7).*

ABS approval is required when a vessel operator wishes to change the survey cycle based on a CM approach.

MHM discussed in this Guide extends traditional CM techniques with added capability, accuracy and reliability. Traditional CM can be used in conjunction with MHM and may also serve as a data source for the data analytics employed by MHM; while MHM provides operational data correlation to CM readings and measurements.

The difference between MHM, as a Smart Function, and traditional CM lies mainly in MHM's use of Operational data trending and one or both of the following model based analytical methods:

i) Machine/system diagnostics/prognostics using physics-based models and techniques.

ii) The use of historical data-driven models and data analytics such as machine learning and similar techniques for equipment/system anomaly detection, diagnostics, or prognostics.

To be considered as MHM, the function is to have the features as described in ii., iii., and *iv.* of 5/1.1

The optional class notations **PMP (PM, CM)**, or **PMP (PM, CM, CBM)** may be assigned for the traditional CM techniques when the corresponding requirements as described in Appendix 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)* are met.

2 MHM Tiers

Smart Function MHM can 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.

The MHM Tiers defined in this Guide are based on the function's capability and are listed as follows:

- *Tier 1*: Anomaly detection for system or machine
- *Tier 2*: Diagnostic capability for system or machine
- *Tier 3*: Prognostic capability for system or machine

3 SMART (MHM) Notation

The optional **SMART (MHM)** Class Notation can be assigned to ABS Classed vessels, on board which the SF system is installed and implemented.

The MHM Function capability is to be assessed following Subsection 5/7 and the system hardware and software are to be assessed following Subsection 5/8.

For assignment of the **SMART (MHM)** notation, at least one machinery item for those systems listed in Section 1, Table 2 is to be covered by the Smart Function. Similar assignment of **SMART (MHM)** may apply to systems for other vessel types under Class scope, not explicitly referenced in Section 1, Table 2 upon consideration by ABS.

The MHM scope (covered system and equipment) and the corresponding MHM Tier are recorded in the vessel records.

The following notation example indicates a vessel with a prognostic Smart Function on one or more machinery items of the propulsion system:

- Notation: **SMART (MHM)**
- Vessel Records: **Propulsion System (Tier 3)**

4 MHM SS Recognition *(1 June 2022)*

MHM capability can be provided either through standalone SF system implementation or with an accompanying human-in-the-loop service to assist the process and confirm the decision-making support function. Service suppliers can play a crucial role in converting the collected data and data analytics outcomes into machinery health state, prediction and recommendations.

SS recognition for MHM can be issued to OEMs, independent 3rd party vendors, shipyards, and operators themselves who provide MHM relevant data handling and data analytics services for various MHM Tiers. See Section 7 of this Guide for the detailed procedure and requirements for SS recognition.

The MHM covered system, equipment and their corresponding Tiers are to be recorded in the certificate of recognition of the Service Suppliers.

5 MHM PDA Attachment *(1 June 2022)*

MHM capability may accompany an ABS type approved OEM equipment item, or a Shipyard designed and built OEM item, as an added feature. When such equipment items have hardware/software installed that enables MHM capability, the equipment is eligible to receive a MHM PDA attachment to the equipment item ABS PDA.

The PDA attachment recognizes the MHM capability Tier for the equipment item as well as the impact on the maintenance strategy by utilizing the MHM capability. When an equipment item with an MHM PDA attachment is installed and commissioned on board an ABS Classed vessel, the modified maintenance strategy and plan for the item is to be reviewed by ABS for the implementation of and use for Alternative Survey.

The PDA attachment is to satisfy the applicable technical requirements defined in Section 6 and the recognition procedure in Section 7.

6 Functional Requirements *(1 June 2022)*

To obtain the optional **SMART (MHM)** notation and MHM SS recognition, the following capabilities are required for the corresponding Tiers.

Variations from the functional requirements defined in 5/6.1 to 5/6.3 may be accepted by ABS on a case-by-case basis. Discussion with and recognition by ABS prior to implementation for the capability variation are encouraged.

The MHM capability can be categorized into three Tiers described in 5/6.1 through 5/6.3 and summarized in Section 5, Table 1. The MHM Tiers are not to be considered as a progression of capability.

6.1 Tier 1: Anomaly Detection

i) Sensing and monitoring operational parameters directly reflecting the monitored equipment or system and providing anomaly detection related to one or more standard operational modes on a system or machine.

ii) Anomaly detection may require further investigation to identify a health condition deterioration or failure mode initiation.

iii) Physics-based or historical data-driven algorithms are to be employed in conjunction with traditional CM to enhance the monitoring capability.

iv) Dashboard with visualization and trending of the monitored parameters and alarming for the anomalies and outliers. The thresholds are defined based on Original Equipment Manufacturer (OEM) recommendations, class rules, industry standards, and best practices.

v) Potential to also include monitoring of utilization (load and time/counter).

vi) Ability to provide data to support survey completion.

6.2 Tier 2: Diagnostic Health Monitoring

i) Sensing, monitoring, anomaly detection, and diagnostics related to one or more standard operational modes on a system or machine;

ii) Diagnostic capability for one or more identified failure modes for each machine that may lead to functional failure;

iii) Physics-based or historical data-driven models or algorithms employed

iv) Dashboard with visualization and trending of the monitored parameters, health condition and alarming for the anomalies and outliers and health condition degradation. Where identified, the diagnostic capability for the onset of a failure mode and the recommended corrective action may be suggested to the operator;

v) Failure mode identification and maintenance task initiation may also be coupled with the monitoring of utilization (load and time/counter);

vi) Ability to provide data to support survey completion.

6.3 Tier 3: Prognostic Health Monitoring

i) Sensing, monitoring, anomaly detection, diagnostics, and prognostics related to one or more standard operational modes on a system or machine;

ii) Diagnostic and prognostic capability for one of more identified failure modes for each machine that may lead to functional failure;

iii) Physics-based or historical data-driven models or algorithms employed

iv) Dashboard with visualization and trending of the monitored parameters, health condition and alarming for the anomalies and outliers, health condition degradtion, and potential failure. Where identified, the diagnostic and prognostic capability for the onset of a failure mode and time to failure and the recommended corrective action and time to completion may be suggested to the operator;

v) Failure mode identification and maintenance task initiation may also be coupled with the monitoring of utilization (load and time/counter);

vi) Ability to provide data to support survey completion.

TABLE 1
Machinery Health Monitoring Tiers

MHM Tier		*MHM Tier Feature*	*Coverage*	*Notation*
1	Anomaly Detection	Sensing, monitoring and anomaly detection related to one or more standard operational modes Ability to provide data to support survey completion	System or machine Anomaly detection, may require further investigation to identify a health condition deterioration or failure mode initiation	**SMART (MHM)** Tier 1
2	Diagnostics	Sensing, monitoring, anomaly detection and diagnostics related to one or more standard operational modes Machinery health assessment Ability to provide data to support survey completion	System or machine Diagnostic capability for one of more identified failure modes for each machine that may lead to functional failure	**SMART (MHM)** Tier 2
3	Prognostics	Sensing, monitoring, anomaly detection, diagnostics, and prognostics related to one or more standard operational modes Machinery health assessment and prediction Ability to provide data to support survey completion	System or machine Diagnostic and prognostics capability for one of more identified failure modes for each machine that may lead to functional failure	**SMART (MHM)** Tier 3

7 Function Assessment

ABS is to verify and validate:

i) The MHM function and its function description are to meet the functional requirements listed in Subsection 5/6 for the corresponding MHM Tier.

ii) The data flow from data source, data processing to analysis and recommendation/actions is to be covered by the function.

iii) The data collected from purposely installed sensors, onboard system interface and other data sources are adequate and suitable for the corresponding MHM Tier.

iv) The capability of the analytics employed are to be verified for the MHM function:

a) MHM capability and its mapping to failure modes are to be verified via FMEA, FMECA, or a similar approach and submitted to ABS, including:

- An FMEA or FMECA from a reliability-based maintenance (RBM) or reliability centered maintenance (RCM) study would fulfill this requirement, if the same has been performed for the MHM capability development.
- Actions based on MHM anomaly detection/diagnostics – covers both threshold of alarms and triggered action (i.e., operational corrective action, maintenance task initiation, etc.).

b) The analytics model employed is to be verified:

- For physics-based models, description on the model's capabilities and the applicable machine types are to be reviewed by ABS.
- For historical data driven models, the model's capabilities, description on the approaches employed, model development, deployment, and sustainment process are to be documented, verified and validated, including:
  - Model development process, assumptions, and limitations
  - The model evaluation metrics, acceptance criteria, and testing procedure
  - The documented prediction capability upon deployment
  - Continuous improvement and sustainment plan for prediction capability
- Where a combination of physics-based and data-driven models are employed, the MHM function is to meet the requirements of both.

v) The MHM function capability including the outcomes are to be demonstrated to the satisfaction of ABS Surveyor.

8 System Assessment

ABS is to verify and validate:

i) The SF system hardware and software are to meet the applicable system requirements defined in Section 6;

ii) In lieu of *i.*, the hardware and software may be accompanied by a Product Design Assessment (PDA) issued by ABS. The PDA is subject to review by ABS for potential gaps between the provided capabilities in the PDA and the applicable technical requirements of Section 6.

iii) The hardware and software are to be surveyed by ABS during installation and commissioning to the satisfaction of the attending Surveyors following Section 8.

9 Service Assessment *(1 June 2022)*

ABS is to verify and validate:

i) The service suppliers have established procedures, adequate capacity, qualified and competent staff for providing the services with compliance to recognized QC/QA standards as defined in Section 7;

ii) In lieu of i., the service suppliers are to be SS recognized by ABS at the "Recognition" stage. The risk level and the approved scope is adequate for the corresponding MHM function;

iii) The services are to be audited by ABS at facility and during deployment against the requirements in Section 7 to the satisfaction of the attending Surveyor.

10 Alternate Means to Credit Survey Requirements *(1 June 2022)*

When MHM functions are implemented, the survey will use health monitoring reports provided by the recognized Service Supplier (SS) and the onboard survey will become informed, targeted and less intrusive. This is possible with the development of alternate means to credit survey requirements. Each class item that is covered by the **SMART (MHM)** notation and which has been qualified for implementation of alternate means to credit survey requirements will be identified with an MHM indicator in the ABS Survey Manager.

Refer also to Sections 8 and 9 of this Guide and 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)*.

SECTION 6
System Assessment

1 General

The technical requirements on the SF system are defined in Subsection 6/2 for various Smart Function risk levels. A Smart Function system with a higher risk level is to satisfy all relevant requirements from the lower risk levels.

1.1 Shared Hardware and Software with Automation and Control Systems

The SF system may share hardware and software with the vessel's automation and control systems. This shared hardware and software (e.g., power supply) is subject to the relevant Class requirements from the *Marine Vessel Rules*, *MOU Rules*, or other relevant Class Rules and Guides.

For the shared hardware and software, the primary purpose and function (e.g., the operation control) is governed by applicable Class requirements, which are embedded in the relevant Class Rules and Guides.

1.2 Integration with Automation and Control Systems

The SF system may integrate or interact with the vessel's automation and control systems through data and control interface. The automation and control systems themselves and the integration and interface with the Smart Function system are subject to the relevant Class requirements.

The SF system boundary, in terms of the integration and interface point, data exchange method and protocol, and estimated data exchange volume, is to be defined by the system designer and reviewed by ABS.

2 Technical Requirements

The SF system and its hardware and software components are to meet the applicable technical requirements as listed in this Section for the assigned Smart Function risk level following the approach of Section 2 of this Guide.

2.1 Cables (Power and Data)

The requirements on cables (power and data) are applicable for all data handling functions.

2.1.1 All Risk Levels

i) Power and data cables are to comply with the cable requirements in 4-8-3/9 of the *Marine Vessel Rules*, as applicable.

ii) Power and data cables are to comply with the cable installation requirements in 4-8-4/21 of the *Marine Vessel Rules*, as applicable.

iii) Power cables are to comply with the cable sizing requirements in 4-8-2/7.7 of the *Marine Vessel Rules*.

iv) Data Cables are to comply with the physical layer of the selected communication protocol.

v) Data cables occupying the same cable tray, trunk or conduit with power cables are to be effectively shielded as per 4-9-10/3.7 of the *Marine Vessel Rules*.

2.2 Power Supplies

The requirements on power supplies are applicable for all data handling functions.

2.2.1 All Risk Levels

Power supplies are to comply with 4-8-3/1.9 of the *Marine Vessel Rules*.

2.2.2 Medium and High Risk Levels

A backup power supply is to be provided. The transfer between the main and the backup power supply is to be effected automatically and without any functional interruptions, upon failure of the main power supply. The backup power supply is to be sized so as to provide power to the Smart Function system for at least 24 hours after main power supply failure.

2.2.3 High Risk Level

Each power supply is to be monitored for voltage failure and protected for short circuit. Each failure is to be alarmed at the Human Machine Interface (HMI).

2.3 Cybersecurity

The requirements for cybersecurity apply to the applicable data handling functions.

2.3.1 All Risk Levels

i) The computer-based system and collected data are to have access control.

ii) The computer-based systems are to be protected against virus and malware attack.

iii) Proper cybersecurity control, such as network separation, is to be implemented to prevent unauthorized access to the vessel's monitoring, control, alarm system through the Smart Function system.

2.3.2 Medium and High Risk Levels

The operating system, anti-virus and anti-malware are to be updated and patched up-to-date.

2.3.3 High Risk Level

i) Data encryption is to be implemented for both onboard and onshore data communication.

ii) The cybersecurity of the Smart Function system is to be assessed following the ABS *CyberSafety® Guide* or equivalent method.

2.4 Electronic Hardware and Sensors

The requirements for electronic hardware and sensors apply to the corresponding data handling functions.

2.4.1 All Risk Levels

i) The specification of the hardware modules and sensors, such as range, accuracy, resolution, repeatability, and response time, are to be suitable for the intended measurements.

ii) The hardware modules and sensors are to be designed such that they will withstand the test conditions stipulated in 4-9-9/Table 1, Nos. 17 and 18 of the *Marine Vessel Rules*, as applicable.

iii) When the hardware modules and sensors are to be installed in a physical location where ambient conditions may affect the system dependability and performance, the module and sensor are to be properly protected, and the protection is to satisfy the requirements in 4-8-3/1.11 of the *Marine Vessel Rules*.

iv) When the hardware modules and sensors are to be installed in a physical location with accessibility limitations, provisions are to be provided for inspection, maintenance and calibration activities, as applicable. Provisions may include Sensors Health Monitoring applications.

v) When the hardware modules and sensors are to be installed in hazardous areas where flammable or explosive gases, vapors, or dust are normally or likely to be present, they are to comply with the in 4-8-3/13 of the *Marine Vessel Rules*.

vi) The hardware modules and sensors are to be calibrated, recalibrated, and maintained according to the manufacture's recommendation. Calibration and maintenance records are to be maintained on board the vessel.

2.4.2 Medium and High Risk Levels *(1 June 2022)*

In addition to those listed in 6/2.4.1, computer-based systems used in delivering SMART functions (risk level medium or high) are to comply with the requirements of Section 4-9-3 of the *Marine Vessel Rules*. See 4-9-3/Table 2 and 4-9-3/Table 3 of the *Marine Vessel Rules*. Additional requirements for risk level high smart functions are listed in 6/2.4.3.

2.4.3 High Risk Level

The expected availability of each module and sensor is to be specified in the Systems Specification document and the acceptable availability level is to be determined using a risk-based approach.

2.5 Software

Software requirements apply to the applicable data handling functions.

Basic Software is defined in 4-9-3/3.9 of the *Marine Vessel Rules*. Application Software is defined in 4-9-3/3.11 of the *Marine Vessel Rules*.

2.5.1 All Risk Levels

The basic software is to be designed so that upon restoration of power supply after power failure, it restarts automatically so that the attached hardware is available, without requiring intervention from the vessel's operating personnel.

2.5.2 Medium and High Risk Levels

i) The basic software is to have self-monitoring capabilities, and any incorrect operation or abnormal condition is to be indicated at the HMI.

ii) The software that performs the Smart Functions is to be tested according to recognized software testing standards such as hardware-in-the-loop.

iii) Software Management of Change is required to confirm system software is under governance and change control.

2.5.3 High Risk Level

i) All processors involved in the Smart Function system are to be operated satisfactorily at the ambient temperature, for increased performance, without forced ventilation. Where forced ventilation is necessary, an indicative warning of high temperature in the processing hardware is to be provided at the HMI.

ii) In order to prevent the loss or corruption of data due to power disruption, application software and associated memory data considered to be essential for the operation of the Smart Function system are to be stored in non-volatile memory.

iii) The software development is to follow the ABS *Guide for Integrated Software Quality Management (ISQM)* or equivalent method,

2.6 Interface to Onboard Systems

2.6.1 All Risk Levels

The onboard system interface is to be comply with the original vendors' instructions for the external interfaced component.

2.6.2 Medium and High Risk Levels

i) Onboard system interface is to be comply by verifying vendor's instructions for the external interfaced component during the Installation Survey.

ii) The onboard system interface is to be designed to Fail-Safe such that failure of any of the onboard system interface hardware and software modules and components are not to cause unsafe operation of the interfaced systems subject to class or statutory requirements.

iii) The onboard system interface is to be monitored for communication failures. Each failure is to be alarmed at the HMI.

2.7 Onboard Network and Communication

2.7.1 All Risk Levels *(1 October 2020)*

i) The communication protocols are to allow for response times less than the sample time of data being gathered from Sensors and Onboard System interfacing.

ii) The onshore communication is to provide mitigations for failures or underperformance of the onshore communication channels towards the Smart Function goals.

iii) The communication protocol(s) are to allow a time synchronization protocol or alternative time synchronization means to be implemented.

iv) Data cable connectors are to be applicable to the vibration levels of the intended installation location.

v) When utilizing wireless communications, the requirements in 4-9-3/13.3.3(c-f) of the *Marine Vessel Rules* are applicable.

vi) Integrity checks on the messages (e.g., error correcting codes, timeouts on communications, status bits associated with measured value) are to be implemented.

2.7.2 Medium and High Risk Levels *(1 October 2020)*

i) The communication network is to be monitored for communication failures. Each failure is to be alarmed at the HMI.

ii) Integrated (not interfaced) with communication networks subject to class or statutory requirements, a Worst Case Network load study is be provided.

iii) When utilizing wireless communications, the wireless equipment is to meet the environmental type testing requirements of 4-9-9/13.1 and 4-9-9/15.7 TABLE 1 of the *Marine Vessel Rules* based on the proposed location of installation. Refer also to 4-9-3/13.3.3(b) of the *Marine Vessel Rules*.

2.7.3 High Risk Level *(1 October 2020)*

i) The communication network is to provide redundant communication paths for resolving communication failures.

ii) The communication network SF System load to the shore side office, is not to adversely affect the vessel's primary communication function. A SF System onshore communications worst case load study is to be provided.

iii) When utilizing wireless communications, the Risk Assessment performed in accordance with Subsection 2/3 is to demonstrate that an interruption or failure in the wireless data communication will not lead to a hazardous situation. Refer also to 4-9-3/13.3.3(a) of the *Marine Vessel Rules*.

2.8 Purposely Installed Sensors Interface

2.8.1 All Risk Levels

i) When utilizing wireless sensors interface functions, the requirements in 4-9-3/13.3.3(a-f) of the *Marine Vessel Rules* are applicable.

ii) When the system is designed with analog inputs (i.e., thermo-couple, RTD (2-3-4 wires), 4 mA to 20 mA), the analog inputs are to provide for inverse polarity protection.

iii) When the system is designed with analog inputs (i.e., thermo-couple, RTD (2-3-4 wires), 4 mA to 20 mA), proper earth connections are to be provided.

iv) When the system is designed with analog inputs, analog signals out of range input is to be prevented.

v) When the system is designed with analog inputs, analog signals rate of change out of predefined limits is to be prevented.

vi) When the system is designed with digital inputs, inappropriate combinations of digital inputs are to be prevented.

vii) The analog to digital conversion is to maintain appropriate resolution for the maximum required signal frequency, to avoid both quantization errors and unnecessary oversampling. The Nyquist-Shannon sampling theorem is to be observed.

2.8.2 Medium and High Risk Levels

The I/O cards or modules diagnostic for internal faults or withdrawal are to be displayed in the HMI.

2.8.3 High Risk Level

A Sensors' Health Monitoring application is to be provided, providing recalibration, maintenance and/or close visual examination tasks to the crew.

2.9 Human Machine Interface

2.9.1 All Risk Levels

i) The HMI functions that require execution within a specified time delay are to be defined in the System Specification Document. This is to address the Performance property.

ii) The workstations, error correcting RAM operations are to be described in the System Specification Document.

2.9.2 Medium and High Risk Levels

i) The maximum time to display a variation is to be specified in the System Specifications Document, starting from the physical variation of the monitored signal.

ii) The maximum applicable call-up time is to be specified in the System Specifications Document. The call-up time of an HMI page is the time necessary to upload, open and fully populate a standard graphic page after the user request.

2.9.3 High Risk Level

The maximum applicable refresh time is to be specified in the System Specifications Document. The refresh time is an indication on how often the displayed page is updated (i.e., the frequency of acquisition of data displayed on the HMI pages).

2.10 Data Management

2.10.1 All Risk Levels

i) All data collected over the measurement period is to be stored with time stamps indicting the point in time the data is collected or generated.

ii) Data collected from various sources is to be time synchronized in the storage.

iii) The data storage device is to have the capacity to record all the collected and processed data from the connected sensors and data analytics outputs. The data storage capacity in terms of the record period without data overwritten is to be described in the System Specification Document.

iv) Any lost data identification strategy is to be described in the System Specification Document.

2.10.2 Medium and High Risk Levels

i) The data storage capacity on board the vessel is to support a minimum 30 days or the typical voyage duration, whichever is longer.

ii) Software is available for backup and recovery, and personnel are trained in executing backup procedures, including manual methods.

iii) Alarms for data interruption and other data collection exceptions are to be generated and visualized at the HMI.

iv) The data storage capacity is to be monitored and alarms are to be generated for potential data overwritten.

2.10.3 High Risk Level

i) The recorded data is to be backed up at an appropriate backup facility on board and/or onshore. The data backup facility is to be physically separated from the main data storage with separate power supply.

ii) The data in memory and the operational parameters are to be automatically backed up in a permanent storage in case of system and software corruption, power disruption and other incidents. The backup is to be supported by a backup power supply.

2.11 Data Processing

2.11.1 All Risk Levels

i) Data consistency mitigation (e.g., assurance that no "bad" data can be sent to analysis and the HMI in the event of failure of the primary central processing units (CPUs)) is to be described in the System Specification Document.

ii) When statistics are generated and used for data analytics and models, the statistical parameters and statistical period are to be adequate so that no main data features are lost.

iii) Data from various data sources are to be time synchronized.

iv) Sensor configuration and mapping is to be described in the System Specification Document (refer to A3/6)

2.11.2 Medium and High Risk Levels

i) Generic and sensor/equipment level of data quality assessment is to be conducted before the data is fed into data analytics (refer to A4/4 and A4/5).

ii) The data quality dimensions and acceptance criteria are to be submitted to ABS.

2.11.3 High Risk Level *(1 June 2022)*

i) Applicable level of data quality validation is to be conducted through witness and survey (refer to A4/6).

ii) The data quality dimensions and acceptance criteria are to be determined through a risk-based analysis. The data quality risks are to be migrated and controlled.

iii) Continuous data quality measurement and monitoring is to be implemented and any data quality issues are to be reported at the HMI (refer to A4/7).

iv) An operational data quality assurance and control plan is to be developed (refer to A4/8)

v) Data quality risk assessment is to be conducted (refer to A4/9).

vi) For the SS who conducts data handling functions, an organizational data quality maturity assessment is to be conducted (refer to A4/10).

2.12 Data Analytics

2.12.1 All Risk Levels

i) The data analytics approaches employed are to be mapped to the Smart Function outcomes, such as the covered equipment/system and the detected failure modes.

ii) The physics-based models employed, if applicable, are to be submitted to ABS with a brief summary on the approach and their beneath physics principles.

iii) The data-driven models employed, if applicable, are to be submitted to ABS with a brief summary on the models themselves, the characteristics of the training data sets, the test data sets, and the test results.

iv) The actions due to data analytics outcomes, such as the corresponding corrective action and maintenance task initiation, are to be defined for each outcome.

2.12.2 Medium and High Risk Levels

i) For the physics-models involving principles, approaches, and/or software that is not well-proven, evidence of the model's accuracy and reliability are to be proven to the satisfaction of ABS during engineering review process.

ii) The data-driven models employed, if applicable, are to be proven to the satisfaction of ABS during engineering review process.

iii) The data analytics model is to be version controlled and the procedure for the model upgrade and deployment are to be submitted to ABS.

2.12.3 High Risk Level

i) The acceptance criteria for data-driven models employed, if applicable, are to be developed through a risk-based approach with consideration of the potential impact to the function's mission.

ii) A risk assessment of the data-driven models, if applicable, is to be conducted considering the uncertainty of the training and testing data sets, data quality, model accuracy and reliability. Any emerging risks found during the risk assessment are to be addressed.

iii) The performance of the data analytics is to be monitored and a fail-safe error handling mechanism is to be implemented.

SECTION 7

Service Suppliers *(1 June 2022)*

1 General *(1 June 2022)*

Smart Functions delivered by way of SF systems and services installed and deployed on board ABS classed vessels may be supported by a range of organizations. These SF systems are often supported by onshore data centers capable of remote health monitoring to provide operators with equipment oversight for operations and maintenance planning purposes. This requires recognition of the Service Supplier for Smart Function services and an associated Product Design Assessment (PDA) for the hardware and software being utilized for the service delivery.

2 Service Supplier Eligibility *(1 June 2022)*

ABS SS recognition for Smart Function can be issued to the following organization types:

i) *Third Party Service Suppliers*. Independent organizations contracted by owners and operators to support the provision of SHM, MHM, AEM, OPM or CAA services, with or without the use of an onshore data center.

ii) *Original Equipment Manufacturers (OEMs)*. Perform technical support services for SHM, MHM, AEM, OPM or CAA services as part of an aftermarket service agreement with the owner or operator of the equipment, with or without the use of an onshore data center.

iii) *Owners and Operators*. Perform SHM, MHM, AEM, OPM or CAA services as part of their daily operations, with or without the use of an onshore data center.

iv) *Shipyards*. Perform SHM, MHM, AEM, OPM or CAA services for their delivered vessels or as retrofitted, as part of an aftermarket service agreement with the owner or operator of the vessel, with or without the use of an onshore data center.

3 Service Supplier Recognition *(1 June 2022)*

ABS has programs in place to recognize a variety of specialist organizations providing enhanced monitoring and/or various levels of Smart Functions. Smart Function SSs recognized by ABS are publicly listed on the ABS website. The SS recognized process encompasses a detailed service assessment on quality policies and procedures, a functional and system assessment of technical capability, including an initial audit of the facility, and a demonstration to verify the SS has the competency and the controls needed to perform the SF services for which recognition is sought from ABS.

The Service Supplier recognition Scope is to cover:

i) ABS recognition of Service Supplier (SS) of SHM, MHM, AEM, OPM or CAA services including data handling functions covering full or partial data flow described in this Guide. The approved service scope, features, and applicable risk level required for the data handling functions are to be met for the defined service.

ii) The Smart Function data handling and analytics tools employed by the SS to deliver SHM, MHM, AEM, OPM or CAA services are to receive a Product Design Assessment approval. The PDA approval is to cover both functional and any applicable system hardware and software, including algorithms and models that accompany the service delivery.

iii) SS recognition can be issued to the entity performing the service.

iv) The SS recognition is to denote the covered systems and equipment types covered and their corresponding capability Tier as defined in Sections 4 and 5 for SHM and MHM, respectively. Capability Tier is specific to the covered equipment type (e.g., MHM Tier 3 for an engine, MHM Tier 1 for a pump).

4 Service Supplier Recognition and SF Incorporation Stages *(1 June 2022)*

Service suppliers are to be recognized and the SF incorporated on board ABS classed vessels in four stages as illustrated in Section 7, Figure 1. This process is outlined in Sections 7 through 9 of this Guide.

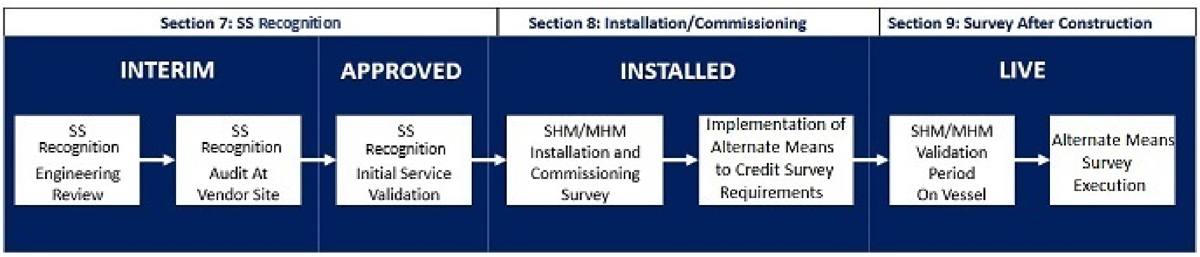
- *Interim*: The service and its associated tools have gone through the engineering review and initial audit or survey with satisfaction of the applicable requirements listed in this Section for the service and Sections 3 through 6 of this Guide for the function and system of the tools.
- *Approved*: The Interim approved service and its associated tools have been satisfactorily validated on a representative installation in actual practice at the SS audit location and/or on board a vessel to the satisfaction of ABS attending Surveyors, as required in Section 7 of this Guide.
- *Installed*: The Approved service and its associated tools have been deployed and installed on ABS Classed vessels and commissioned to monitor the actual equipment, system or vessel as applicable to the satisfaction of the attending Surveyors for the installation and commissioning survey, as required in Section 8 of this Guide.
- *Live*: The Installed service and its associated tools have been validated in actual practice on board ABS Classed vessels to the satisfaction of the attending Surveyors for the survey after construction requirements and are ready for Survey utilization of the Smart Function as listed in Section 9.

The Approved stage is to be achieved within one (1) year from date of completion of the Interim stage.

The Interim and Approved stages are relevant to SS recognition, with only the SS involvement. The last two stages involving the incorporation of the SF services to actual vessel equipment or structure. The Installed and Live stages are applicable to the involvement of the owner/operator and are necessary steps for implementation of alternate means to credit survey requirements.

Before moving to the Live stage and preferably, before the Installed stage is complete, the implementation of alternate means to credit survey requirements is to be agreed mutually by the owner and ABS.

FIGURE 1
Service Supplier Recognition and SF Incorporation Stages *(1 June 2022)*



5 PDA for Smart Function Tools Employed by Service Suppliers *(1 June 2022)*

ABS will issue a Product Design Assessment (PDA) to Smart Function tools being employed by the SS to deliver SHM, MHM, AEM, OPM or CAA services covering its data handling and data analytics.

The PDA is to cover both functional and applicable system review covering hardware and software utilized for the service delivery. The functional review for AEM, OPM and CAA excludes review of the stated quantitative performance benefits.

i) The PDA will be issued relevant to the capability to be utilized with individual systems and/or equipment types.

ii) The PDA is to cover requirements as applicable in Sections 4 through 6 for the risk level appropriate to the SS service and scope. The approved function, scope, and risk level are to be recorded on the PDA certificate.

6 PDA for Smart Function Tools Supplied with OEM Equipment

ABS will append the PDA referenced in Subsection 7/5 to the original OEM equipment item PDA as an attachment when the equipment has SF features, upon request of the manufacturer.

At the OEM's discretion, the PDA may also cover a health report template for the covered equipment covering both health status and alternate means of survey execution, jointly created by the owner and ABS.

7 Service Supplier Recognition Process *(1 June 2022)*

Completion of verification activity via engineering review and site audit, coupled with an initial validation of service delivery as defined in the Interim and Approved stages, enables the Smart Function tools and services as applicable to be qualified as a smart function capability on board ABS classed vessels.

Upon satisfactory completion of review based on 7/7.1, 7/7.2 and 7/7.3, the SS will receive PDA approval for their relevant hardware and software and SS recognition for their SHM, MHM, AEM, OPM or CAA services.

Implementation of alternate means to credit survey requirements is to include validation of SF incorporation and use on board by the Surveyor during installation and commissioning survey and survey after construction, defined as the Installed and Live stages. These aspects are covered in Sections 8 and 9.

7.1 Service Supplier Engineering Review *(1 June 2022)*

The documents for SS recognition and PDA per Section 1, Table 6 are to be submitted to ABS to perform PDA and SS recognition review.

The system verification of the hardware and software is to be conducted against the applicable requirements of Section 6 of this Guide.

The capacity and scope of the SHM and MHM functions are to be reviewed per Subsection 4/6 and Subsection 5/7, respectively.

7.2 Service Supplier Program Audit *(1 June 2022)*

SS audit approval will be accomplished by reference to the Design Review Letter issued by ABS with completion of 7/7.1. The following aspects of the service delivery are to be audited at the SS's facility where the service is conducted:

7.2.1 Organizational Capability *(1 June 2022)*

i) Organization Chart showing roles, duties and skills necessary to the service delivery.

ii) Quality Manual and procedures and processes governing the service provision.

iii) Certificates and 3rd party applicable quality system certifications under which the service delivery lies.

iv) For positions on the organization chart requiring equipment domain understanding, condition monitoring skill levels, and algorithm development and deployment skill levels, a matrix showing position qualification along with verification and maintenance of qualifications to recognized standards, when applicable. This includes knowledge relevant to data collection, interpretation of results, determination of acceptable ranges and alerting thresholds, procedure development, system or equipment specific threshold level and actions, and applicable corrective actions.

v) Training of personnel is documented in accordance with requirements set forth by recognized standards, whenever possible.

vi) Where recognized standards do not exist to confirm training and qualification of personnel, the SS is to define the standards for the training and qualification of its personnel relevant to the tasks or roles they are authorized to perform.

7.2.2 Tool Development and Deployment Process *(1 June 2022)*

i) Controllable process for the development, testing, and deployment of physics-based and data-driven models with any differentiation by equipment type:

ii) For data-driven models, plan indicating the learning period, training methods including the data set separateness for training, testing, and validation and acceptance criteria. The acceptance criteria shall include probability of detection, false alarm rate, alarm volume per asset-time and analytic run success rate.

iii) Process is in place for model re-validation based on substantial variation within equipment type (e.g., different manufacturer, different product line, different operating environment, etc.)

iv) Processes are in place for methodology and for understanding and consideration of design envelope as well as modes of operation for the covered item.

v) Process is established for on-going data assurance, model acceptance matrices, Management of Change (MoC) and re-deployment.

vi) Process for SS verification of sensor tag mapping and units of measurement alignment.

vii) Process and ownership of decision-making for anomaly alarming and disposition. Where applicable, ties to the organization chart showing roles and duties for the SHM, MHM, AEM, OPM or CAA service delivery mode. This is to cover how service is delivered including results directly used by onboard crew, human-in-the-loop review by personnel ashore, or the use of one or multiple data centers, with demonstration that qualified personnel are available as needed to support the service at the location where vessels or equipment are being monitored.

7.2.3 Data Center Support *(1 June 2022)*

The SS's remote monitoring and services are typically provided by way of an onshore data center. the onshore data center enables the service to be fully supported by an organizational structure and necessary domain expertise. The following is also to be verified during the data center audit:

i) Organization Chart is also to show roles, duties, and program coverage for the service delivery and proposed service delivery mode, with specific attention to processes requiring a human in the decision-making loop.

ii) Technical support in terms of qualified and competent staffing to support the service is to be reflected in the quality manual and verified by the attending Surveyor during the audit. The applicable requirements to deliver the service in this delivery mode are covered in 7/7.2.1 and 7/7.2.2 and are to be satisfied to the auditing Surveyor’s satisfaction.

7.3 Service Supplier Initial Service Validation *(1 June 2022)*

7.3.1 On-Site Validation

The following scope is to be conducted at the audit site to validate at least one representative case (SHM for hull and/or a selected system or equipment item for MHM covering an actual instance of deployment):

i) Demonstration of service delivery for a selected item through a minimum of one real case example to validate the service delivery capability.

ii) Ability for data to be transferred from vessel to onshore facility consistently and with data quality control.

iii) Demonstration of data quality control, "bad" data detection and model robustness in case of "bad" data.

iv) Demonstration of service delivery, covering anomaly/diagnostic/prognostic reporting and disposition.

7.3.2 Vessel-Based Validation:

The service delivery capability is to be validated on an actual vessel deployment on at least one representative case for a selected item (SHM for hull and/or a selected system or equipment item for MHM covering an actual instance of deployment).

8 Service Supplier Recognition Periodic Audits *(1 June 2022)*

8.1 Scope *(1 June 2022)*

For the SS and PDA to maintain their recognition/approval, periodic re-assessments by ABS will be required covering both audit scope and engineering review. ABS's scope during a SS periodic audit and PDA update will cover the following:

i) QA/QC system changes and updates, and new certifications attained.

ii) Changes to organization structures and program control.

iii) Smart Function performance monitoring and required data quality checks (as applicable to risk level).

iv) If applicable, engineering review covering any enhancements and change to scope of coverage (new equipment types or system) and any addition and change of capability for each covered equipment type or system (scaling and change of SHM and MHM Tiers).

v) Software version control in association with the above.

Upon completion of the periodic audit and review, ABS will issue a new SS recognition and PDA certificate to reflect changes to scope or capability Tier for the SS and its tools.

8.2 Validity *(1 June 2022)*

PDA certificates are valid for two (2) years. However, any changes to capability, system hardware and software require reissuance per scope as described in 7/8.1. The SS recognitions are valid for three (3) years subject to annual audit of the scope described in 7/8.1. The following are to be confirmed during the annual SS audit and PDA validation as applicable.

i) For SHM, MHM, AEM, OPM and CAA approval, no changes or additions to the list of equipment types or structural scope covered.

ii) No changes of SHM and MHM capability Tier for previously covered items in scope.

iii) For MHM Tiers 2 or 3, no changes in the range of coverage associated with failure mode detection and capability to impact associated maintenance task frequency.

SECTION 8

Surveys for Installation and Commissioning and Alternate Means Implementation *(1 October 2020)*

1 General *(1 October 2020)*

This Section outlines the Class survey requirements for the SF system installation and commissioning and implementation of alternate means to credit survey requirements for vessels with Smart Function SHM and MHM.

The survey requirements for SF system on board a vessel include system setup, calibration, installation, and commissioning as per the reviewed and approved documentation.

For the implementation of alternate means to credit survey requirements for machinery items, each machinery item is to be enrolled in a Preventative Maintenance Program (PMP) in accordance with the requirements of 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)*.

2 Installation and Commissioning Survey *(1 June 2022)*

The SF system installation and commissioning survey is to be carried out onboard the vessel to validate the setup, calibration, and commissioning of the installed SF system is in accordance with approved documentation.

The installation and commissioning survey requirements are applicable to both newbuild and existing vessels.

During the installation and commissioning survey, the Surveyor is to witness and verify the Smart Function(s) utilizing the approved Installation and Commissioning Plan.

Upon completion of the installation and commissioning activity, the vessel and its associated systems will be eligible for assignment of the applicable optional **SMART (SHM, MHM, INF)** notations.

When the equipment of a Service Supplier (SS) is installed on board the vessel, the SF incorporation stage of Installed as defined in Subsection 7/4 is achieved upon completion of the installation and commissioning activities covering the SS's equipment.

Class items covered by the Smart Functions may be eligible for implementation of alternate means to credit survey requirements, after satisfactory completion of installation and commissioning.

2.1 Documentation

The following documents are to be made available to the Surveyor, as applicable:

- The approved installation and deployment plans for setup, installation and testing of the SF system,
- The Smart Function Operations and Maintenance Manual.

- Installed hardware calibration and software configuration records as applicable.

2.2 Installation

The setup including the purposely installed sensors and measuring instruments, wiring, programmable logic controllers (PLCs), data processing units, and other system components is to be verified in accordance with the approved plans. The setup is to be carried out, in accordance with Section 4-8-4 of the *Marine Vessel Rules*, Section 4-3-3 of the *MOU Rules*, or other ABS Rules, as applicable, to the attending Surveyor's satisfaction.

2.3 Calibration *(1 June 2022)*

Purposely installed sensors, measuring instruments, and other relevant system components are to be calibrated by qualified personnel from the OEM or service supplier. Calibration records are to be maintained on the vessel with the Smart Function Operations and Maintenance Manual for future reference.

2.4 Commissioning

Each Smart Function is to be tested to the extent practicable in accordance with the approved test program. The test program is to include the following test details:

i) Integration is to be tested to verify that intended capability has been achieved.

ii) Automatic resumption of SF system is to be demonstrated following a blackout simulation.

iii) Verification for each Smart Function that the data acquired is being captured, recorded, and displayed, as applicable.

iv) Data acquisition check.

- *a)* Sensor measured data recorded in the system.
- *b)* Communications and synchronization between system, equipment, and SF system components with the dashboard onboard the vessel.
- *c)* Communications and synchronization between vessel dashboard and onshore data center, as applicable.

v) Data storage check

- *a)* The data stored on board the vessel.
- *b)* Data backup arrangements on board and/or at onshore data center.

vi) Data processing check

- *a)* The acquired data is processed, cleaned, aggregated, filtered and categorized or grouped.
- *b)* The processed data conforming to actual measurements made by the sensors for equipment.

vii) Reports and actions check

- *a)* The health status reported as required by the Smart Function Operations Manual.
- *b)* The established process on board and/or at onshore data center to monitor anomalies detected, triggers for actions, and follow through the corrective actions.

viii) Security checks

- *a)* Security system and collected data has access control
- *b)* The computer system has anti-virus and malware software installed.

3 Alternate Means Implementation Survey and Assignment of Smart Function Indicators *(1 June 2022)*

Class items (structures, systems and equipment) having health monitoring covered by SHM and MHM functions may be eligible for implementation of alternate means to credit survey requirements. The implementation Survey is to be carried out after the satisfactory completion of the SF system installation and commissioning survey.

The class items that have been deemed by ABS as eligible for implementation of alternate means to credit survey requirements, will be designated in the ABS Survey Manager with status indicators when the Live stage as described in Subsection 7/4 is achieved. ABS may consider the Live stage as achieved depending on the Smart Function capability and model types employed immediately upon completion of the installation and commissioning activity up to and including the first annual confirmatory survey.

Alternate means to credit survey requirements may be implemented for the class items with health monitoring detailed in Subsection 9/3. Such class items are to be provided with a health report based on health monitoring conducted using SHM and/or MHM functions. The content of the health reports is to be mutually agreed between the Owner/Operator, Service Supplier and ABS. The alternate means are to be based on the health information provided in the reports.

The Alternate Means Implementation Survey is normally conducted while the Owner is in possession of the vessel, as the Owner must have an agreement with a Smart Function SS and the personnel onboard are to be familiar with the Smart Function(s).

For existing vessels, the Alternate Means Implementation Survey may be included in the SF system installation and commissioning survey.

3.1 General *(1 October 2020)*

The requirements for alternate means implementation are as follows:

i) Onboard personnel are to be familiar with the SHM or MHM function and personnel on board are to have access to the SHM and MHM health monitoring status at any time.

ii) The role of the crew, the onshore data center, and procedures for actions to be taken as a result of SHM or MHM alerts, are to be established.

iii) Demonstrate ability to produce and send health reports.

3.2 SHM Function Implementation *(1 June 2022)*

The alternate means implementation of class items covered by **SMART (SHM)** notation is to better understand the vessel's exposure to the environment and utilize the information to conduct a vessel-specific survey.

i) Alternate Means implementation for SHM will utilize the SHM health report information for an informed and targeted survey.

ii) The enhanced monitoring and use of operational data may be coupled with existing ABS Survey Planning Document (SPD) and/or vessel specific inspection plans to provide for a more vessel-specific and targeted survey.

iii) Alternative survey requirements including health reports content and format are to be discussed in a joint effort with the Service Supplier (SS), the Owner and ABS during alternate means implementation.

3.3 MHM Function Implementation *(1 June 2022)*

The alternate means implementation of class items covered by **SMART (MHM)** notation will provide the alternative means of crediting survey requirements based on the health monitoring information to conduct a more informed survey.

i) The MHM function for a class item enables the operator to monitor health in a condition-based approach. The vessel is to be on a Special Continuous Machinery Survey (CMS) cycle and each item is to be enrolled in a Preventative Maintenance Program in accordance with the requirements of 7-A1-14 of the ABS*Rules for Survey After Construction (Part 7).*

ii) Class items covered by the MHM function will have health reports developed in a joint effort between the Service Supplier (SS), the owner/operator and ABS during alternate means implementation.

iii) The health report defined in Subsection 8/4 may be pre-approved as a result of an OEM PDA Attachment as defined in Subsection 7/6.

3.4 Cancellation of Alternate Means *(1 June 2022)*

The implementation of alternate means to credit survey requirements may be cancelled by ABS with the vessel reverting to traditional survey approaches if the alternate means implementation is not being satisfactorily carried out based on physical evidence on board or health report indications. The SHM or MHM functions shall remain operational so as to meet their stated goals. When the health monitoring of the class items with SHM or MHM functions are deemed to be non-functional or disabled for a period that calls into question their ability to assess health and adequately produce the required health reports, the alternative means of crediting survey requirements may be suspended at the Surveyor's discretion. In all such cases, the traditional survey requirements for the class item as outlined in the ABS *Rules for Survey After Construction (Part 7)* or other applicable Rules will be applied.

Sale, change of vessel management, change of Service Supplier (SS), or transfer of class may be cause for reconsideration of the alternate means implementation. If deemed necessary, the current alternate means implementation will be cancelled, and a new implementation may need to be submitted for approval.

The Owner may at any time cancel the alternative survey arrangement for class items with SHM or MHM functions by informing ABS in writing. For this case, items which have been surveyed under alternate means implementation since the last Annual Survey may be credited for class at the discretion of the Surveyor.

4 Health Monitoring Information Sharing and Reports *(1 June 2022)*

For vessels that have implemented alternate means to credit survey requirements, an information sharing agreement is to be established between the owner/operator, service supplier and ABS for exchange of health monitoring information and report for each covered class item (structures or machinery). The reporting frequency is to be established upon Owner/ABS agreement but is not to be less than once per year.

For structures, the structural health report content, format, links to ABS SPDs, RBI plans or similar ABS programs are to comply with 8/4.1.

For machinery items, the frequency and content of the health report may vary upon method of information sharing, alternative survey requirements and Owner/ABS agreement. The health report template, contents and format will be based on 8/4.1 or 8/4.2.

4.1 Structural Health Report

The information sharing agreement is to specify provisions related to data fields, data access, and data streaming that go beyond the minimum requirements specified below. The agreement will depend on the following factors:

- SHM Tier conducted
- Reporting and streaming capabilities to demonstrate the health of structures
- SHM events where ABS is to be notified

The health report content is to include the following information at a minimum:

i) A summary report for health state trending over time coupled with any alerted health anomalies that may have occurred. The health state may be presented in a traffic light format recorded by the system for ease of interpretation by the Surveyor.

ii) This tracking of heath state may include strength threshold limit monitoring and/or fatigue exposure and damage accumulation. When the SHM function provides a complete assessment of the strength and fatigue damage accumulation for the overall hull structure, it may be tagged within and specified in the structural health report and SPD, RBI plan, or similar structural inspection program-developed locations where possible range exceedance occurred.

iii) When the system is capable of trending both strength and fatigue damage accumulation, the trend information based on actual load (site-specific or voyage history) is to show whether trending damage accumulation is on par with, greater than, or less than the design predictions. If the rate of damage accumulation is approaching design limits, the system is to report to the SPD, RBI plan, or similar structural inspection program the locations for examination on the hull structure where leading indicators of fatigue damage may be located.

4.2 Machinery Health Report

The information sharing agreement between the Owner and ABS will depend on the MHM functions.

The health report content is to include the following as a minimum:

i) A summary report listing all machinery covered under MHM, clearly stating the overall condition of the machinery (i.e., Satisfactory, Marginal, or Unacceptable).

ii) Trend reports that evidence the health state of the machines (see Note 1). The results are to be simplified as indicated (e.g., good, degrading, unacceptable, or failure occurred) on the approved periodic basis.

- MHM trending results: description of anomalies, diagnostics, or prognostics observed and corrective action taken. See Notes 2 and 3 below for clarification.
- Planned maintenance tasks performed as a result of trending and any routine planned maintenance tasks performed.
- MHM capabilities and reporting specific to each machine confirming functionality of machine and alarm/trip functionality.

iii) Changes to the list of machinery covered under MHM with any additions or deletions from the previous report and any replacements performed.

iv) Description of maintenance completed on each machine since the last submitted report with reference to related tracking numbers for details.

v) Modifications (with justifications) to planned maintenance schedules or intervals (e.g., recommended by an OEM technical bulletin).

vi) Next scheduled overhaul of equipment, if known.

vii) Data trends, statistics, or evidence of testing and/or shutdowns that support alternative methods for survey, if applicable.

Notes:

1 Overlaying trends with bands for normal operation and thresholds for triggers of alarms, maintenance, shut-down, or other actions is recommended to illustrate parameter anomalies or lack thereof.

2 In the context of this Section, examples of machinery anomalies include machinery/component failure, unplanned maintenance, corrective action triggered by condition monitoring, sensor failure (e.g., loss of signal, signal drift, or other malfunction), or suspected failure.

3 Corrective action may include a change in monitoring, performing a maintenance task (or consideration of maintenance task), or an operational/behavioral adjustment.

SECTION 9
Surveys After Construction for Smart Functions *(1 October 2020)*

1 General *(1 October 2020)*

This Section provides the survey requirements for the SF system as per the assigned notations as well as on alternate means to credit survey requirements for the class items covered by SHM and MHM. Alternative methods for survey are based on health monitoring information shared with ABS, such as health reports and possible remote access to the health and maintenance status of the machinery systems and structural items.

2 Survey Requirements for SF Systems *(1 June 2022)*

2.1 Annual Surveys for SF Systems *(1 June 2022)*

See 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)*.

3 Alternate Means to Credit Survey Requirements *(1 October 2020)*

Health monitoring reports for class items covered by Smart Functions will provide evidence from the Owner to ABS of the health and condition of the machinery and/or structural items. The information is to be sent in accordance with the method of sharing agreed between Owner and ABS for alternate means to credit survey requirements implementation.

Structural items covered by SHM and machinery items (systems and/or equipment) covered by MHM will be identified in the ABS Survey Manager.

The alternative survey approach will be as per the approved survey and data sharing agreement developed during the alternate means implementation, for all class items with Smart Function.

3.1 Smart Function Indicator *(1 June 2022)*

The machinery items designated with the **MHM** indicator as detailed in Subsection 8/3, will be placed on a Special Continuous Survey of Machinery (CMS) cycle.

The hull items designated with the **SHM** indicator as detailed in Subsection 8/3, will be placed on a Special Continuous Survey of Hull (CHS) cycle.

3.2 Alternative Means to Credit Survey after Construction Requirements *(1 June 2022)*

Machinery items designated with Smart Function indicators are eligible for alternate methods of survey crediting based on the alternate survey requirements referenced in Section 7-A1-14 of the ABS *Rules for Survey After Construction (Part 7)*.

For each class item with Smart Function indicator, ABS will have reviewed and accepted a specific set of alternative survey requirements organized in a Survey Plan by Annual and/or five (5) year Special Surveys, as applicable. The alternative survey requirements along with health reports from the recognized service supplier(s) will enable crediting of the class items. The Smart Function capabilities, data utilized and health report formats for each machinery and structural item will be documented in the Smart Functions Operations Manual.

The health reports, maintenance records and evidence applicable to survey scope are to be available to the Surveyor prior to attending the vessel and will be used to qualify machinery items for alternate survey crediting approaches. The health reports will be as per the health monitoring information and report sharing details noted in Subsection 8/4. The health report may also provide data that evidences equipment is running properly, shows that equipment starts on demand, and show that equipment shuts down upon unfavorable conditions, when prompted remotely, or tripped locally.

APPENDIX 1
Definitions (1 June 2022)

Data Handling Function: A hardware and software system that is capable for handling data through the data flow, including data acquisition, data movement, data management, data processing and analytics, and data visualization and reporting.

Data Quality Dimension (DQ Dimension): Aggregated DQ Metrics that reflects a certain attribute on the quality of data.

Data Quality Metrics (DQ Metrics): Rules used to measure certain aspects of the quality of data.

Function Assessment: A verification and validation procedure to confirm the capability and scope of the Smart Function are suitable to satisfy the implementation goals.

Functional Requirement: A set of Smart Function tasks necessary to accomplish the specified goals

Product Design Assessment (PDA): A verification procedure to verify product compliance with manufacture's specifications, applicable ABS Rules and national or international standards.The PDA lists the Smart Function capability, covered scope and applicable risk level.

Product Design Assessment Attachment (PDA Attachment): An attachment to ABS approved OEM system/ equipment PDA for the Smart Function features of the system/equipment. The PDA attachment lists the Smart Function capability, covered scope, applicable risk level, and potential alternate survey approach by utilizing the Smart Function.

Service Assessment: A verification and validation procedure to confirm the SF service is supported by QA/QC procedures and practices, personnel qualifications and competencies to confirm that the service can be delivered consistently and reliably for its intended purpose.

Service Supplier (SS): An organization that provides SF services.

Service Supplier Recognition (SS Recognition): A verification and validation procedure to confirm the Service Supplier has adequate capability, qualified staff, and controlled procedure and quality to provide SF services.

Smart Function (SF): Systems installed and service deployed to continuously collect, transmit, manage, analyze, and report data for enhanced health and condition awareness, operational assistance, operational optimization, and decision-making support.

Smart Function Category (SF Category): The types of Smart Functions in terms of the functional capacity and their covered assets and operation aspects. In this Guide, SF category includes Structural Health Monitoring, Machinery Health Monitoring, Asset Efficiency Monitoring, Operational Performance Management, and Crew Assistance and Augmentation.

Smart Function Service (SF Service): The human-in-the-loop service that facilitates the decision-making aspect for the SF system including actions related to anomaly detection, structural and machinery health diagnostics and/or prognostics.

Smart Function System (SF System): A combination of hardware and software, including data source, data analytics algorithms and models that realize the identified Smart Functions and satisfy the functional requirements.

System Assessment: A verification and validation procedure to confirm the SF system hardware and software and its interaction and integration with onboard system(s) is to satisfy the system technical requirements of the appropriate risk level.

APPENDIX **2**

Acronyms and Abbreviations *(1 June 2022)*

AEM: Asset Efficiency Management

AI: Artificial Intelligence

CAA: Crew Assistance and Augmentation

CBM: Condition Based Maintenance

CM: Condition Monitoring

CMMS: Computerized Maintenance Management System

CMS: Continuous Machinery Survey

CPU: Central Processing Unit

CV: Cross Validation

DQ: Data Quality

DQA: Data Quality Assessment

DQI: Data Quality Index

DQMA: Data Quality Maturity Assessment

FE: Finite Element

FMEA: Failure Modes and Effects Analysis

FMECA: Failure Mode Effects and Criticality Analysis

HCM: Hull Condition Monitoring

HMI: Human Machine Interface

I/O: Input/Output

ISQM: Integrated Software Quality Management

MHM: Machinery Health Monitoring

MoC: Management of Change

OEM: Original Equipment Manufacturer

OPM: Operational Performance Management

PDA: Product Design Assessment

PLC: Programmable Logic Controllers

PM: Planned Maintenance

PMP: Preventative Maintenance Program

QA: Quality Assurance

QC: Quality Control

RAM: Random Access Memory

RBI: Risk Based Inspection

RBM: Reliability Based Maintenance

RCM: Reliability Centered Maintenance

RTD: Resistance Temperature Differential

SC: System Category

SDA: Sophistication Level of Data Analytics

SF: Smart Function

SFD: Smart Function Decision-making

SFI: Smart Function Integration

SFN: Smart Function Network

SHM: Structural Health Monitoring

SME: Subject Matter Experts

SS: Service Supplier

SPD: Survey Planning Document

SSH: Special Periodic Survey of Hull

APPENDIX 3
Submittal Requirements

1 Concept of Operations

A Concept of Operations (ConOps) is a document describing the characteristics of the Smart Function(s) from the viewpoint of an individual who will use these function(s). This document is to include, as the minimum, the following descriptions and statements:

i) Description of goals to be achieved by the Smart Function implementation;

ii) Functional requirements and identification of SF categories for each of the stated goals;

iii) The overall decision-making process and the role of the Smart Function in the decision making;

iv) SF system and services that accomplish the functions and their mapping to the functions;

v) The interaction and communication between the SF system and services;

vi) Operational envelope, operational scenarios, and any exclusions thereof.

2 Smart Function Risk Level

The assigned risk level for the employed Smart Functions according to Subsection 2/2 with the considered risk factors, risk matrices, and risk score of the factors.

3 Smart Function Description

i) The capability of the Smart Function:

- *a)* Smart Function's capability and its coverage on structures/system/equipment and the corresponding failure modes
- *b)* Recommended actions based on Smart Function output. This covers both threshold of alarms and triggered actions (i.e., operational corrective action, inspection, and/or maintenance task initiation)
- *c)* The analytics algorithm and models employed:
  - For physics-based models, the model's capabilities, description and the applicable scope
  - For historical data-driven models, the model's capabilities, description on the approaches employed, model development, deployment, and sustainment process, including:
    - – Model development process, assumptions, and limitations;
    - – The model evaluation metrics, acceptance criteria, and testing procedure;
    - – The documented prediction capability upon deployment

– Continuous improvement and sustainment plan for prediction capability.

ii) When a risk-based framework is implemented

a) A description on the risk-based framework and risk assessment approach employed

b) A list of the uncertainties and their impact (criticality) to the assessment accuracy and reliability

4 Stakeholder Role Matrix for Implementation *(1 June 2022)*

i) The list of stakeholders and their roles

ii) The list of equipment and systems provided by the OEMs and vendors

iii) ABS confirmation of PDA or Design Review Letter (DRL) as applicable

iv) The list of services provided by the SF service suppliers

v) The SS recognition certifications, as applicable

5 SF System Architecture

i) System functionality statement

ii) System topology in a block diagram

iii) System boundary and integration/interface points with onboard automation, control, and other systems subject to class or statutory requirement, if applicable

iv) The list of hardware and software subsystem/components that form the SF system

v) The list of retrofitted/installed hardware and software and their interface with the SF system

vi) The integration and interface approach with onboard automation, control, and other systems, if applicable

vii) The data flow and onboard communication approach and protocol

6 SF System Specification

i) SF system inputs and outputs, including the description on visualization and reporting

ii) Sensor I/O list, I/O type (analogue/digital/serial), I/O mapping and metadata definitions

iii) For retrofitted/installed hardware and software (i.e., cables, power supplies, cybersecurity, electronic hardware and sensor, software, onboard system interface, onboard and onshore communication, sensors interface, human machine interface, data management, data processing, data analytics): the specification and data sheet provide the information required in Section 6 Technical Requirements

7 For Medium and High Risk Levels

i) Load estimation introduced by the SF system on the onboard computing capacity and communication network

ii) Network load analysis for all anticipated conditions for a sufficient time period capturing best case and worst-case network loads

iii) Data quality assessment, control, and monitoring plan, including but not limited to data quality dimension and metrics, and acceptance criteria

iv) Data analytics method employed, acceptance criteria, and testing plan, if applicable

v) Cybersecurity approach employed

vi) Software quality standards followed for software development *vii)* Software testing plan and results

viii) Backup plan for vessel-shore communication interruption and failure

ix) Data backup system and procedure

x) Data and condition anomaly handling procedure

8 For High Risk Level

i) Risk assessment report including the scope and objectives, assumptions, methodology or models, risk evaluation criteria or risk matrix, risk evaluation results, identified risk control measures and recommendations, and risk assessment worksheet (refer to the ABS *Risk Evaluation Guide* and ABS *FMEA Guidance Notes* for details)

ii) Risk assessment validation program and test procedures as described in Section 2

iii) Management of Change (MoC) program as described in Section 2

iv) Additional documents determined by ABS

9 Installation and Commissioning Plan

i) For retrofitted/installed hardware: installation plan and procedure including installation locations, method, and protection

ii) For deployed software: the installation/deployment method and provisions for update and revision

iii) Hardware and software installed/deployed in Hazardous Areas (as defined in Section 4-3-6 of the *MOU Rules*)

iv) The plans for setup, installation, and testing of the SF system

v) Retrofitted/installed hardware and software: maintenance, calibration, and recalibration plan

vi) SF system Operations Manual and Maintenance Manual, including the following

  a) Means to alerts/alarms for system faults

  b) Ease to access and maintain

  c) Methodology for component repair and replacement (with consideration of installed environment)

10 Organizational Capability

i) Organization Chart showing roles, duties, to deliver the skills necessary to support the program

ii) Quality Manual and procedures and processes governing the service provision

iii) Certificates and third-party applicable quality system certifications under which the program lies

iv) For positions on the organization chart requiring equipment domain understanding, condition monitoring skill levels, and algorithm development and deployment skill levels, a matrix showing position qualification along with verification and maintenance of qualifications to recognized standards, when applicable. This includes knowledge relevant to data collection, interpretation of results, determination of acceptable ranges and alerting thresholds, procedure development, system or equipment specific threshold level and actions, and applicable corrective actions.

v) Training records of personnel in accordance with requirements set forth by recognized standards, whenever possible

vi) Where standards do not exist to confirm training and qualification of personnel, the party-defined standards

11 Tool Development and Deployment Process *(1 June 2022)*

i) The process for the development, testing, and deployment of physics based and data-driven models with any differentiation by equipment type

ii) Plan indicating the learning period, training methods, and acceptance criteria for data driven models including probability of detection, false alarm rate, alarm volume per asset-time, analytic run success rate, verification of process of separateness between Train/Test/Validate samples, and model training process such as Leave One Out (LOO)/Cross Validation (CV)/etc.

iii) Process for model re-validation based on substantial variation within equipment type (e.g., different manufacturer, different product line, different operating environment, etc.)

iv) Process for methodology/process for design space coverage

v) Process for on-going data assurance, model acceptance matrices, Management of Change (MoC) and re-deployment

vi) Process for SS verification of sensor tag mapping and units of measurement alignment

vii) Process and ownership of decision-making for anomaly alarming and disposition. Where applicable, ties to the organization chart showing roles and duties for the service delivery mode. This is to cover how service is delivered including results directly used by crew on board alone, human in loop review by support personnel ashore, results requiring or via use of one or multiple data centers, etc.) with demonstration that qualified personnel are available as needed to support the service at each location based on vessels or equipment being monitored.

12 Data Center Support

i) Organization Chart showing roles, duties, and program coverage for the service delivery and proposed service delivery mode, with specific attention to processes requiring a human in the decision-making loop.

ii) Technical support in terms of staffing to support the service is to be reflected in the quality manual.

APPENDIX 4

Data Quality Assessment, Monitoring and Control

1 Introduction

The Data Quality Assessment (DQA) is a process to assess the Data Quality (DQ) against the pre-defined DQ rules (metrics) and dimensions (aggregated from various metrics). The DQ metrics and dimensions are typically established through an impact analysis of each DQ dimension and metrics on the Smart Function.

The DQ assessment and control method presented in this appendix is not mandatory and is to provide a reference to assist the audience in establishing their DQA.

2 Data Quality Assessment Tiers

Three tiers of DQA, which aligns with the three DQ categories as specified in ISO 8000-8, the international standard for data quality (Part 8, published in 2015, "Information and data quality: Concepts and measuring"). A4/2 TABLE 1 provides a summary of the DQA Tiers:

TABLE 1
Data Quality Assessment Tiers

Tier		*ISO 8000-8*	
		DQA Category	*Focus Area*
1	Generic	Syntactic	Structure of the data
2	Sensor/Equipment	Semantic	Meaning of the data
3	Application	Pragmatic	Usage of the data

2.1 Generic Level

DQA Tier 1 (Generic Level) is to verify the degree to which the data conforms to its specific syntax (i.e., requirements stated by the metadata). The assessment goal is consistency where data values for particular data elements use a consistent symbolic representation (database hierarchy, data field type, data format, value domain, precision, etc.).

A Generic level quality check can be applied to any time-series and transactional data without requiring domain knowledge (e.g., sensor specification).

2.2 Sensor/Equipment Level

DQA Tier 2 (Sensor/Equipment Level) is to verify the degree to which the data corresponds to what it represents (e.g., how accurately the measurement reflects the sensed physical values).

Sensor/Equipment level quality check typically requires domain knowledge on sensor, equipment, system working principles, measured physics and environment, and operation conditions.

2.3 Application Level

DQA Tier 3 (Application Level) is to validate the degree to which the data is found suitable and worthwhile for a particular purpose. The assessment goals are usability and usefulness. Usability is the degree to which data consumers (users and/or functions) can effectively access and use the data. Usefulness is the degree to which the data supports the consumers in accomplishing their tasks.

In addition to the domain knowledge, an Application level check may also require IT and data analytics skills. This may include confirming the data is easy to access and interpreting the unclear physical relationship and/or over-complicated physical and operational conditions represented by the data analytics model.

3 Sensor Configuration and Mapping

Sensor configuration and mapping is a basic task associated with DQA Tier 1. The following documents can assist on the sensor configuration and mapping review.

i) *Sensor Configuration File*. The sensor configuration file is to contain the information on sensor type, measurement range (amplitude and sampling frequency), unit of the measure, installation location, operation mode, and alarm threshold.

ii) *Data Mapping Specification*. Data mapping specification defines the logic for data movement and transformation. The data mapping specification is to contain the following elements:

- *List of attributes for the original source of data*, such as attribute name (e.g., a unique identifier), attribute type (an allowable data type in a field, including text, numeric, date/time, enumerated list, look-ups, Booleans, and unique identifiers), optional/required (indicating whether information is required in an attribute before a record can be saved)
- *A corresponding (or "mapped") list of attributes for the data repository*, such as attribute name, attribute type, optional/required
- *Translation rules* defining any data manipulation during the data moves, such as to incorporate business or industry standards into the data set for data type transformation, apply consistent representation to data, and correct misspellings

4 Generic Level DQA

DQA Tier 1, Generic Level DQA is to be verified through review of the following information:

i) *Metadata*. Sensor Configuration File and Data Mapping Specification that provide the specification of how the data is presented by metadata (e.g., sensor properties and data structure).

ii) *A Complete Set of Syntactic Rules*. The syntactic rules are to be defined using "natural language". The following validation rules are typically considered (reference to A4/4 TABLE 2):

- Data type conformance
- Data format/pattern compliance
- Value domain conformance

iii) *A Corresponding Set of Syntactic DQ Dimensions*. A list of DQ dimensions is to be described corresponding to the defined syntactic rules (reference to A4/4 TABLE 2):

- Validity/Structural validity
- Structural consistency
- Precision

iv) For each syntactic rule (reference to A4/4 TABLE 2):

- *A description of the DQ issues* that will arise in the data set if the data does not comply to the defined syntactic rules
- *The definition of measurement methods* that indicates how compliance is to be measured
- *A description of what it means not to comply to a rule*, a sample of the non-compliance case is to be provided.
- *The value range of the DQ score* is to be defined (e.g., 0-100).
- *The definition of threshold values, weighting factors, and acceptance criteria* that are used for assessing data quality at both metrics and dimensions levels. These values are configurable on a case-by-case basis.

v) *The Results of DQ Scores*. The DQ scores at both metrics and dimension levels are to be provided. The number of checks performed for each rule, and the number of occurrences that comply with each rule are to be identified.

TABLE 2
Syntactic Data Quality Rules and Dimensions Sample

Metrics Level				*Dimension Level*
DQ Issue	***Problem Description***	***Syntactic Rule***	***Measurement***	***DQ Dimension Category***
Invalid Data Type	Invalid data type for the same data unit (e.g., a text string found in a list of floating numbers)	Data type for the same data unit must conformance to the metadata of its definition (e.g., text, number or date/time)	Percentage of invalid/ inconsistent data values	Structural Validity
Different Data Format/ Pattern	Different data format/ pattern for the same data unit (e.g., different format in Timestamp that makes data manipulation/ comparison difficult)	Data format/pattern for the same data unit must conformance to Metadata of its definition (e.g., DD.DD, DDDD-DD-DD DD:DD, where D represents a digit)		Structural Consistency
Values out of Range (unreasonable data values)	Data values are out of range for the domain under observation (e.g., value spikes or sudden changes which are implausible (e.g., -99999 or 99999) for the domain)	Data value for the same data unit must conform to Metadata of its definition (e.g., the assigned value is within a defined numeric, lexicographic, or time range)		Validity
Different Data Accuracy	Different level of data accuracy for the same data unit (i.e., significant digits: number of digits on the right of the decimal point)	The level of data accuracy for the same data unit must be same		Precision

Note: The list of syntactic quality rules specified above does not exclude use of additional or alternative sets of syntactic quality rules.

5 Sensor/Equipment Level DQA

DQA Tier 2, Sensor/Equipment Level DQA is to verify the unique and unambiguous correspondence of the data unit to the entity represented. The following information assists the review and conform its compliance:

i) *A Documented Domain/Conceptual Model*. A description of the basic domain knowledge that is related to the intended application of the subject dataset (e.g., SHM, MHM). The domain/conceptual model characterizes the underlying relationships between a set of influencing data units (input and output). The fundamental assumptions of the domain model are to also to be described.

ii) *A List of Selected Data Units*. This list presents all the subject data to be analyzed for a specific application as described in the domain/conceptual model.

iii) *A Set of Semantic Rules*. The semantic rules are to be defined using "natural language". The following validation rules are to be considered (refer to A4/5 TABLE 3):

- Completeness verification
- Uniqueness verification
- Accuracy verification
- consistency verification
- Integrity verification
- Plausibility verification
- Timeliness validation
- Usefulness validation

iv) *A corresponding set of semantic quality dimensions*. A list of quality dimensions is to be described corresponding to the defined semantic rules (refer to A4/5 TABLE 3):

- Completeness
- Uniqueness
- Accuracy
- Semantic consistency
- Integrity
- Plausibility
- Timeliness
- Currency

v) For each semantic rule (refer to A4/5 TABLE 3):

- *A description of the DQ issues* that will arise in the data set if the data does not comply to the defined semantic rules
- *The definition of measurement methods* that indicates how compliance is to be measured.
- *A description of what it means not to comply to a rule*, a sample of the non-compliance case is to be provided.
- *The value range of the DQ score* is to be defined (e.g., 0-100).

- *The definition of threshold values, weighting factors, and acceptance criteria* that are used for assessing data quality at both metrics and dimension levels. These values are to be configurable on a case-by-case basis.

TABLE 3
Semantic Data Quality Rules and Dimensions Sample

Metrics Level				*Dimension Level*
DQ Issue	***Problem Description***	***Semantic Rule***	***Measurement***	***DQ Dimension Category***
Missing Data Values	There are gaps in the time series data	The missing values under a specific condition are unacceptable	Percentage of errors in data/population sample	Completeness
Duplicated Data Records	The data units are recorded more than once within the dataset that is unacceptable to what it represents in the real world (e.g., duplicated timestamps)	The data units must have a unique representation in the real world		Uniqueness
Inaccurate Measurement	The value is wrong which might result in the detection of a wrong trend, etc.	The measured data value is to match the property value for the real-world object it represents		Accuracy
Diverging Sampling Rate	Different sampling rates in the same time series (same data source) can leads to problems (e.g., irregular timestamps)	The sampling rates in the same time series (same data source) are to be consistent		Semantic Consistency
Divergent Despite High Correlation	Values which are normally correlated behave unexpectedly	The intended data relationship linkage is to be retained within the dataset		Integrity
Forced/ Calculated Value	Compensated values are used instead of real measurements	Minimize the corrected (e.g., interpolation) data values which may reflect the assumptions made and no longer represent reality		Plausibility

Metrics Level				*Dimension Level*
DQ Issue	***Problem Description***	***Semantic Rule***	***Measurement***	***DQ Dimension Category***
Wrong Timestamps or Wrong Timestamp Order	Timestamps are mismatched to the actual time (e.g., there are gaps/ redundancies in timestamps); Timestamps are not in chronological order	The recorded time is to match to the standard time	Percentage of mismatched timestamps	Timeliness
Data not updated (stuck values)	Data is not up-to-date. Sensor might still display old values (e.g., defective sensors for which the data value is out of calibration)	Data is to be updated with time	Percentage of stuck values	Currency

Note: The list of semantic quality rules specified above does not exclude use of additional or alternative sets of semantic quality rules.

6 Application Level DQA

DQA Tier 3, Application Level DQA is to confirm the data accessibility and the use data fulfilling function's intention. The Application Level data quality assessment is to validate, through witness and test, if the function's outcomes meet the application's objectives and requirements.

i) *A Set of Pragmatic Rules*. The pragmatic rules are to be defined using "natural language" and are typical application-specific.

ii) *A Corresponding Set of Pragmatic Quality Dimensions*. The quality dimensions can be defined either quantitatively or qualitatively.

iii) *The definitions of methods* applied for collecting the data to be used for measuring the DQ dimensions (e.g., user surveys through questionnaires or interviews)

iv) *The definitions of threshold values and acceptance criteria* that used for assessing data quality for each validated DQ dimensions. These values are not fixed, can be configurable on a case-by-case basis.

v) *The Results of DQ Scores*. The pragmatic DQ scores at dimension level are to be provided.

7 Data Quality Monitoring

DQ monitoring in relation to the defined DQ rules can be conducted based on full-scan or sampling methods. DQ monitoring can be performed either continuously through automated process or periodically via manual process. The following information is to be documented:

i) *DQ scorecard*, which provides multiple levels of DQ scores/dashboard related to DQ metrics, dimensions and an consolidated score for overall data quality measurement. The DQ scores can be represented by a Data Quality Index (DQI) which are typically defined by percentage of "good" data (valid DQI) or percentage of exceptions (invalid DQI).

ii) *DQ trends*, which show over time how the quality of each data element (e.g., individual sensor) changes, and the DQ score's trends.

iii) *DQ performance*, which monitors how well and how fast the operational staff responds to DQ incidents for DQ issue root cause diagnosis and timely resolution. An operational procedure for managing DQ issues is to be developed and implemented.

8 Data Quality Assurance and Control Plan

Data quality assurance and control plan can be developed with the following information:

- Data elements covered by the DQ assurance process
- Business impacts associated with data flaws
- Data quality dimensions associated with the subject data elements
- The expectation for quality for the subject data elements, including DQ metrics and rules in relation to the identified dimensions
- The methods for measuring against those expectation
- The acceptability threshold for each measurement
- The individual(s) to be notified in case the acceptability threshold is not met. The timelines and deadlines for expected resolution or remediation of the issue
- The escalation strategy and possible rewards and penalties when the DQ issues are not addressed within the specified resolution times

9 Data Quality Risk Assessment

The criticality of data quality issues associated with their potential business impacts (operations, environment and safety) is to be evaluated and ranked by technical and business subject matter experts (SMEs). Risk analysis tools can be employed to evaluate and prioritize mitigation actions. If improvements are needed, a risk-based data quality improvement plan is to be developed. DQ improvement can take different forms:

i) *Simple Remediation*. Correcting the data issues on records (e.g., data cleansing/correction)

ii) *Remediation of Root Causes*. Remediation and improvement plans is to account for quick hits (e.g., the issue that can be addressed immediately at low cost) or Longer-term strategic changes (e.g., modification of the systems). The strategic changes focus on modifying the systems to address root causes of issues and to put in place mechanisms to prevent issues in the first place. Preventing issues generally costs less than correcting them.

iii) *Longer-term Strategic Changes*. The strategic focus of such plans is to be to address root causes of issues and to put in place mechanisms to prevent issues in the first place. Preventing issues generally costs less than correcting them.

10 Organizational Data Quality Maturity Assessment

An organization DQ Maturity Assessment (DQMA) is to be able to rank and address the organizational data quality issues in a structured and proactive manner. The DQMA can help organizations gauge the maturity level of their DQ methodology by analyzing the core building blocks for successful data improvement initiatives (e.g., people and resources, standards, process, methods and tools), so as to put in place a plan to improve the quality of data.

The following information can assist the assessment:

i) Applied assessment levels and characteristics.

ii) Applied assessment criteria.

iii) Assessment results – DQMA rating and ranks

iv) Applied Maturity Baseline

v) Recommendations

vi) Action plans

vii) Periodic re-evaluation

APPENDIX 5
References

ABS *Guide for Integrated Software Quality Management (ISQM)*.

ABS *CyberSafety® Series Guides and Guidance Notes: Volume 1 to Volume 5 (CyberSafety®)*

ABS *Rules for Building and Classing Marine Vessels*

ABS *Rules for Building and Classing Mobile Offshore Units*

ABS *Rules for Survey after Construction*

ABS *Guide for Hull Condition Monitoring Systems*

ABS *Guide for Surveys Based on Machinery Reliability and Maintenance Techniques*

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ABS *Guidance Notes on Structural Monitoring using Acoustic Emissions*

ABS *Guidance Notes on Self-Elevating Unit Motions Monitoring*

ABS *Guide for Ice Loads Monitoring Systems*

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ISO 8000-8, The International Standard for Data Quality (Part 8, "Information and data quality: Concepts and measuring")