Guidance Notes on

Smart Function Implementation

November 2018

GUIDANCE NOTES ON

SMART FUNCTION IMPLEMENTATION
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Foreword

Smart Functions, which provide crew and support personnel with key information to aid in decision-making, are becoming increasingly common on board marine and offshore vessels. 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 facilitates the use of aggregated data from sensors and other sources, data communications, data processing, data analytics, and data synthesis for reporting, decision making and actions.

These ABS *Guidance Notes on Smart Function Implementation* define the goals, functional requirements, and verification and validation principles for the implementation of Smart Functions on board marine and offshore vessels. The goals and subsequent functional requirements, together with the general implementation procedure, describe a framework for Smart Function implementation and are intended to provide clarity on the subject.

The aspects covered in this document include the definition of Smart Functions, their intended purpose and capabilities, a goal-based approach, and a set of risk-based verification and validation principles for implementing Smart Functions for condition, performance, and situational awareness and informed decision support, be it onboard or remote to the vessel itself.

These Guidance Notes become effective on the first day of the month of publication.

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GUIDANCE NOTES ON

SMART FUNCTION IMPLEMENTATION

CONTENTS

1 Objectives

Marine vessels and offshore units, equipped with digitally enabled functions that assist in providing various forms of decision-making support to an owner/operator, are becoming increasingly prevalent.

Classification societies acknowledge that data-driven monitoring techniques, data analytics applications, and streaming data for troubleshooting and operation assistance are changing vessel operations and management. By applying technical requirements established upon risk-based verification and validation principles, ABS can assist owners and operators to identify, assess and eventually incorporate data-enabled functions with onboard vessel equipment and systems and provide guidance on the use of supporting technologies with ABS class programs and services.

These Guidance Notes serve as a reference for marine and offshore vessel owners, operators, designers, shipyards, and equipment and system manufacturers, as well as Smart Function product and service providers, vendors, and equipment/system integrators.

The objectives of this document are:

i) Establish the concept of Smart Functions

- Define a range of Smart Functions for marine and offshore vessels
- Outline each Smart Function’s capability applicable to marine and offshore vessels

ii) Provide a goal-based approach for Smart Function implementation

- Set the goals for Smart Function implementation
- Define Smart Function scope associated with the goals
- Outline a goal-based procedure for a Smart Function implementation

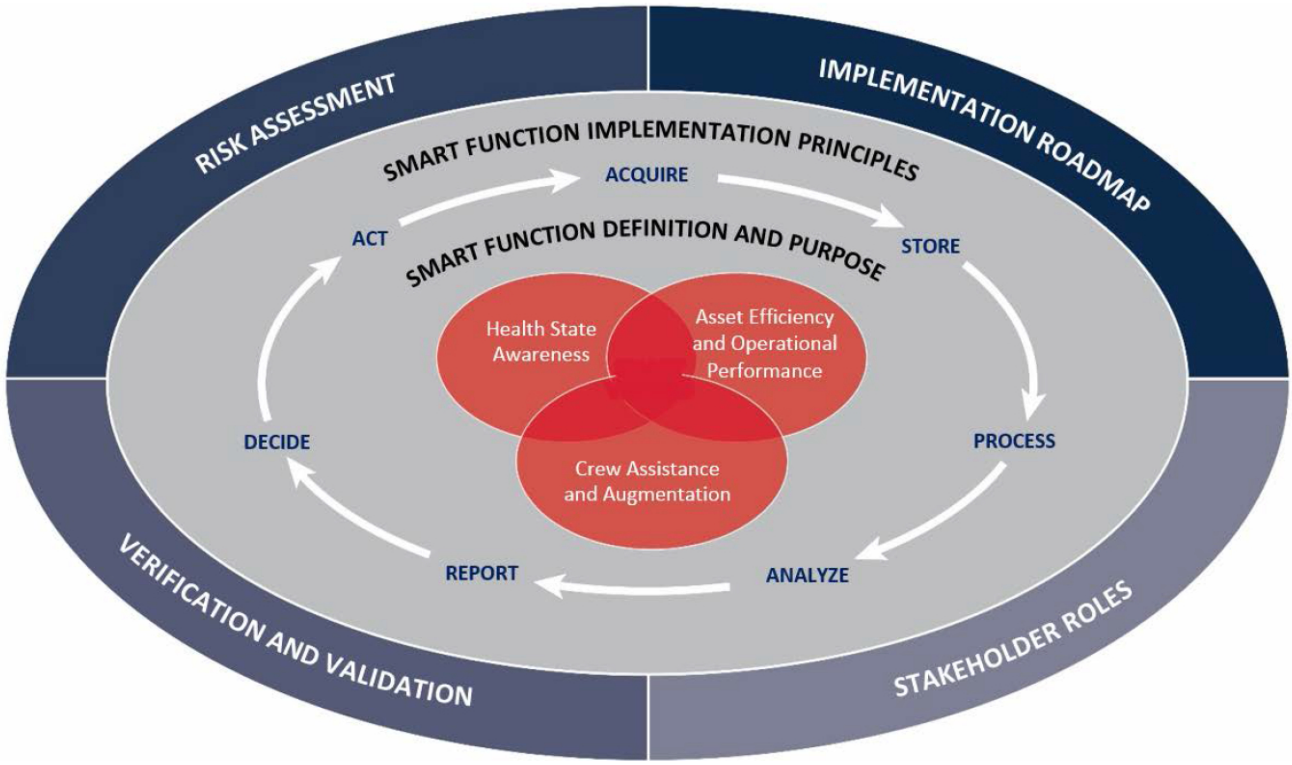
iii) Lay out a set of risk-based verification and validation principles for Smart Function implementation

2 Scope of Application

This document applies to the implementation of Smart Functions for ships and offshore units, herein referred to as marine and offshore vessels. The document is organized into four Sections. It covers the definition, goals and functional requirements, verification and validation principles, and a roadmap covering stakeholder roles for the implementation of Smart Function, as shown in Section 1, Figure 1.

These Guidance Notes cover Smart Functions that are permanently installed, or intended to be permanently installed on marine or offshore vessels, either during construction or via retrofit. Temporarily installed equipment and systems are outside of this document’s scope.

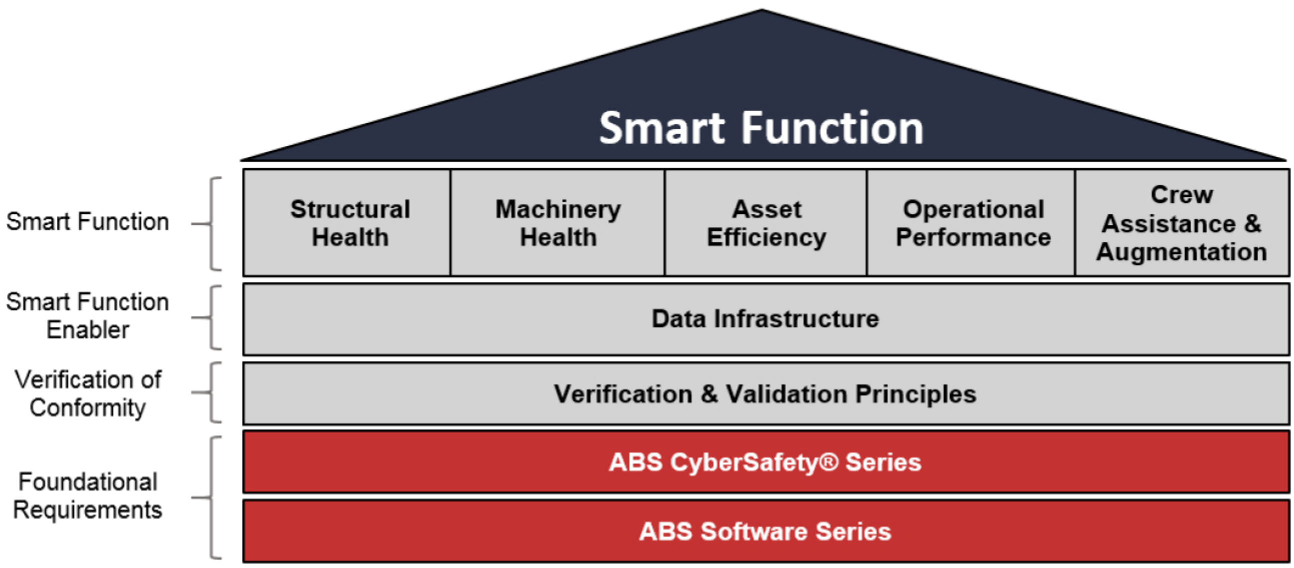
FIGURE 1
Smart Function Concept and Guidance Notes Outline



3 Smart Function Framework

The Smart Function framework is shown in Section 1, Figure 2. The functional requirements as well as the verification and validation processes performed by ABS are supported by foundational requirements covering the vessel data infrastructure that enables the Smart Functions, namely the hardware, software, data integrity, data analytics, and cyber security.

FIGURE 2
ABS Smart Function Framework



4 Definitions

4.1 Data Infrastructure

The data infrastructure enables data gathering, storage, management, and transmission from onboard and external data sources, both time-series and transactional in format, in a variety of real-time or periodic-to-continuous approaches.

The data infrastructure establishes the foundational elements for data applications and enables the Smart Functions implementation, and ensures reliable and efficient data flow, data sharing, data management, data quality, data integrity, and cyber safety.

4.2 Smart Function

The Smart Functions described in this document refer to equipment, systems, services, or a combination thereof installed or implemented to continuously collect, transmit, manage, analyze, and report data for enhanced awareness, operational assistance and decision making support.

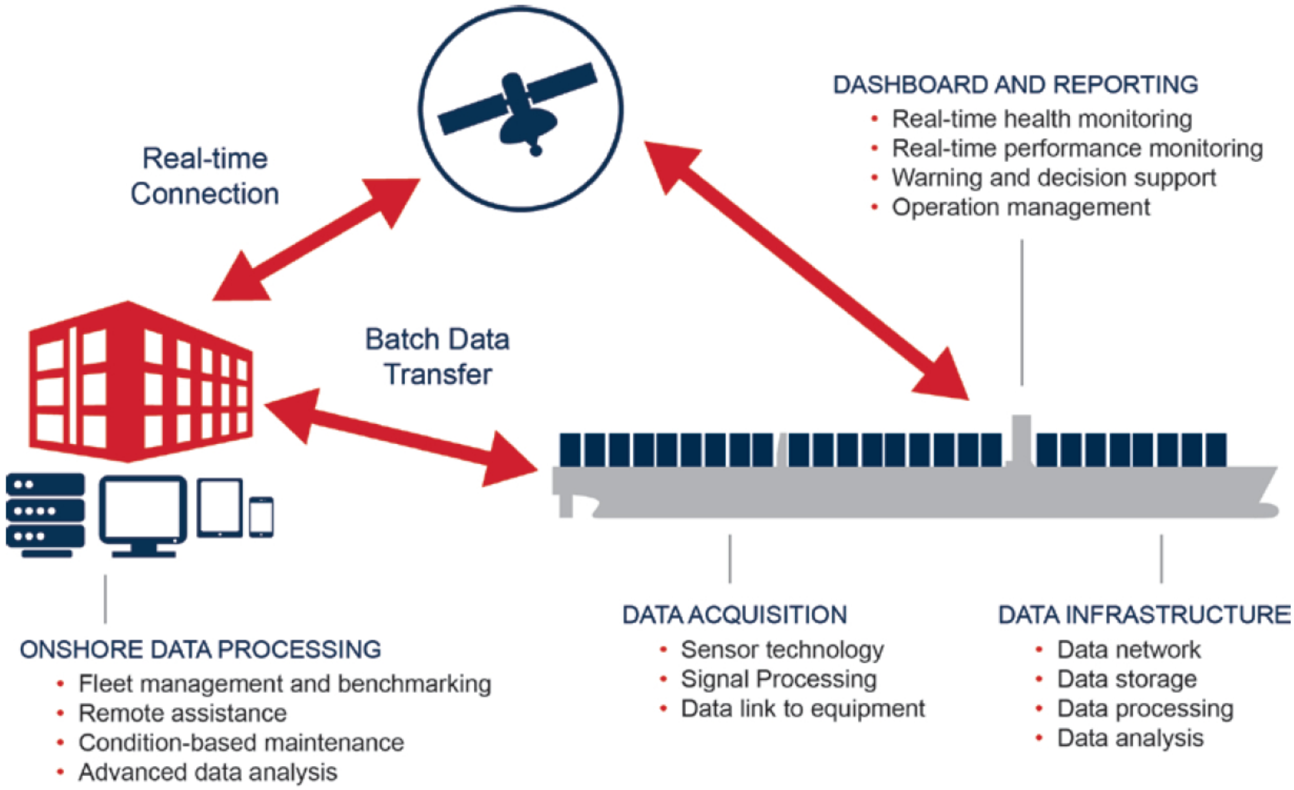
Smart Functions can be implemented for individual onboard equipment, across functional systems, or holistically across the entire vessel to provide enhanced insights on health state and/or performance and high frequency feedback to assist and augment crew.

Smart Functions can be implemented on top of the established and verified onboard data infrastructure as described in 1/4.1 or independently as standalone systems with their own hardware and software, isolated from other onboard systems.

A Smart Function commonly applies data analytics at various levels of sophistication and typically provides passive decision support for human-initiated operational decisions and actions. The passive role refers to the fact that Smart Functions typically do not initiate any action but merely provide information and/or recommendations for human decision-making.

A typical configuration for a vessel with Smart Functions includes onboard modules and onshore supporting facilities, which are interlinked for continuous or periodic data exchange capabilities, as shown in Section 1, Figure 3.

FIGURE 3
Typical Configuration for a Vessel with Smart Functions



Depending on the technologies employed, a Smart Function may be capable of detecting condition and operational anomalies (diagnosis) with consideration of system and operational correlation, predicting asset health and performance trends (prognosis), and providing prioritized recommendations for corrective and preventive actions (decision making support). Data analysis approaches may combine the use of data-driven models, physics-based models, and also the use of well-established condition monitoring (CM) and performance monitoring techniques. Smart Functions can be realized through onboard systems with or without onshore data and domain support. Smart Functions can be capable of the following:

- *Sensing and Monitoring*: Measuring and collecting data on parameters directly reflecting the monitored environment, structure, equipment, and systems, for understanding various aspects of vessel operations, health, and/or performance through integrated or retrofitted sensors. A real-time onboard/onshore dashboard typically visualizes the data and alarms any threshold-based outliers. It can also identify and display trends. The outlier thresholds are often established using Original Equipment Manufacturer (OEM) recommendations, operator knowledge, relevant class rules, industry standards, and industry best practice.

- *Diagnostic and Prognostic Health and Efficiency Monitoring*: Traditional condition monitoring approaches as outlined in the ABS *Guidance Notes on Equipment Condition Monitoring Techniques*, such as vibration and oil analysis, operational parameter monitoring, or other similar techniques, are combined with diagnostic and potentially prognostic models using physics-based and/or historical data driven approaches. These functions are typically capable of detecting health and/or performance anomalies in the form of impending failure or performance degradation at an early stage. This provides valuable information for corrective and preventative actions including operational adjustment(usage and behavioral) as well as adjustments to inspection and maintenance planning to avoid unexpected down time and/or productivity loss in operations.

- *Performance Optimization*: Data analysis converts collected datasets into actionable insights on machinery and vessel performance and provide prediction capability using one or more performance models along with the forecasted operational environment. The performance and recommended operational parameters are derived by examination of possible parameter combinations and operational scenarios for the optimization goals, such as minimized energy consumption.

- *Crew Assistance and Augmentation*: Electronic data logging, and centralized data management and processing enable automatic reporting for use in regulatory compliance reporting and meeting stakeholder's needs with the aim of reduced crew workloads and decreased human errors. Advanced sensor and data analytics-based approaches can also assist and augment crew in situational awareness for vessel operations and navigation, such as image recognition using sensor arrays and pattern mapping approaches that can identify obstacles for collision avoidance.

5 The IMO Goal Based Approach

According to the IMO *MSC.1/Circ.1394 "GENERIC GUIDELINES FOR DEVELOPING IMO GOAL-BASED STANDARDS"*, a goal-based standards framework consists of goal-based standards and the associated detailed requirements of rules and regulations for vessels (see Section 1, Figure 4).

Goal Based Standards (GBS) as defined by the IMO:

High-level standards and procedures that are to be met through regulations, rules and standards for ships. GBS are comprised of at least one goal, functional requirement(s) associated with that goal, and verification of conformity that rules/regulations meet the functional requirements including goals.

The IMO goal based definitions form the foundation for the ABS Smart Function implementation.

5.1 Goal Based Definitions

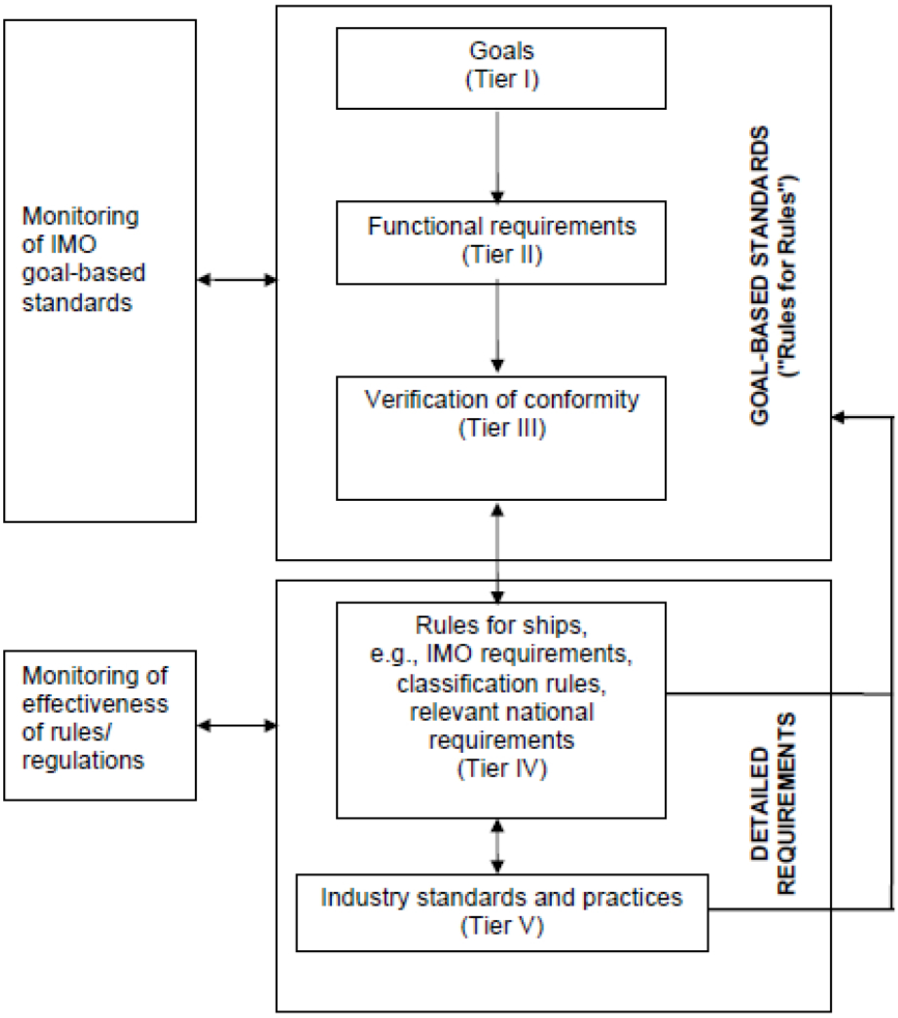
Goals: Goals are high-level objectives to be met. A goal should address the issue(s) of concern and reflect the required level of safety.

Functional Requirements: Functional requirements provide the criteria to be satisfied in order to meet the goals. Once a goal has been set, functional requirements are defined to cover all functions/areas necessary to meet the goal. The functional requirements are developed based on experience, an assessment of existing regulations, and/or systematic analysis of relevant hazards.

Verification of Conformity: Establishes the method and criteria to demonstrate and verify that the Smart Function specification and implementation conforms to the goals and functional requirements. A verification plan should be developed followed by subsequent initial and continued validation that the goals and functional requirements are met. The Smart Function's risk level, assigned due to its potential function failure or under-performance, forms the basis for setting the required criteria for the verification and validation process. A risk assessment of system activities will help map to requirements in existing standards and Rules or determine the need for additional requirements. Safety of the vessel and risk expand beyond just the crew or humans on board, but also to the maritime community that interacts with the vessels.

This document covers Tier I to Tier III as defined in the IMO Goal Based Standard Framework, as shown in Section 1, Figure 4, for Smart Function implementation.

FIGURE 4
IMO Goal Based Standard Framework



GOAL-BASED STANDARDS FRAMEWORK

SECTION 2

Goal Based Approach for Smart Function Implementation

1 The Vision for Smart Function Implementation

The ABS vision for Smart Function implementation is the enablement of improved decision making by all stakeholders, including both crew and shore-based personnel, to better manage vessel operations in the fulfillment of the vessel's mission.

The vision for Smart Function implementation should support the primary purpose of vessel operations, which ABS considers to be:

Design, Construct and Maintain vessel for planned mission with safety and reliability. Safe vessel operations include the security of life, property, and preserving the natural environment.

Smart Functions, when incorporated on marine and offshore vessels, may support the pursuit of best-in-class results and the standards and regulations for design, construction, maintenance and survey.

2 Smart Function Implementation Goals

Based on the vision statement in Section 2/1 and the premise that Smart Functions, when applied as intended, address and further enhance data-driven optimization of onboard systems and operations, the following goals have been defined for Smart Function implementation:

i) Increase health state awareness in order to enhance safety and asset integrity and to minimize downtime associated with failures and maintenance, via a comprehensive data-driven approach.

ii) Operate the vessel optimally to maximize 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:

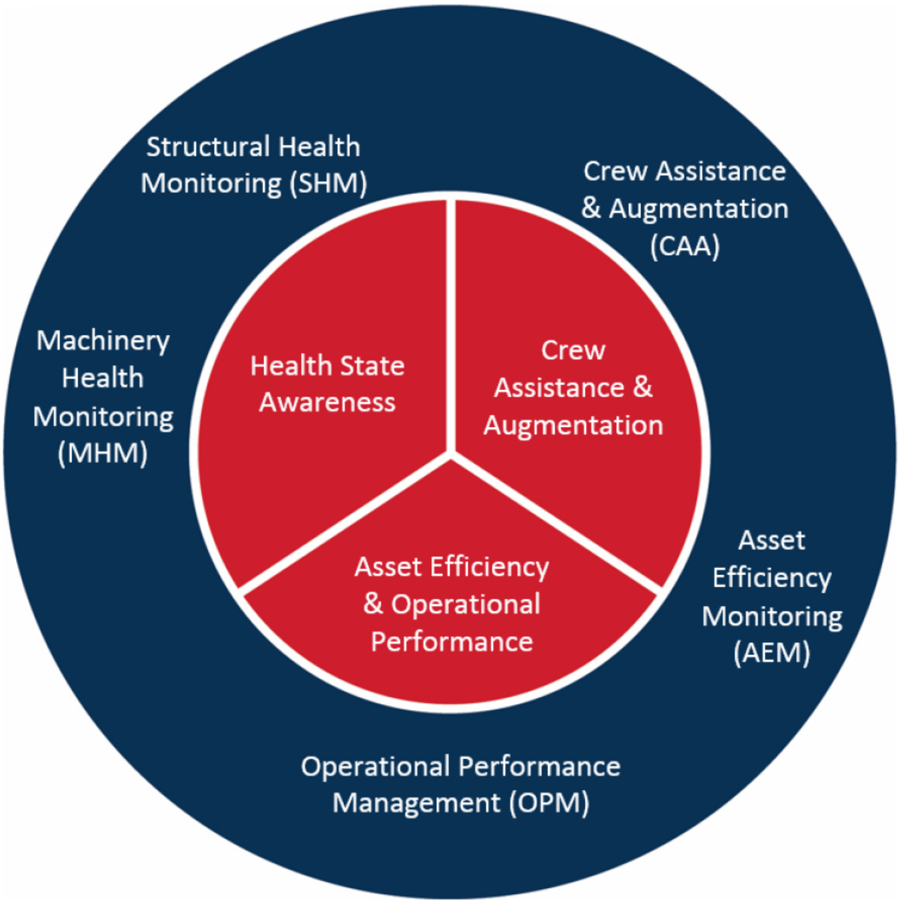
- Enhance vessel situational awareness and navigation safety
- Reduce crew workload burden and reporting errors
- Reduce potential for human error related incidents

Smart Functions should be implemented in a secure manner without decreasing the vessel's safety and operability. The implementation of Smart Functions in pursuit of the above goals should not adversely affect the vessel's primary functions and core system operations.

3 Functional Requirements for Smart Function Implementation

Section 2, Figure 1 shows the main and subordinate Smart Function categories and their association with the above defined goals, described in detail further below.

FIGURE 1
Smart Function Categories



3.1 Health State Awareness

The health state of structures and machinery is crucial in determining a marine and offshore vessel's safety, integrity, and operability. Health state awareness is improved via the following two Smart Function categories:

- *Structural Health Monitoring (SHM)*: Monitors structural loads, responses, and health conditions to assess the structural integrity, provide structural health awareness, and help minimize the potential of structural damage and failure.
- *Machinery Health Monitoring (MHM)*: Monitors the health state and operational conditions of onboard machinery and systems to detect operation and condition anomalies and predict the onset of any form of condition degradation and impending functional failure.

For detailed descriptions of SHM and MHM Smart Function categories including objectives, features, employed techniques and outcomes, refer to Appendix 2.

3.2 Asset Efficiency and Operational Performance

Two main factors contribute to the performance of an equipment, system, or vessel during its lifetime:

- The efficiency of equipment, systems, or vessels in performing its function based on inherent design and manufacture characteristics, and the current operational readiness status (presence of degradation and status with respect to prescribed maintenance).

- The operational efficiency of equipment, systems, or vessels to achieve optimum performance through adjustment of operational parameters within the design envelope, system and plant management (human-machine interaction, "behavioral" and operational planning aspects).

Accordingly, the following two Smart Function categories define these areas:

- *Asset Efficiency Monitoring (AEM)*: Assesses equipment, system, or vessel efficiency and provides maintenance and tune-up activity triggers to maintain or improve efficiency levels. Examples of asset efficiency include ship water resistance (determined by hull design and hull cleanliness) and engine efficiency. AEM is often offered in tandem with a health monitoring function, as it usually monitors efficiency.
- *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. Examples of OPM functions include voyage optimization, route planning and power plant balancing.

AEM focusses on the inherent design characteristics as well as assuring proper maintenance, whereas OPM targets the behavioral aspects and human-machine interaction.

For detailed descriptions of the AEM and OPM Smart Function categories including objectives, features, considerations and outcomes, refer to Appendix 2.

3.3 Crew Assistance and Augmentation

Vessel operations rely on crewmembers to satisfy and meet the demand for growing regulatory reporting requirements, and meet an industry demand for increased monitoring and transparency. Accordingly, the following Smart Function category aims to reduce onboard crew workload and potential human errors by use of data-driven applications that include auto-logging, reporting, and also enhanced situational awareness:

- *Crew Assistance and Augmentation (CAA)*: Assists crew reporting and other onboard activities through automatic data collection, electronic logging, data processing, fusion, and 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's ability, such as night vision, obstacle detection, collision avoidance, and assists the crew in vessel operations.

For detailed descriptions of the CAA Smart Function category including objectives, features, and outcomes, refer to Appendix 2.

3.4 Map of Smart Function Category with Vessel Systems

The following table aligns the applicability of Smart Function categories with common vessel functions, structures, and systems, as applicable for reference purpose.

TABLE 1
Map of Smart Function Categories to Vessel Functions, Structures and Systems

Vessel Function/Structure/Systems	*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	
Hull Strength & Fatigue	X				
Local Structural Strength & Fatigue	X				
Shafting/Propeller	X	X			
Navigation		X		X	X
Station Keeping/Mooring	X	X		X	X
Hull & Propeller Performance			X	X	X
Compliance Reporting					X

SECTION 3
Verification and Validation Principles

1 Assignment of Risk for Smart Functions

Smart Functions rely on an infrastructure of sensors, instrumentation, data, software, information systems, and communication networks. Establishing and maintaining the integrity, reliability, and performance of those systems, individually and as a whole, is crucial to meeting the goals for Smart Function implementation as defined in Subsection 2/2. When Smart Functions are integrated with onboard systems in the form of hardware (such as retrofitted sensors and cables), software, or data interface, they may introduce potential risks to the onboard system's safety, performance, and operability. Risk-based requirements covering recommended Smart Functions verification and validation should consider all relevant risk factors for the Smart Function implementation, such as the level of decision making the function will have, system complexity and integration approach, criticality of the systems to which the function is integrated, and the sophistication level of the data analysis models employed.

In the current state of practice, Smart Functions mostly provide passive decision support and stop short of auto-initiation of decision-making with human supervision. A risk assessment approach can be used to rank various risk factors associated with Smart Function implementation, and it forms the basis for setting the principles for the verification and validation process.

The risk-based approach can also be applied for vessels implementing more active machine-initiated decision making functions. However, the technical approach for such functions are considered beyond the scope of the Smart Function framework as described in Section 1, Figure 2.

1.1 Likelihood of Failure

For Smart Function implementation, a qualitative approach should be used for the assignment of likelihoods. The likelihood of a Smart Function failure or under-performance is determined by the complexity level of the network and data analysis model(s) employed. The likelihood is dependent on the following two aspects:

- Complexity level of Smart Function Network *(SFN)*
- Highest Sophistication level of Data Analysis method employed *(SDA)*

The characteristics levels for *SFN* and *SDA* are defined in Section 3, Table 1.

TABLE 1
Smart Function Key Likelihood Characteristics Levels

Complexity Level of Smart Function Network (SFN)	
0	Simple (Standalone system)
1	Simple Network (Partial integration with other systems, not all systems networked)

Complexity Level of Smart Function Network (SFN)	
2	Complex Network (All networked and fully integrated, onboard access only)
3	Multi-Attribute Connected (Remote and onshore accesses, 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
2	Data Driven Models (Machine learning and AI models, with or without use of physics based models)

The likelihood of a Smart Function failure or under-performance is defined as the summation of the assigned levels of above key likelihood characteristics (*SFN+SDA*), and 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)

1.2 Consequence of Failure

Consequence levels refer to the potential consequence of the Smart Function failure or underperformance and its impact on the vessel safety and operation. Consequence levels are influenced by the following three factors:

- The Smart Function level of Decision-making support *(SFD)*
- The Smart Function Integration level with the onboard systems *(SFI)*
- The System Category that the Smart Function integrates with *(SC)*

The Smart Function decision-making support (SFD) and integration level (SFI) are defined in Section 3, 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 the 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 the ABS *Rules for Building and Classing Marine Vessels* (MVR 4-9-3, Table 1) according to the potential extent of the damage that may be caused by a single failure within the computer-based system. This categorization is implemented here for marine and offshore vessels as shown in Section 3, Table 4.

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 assignement to system categories are shown in MVR, 4-9-3-A2/5 and listed here below (not all exhaustive).

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, ship systems involved in operation of lifesaving appliances equipment
- 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

Likelihood 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)

When considering the Smart Function integration level with onboard systems, the integration interface (hardware, software, and data communication) between the Smart Function and the onboard system should be clearly defined. The automated system components, such as sensors, attached cables, and software for the vessel's operations and controls are subject to the Class requirements covered in the relevant ABS Rules and Guides. When sensors, cables, instruments, attachments, and software are retrofitted on the structures and systems that are within Class scope, they are subject to Class requirements and a Class compliant installation should be ensured.

1.3 Risk Matrix

A risk matrix should be utilized based on the level of likelihood and consequence described in 3/1.1 and 3/1.2, respectively, and as shown in Section 3, Table 6. Alternatively, a similar approach can be employed using similar recognized methodologies.

When a Smart Function's likelihood and consequence level cannot be assessed via the descriptive procedure as defined in 3/1.1 and 3/1.2, or additional risk factors exist that are not covered in 3/1.1 and 3/1.2, a recognized risk analysis approach should be used to assess these factors.

The risk matrix covers three risk levels, and can be used to set a verification and validation process for the Smart Function implementation.

TABLE 6
Risk Matrix

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

2 Smart Function Verification and Validation Principles

A verification and validation process for Smart Function implementation involves the verification of system design features which satisfy the functional requirements and prescriptive safety and performance requirements through engineering review. Initial and continuous/periodical validation of the functionality should be conducted through independent survey to ensure the system capabilities meet its design purpose.

The verification and validation principles should be based on the risk level assigned by following the descriptive procedure as described in Subsection 3/1 or other acceptable method.

2.1 Basic Principles

For Smart Functions of ALL risk levels, the verification and validation process should address the following basic principles, including:

i) *Functionality*: The hardware and software are functional per their design specifications and suitable for the installation and operation in the marine environment, including but not limited to enduring ambient temperature, moisture, noise, vibration, and dust. The installation and protection of the hardware should consider service conditions and installation location for the entire service life.

ii) *Safety*: The installation and operation of the hardware and software do not introduce a potential risk to the vessel's safety and operability, or the potential risk is thoroughly evaluated and controlled. This includes, but is not limited to the avoidance of system failure propagation, and the infiltration and spread of cyber risks. For Smart Functions integrated and/or sharing resources with onboard control, alarm, and monitoring systems (e.g., onboard data communication and power supply), the additional loads caused by the Smart Functions should not adversely affect the primary system performance, in terms of communication bandwidth, system response time, and the additional load on the power supply. When installed or integrated to structures and onboard systems that are subject to Class requirements, the hardware and software retrofiited for the Smart Function implementation should be compliant with applicable Class requirements.

iii) *Operability*: The hardware and software should be capable of continuous operation under all design conditions for the entire design service life. The instrumentation should be maintained, calibrated, and re-calibrated as recommended by the OEM.

iv) *Data Processing*: The sensed and collected data should be adequately processed from its raw state into a useable form, adaquate for its intended purpose.

v) *Data Security*: The collected data is adequately protected from possible physical damage due to the environment.

vi) *Data Analytics*: The data analytics models themselves, if adopted, should be validated for their intended scope of capability and independently verified via a functional verification method.

vii) *Software Quality*: The software is designed, developed, deployed, maintained, and upgraded according to recognized industry quality standards.

viii) *Cyber Security*: The hardware and software systems and the information contained therein are protected from and/or defended against damage, unauthorized use or modification, or exploitation.

The following ABS Guides and Guidance Notes provide requirements and general guidance regarding information system integrity:

- ABS *Guide for Integrated Software Quality Management* (ISQM Guide)
- ABS *Guidance Notes on The Application of Cybersecurity Principles to Marine and Offshore Operations – CyberSafety™ Volume 1*
- ABS *Guide for Cybersecurity Implementation for Marine and Offshore Operations – CyberSafety™ Volume 2* (Cybersecurity Guide)
- ABS *Guidance Notes on Data Integrity for Marine and Offshore Operations – CyberSafety™ Volume 3* (Data Integrity Guidance Notes)
- ABS *Guide for Software Systems Verification – CyberSafety™ Volume 4*
- ABS *Guidance Notes on Software Provider Conformity Program – CyberSafety™ Volume 5*

2.2 Principles Based on Medium Risk Level

For Smart Functions with a risk level ranking of Medium or higher, the following additional requirements should be satisfied, including:

i) *Performance*: The performance of the hardware and software should satisfy the Smart Function design purpose to maintain timely response of the system in all design conditions.

ii) *Reliability*: Reliablity of hardware and software may be achieved through

- Reliability specification, strict design requirements, quality control procedure, and more comprehensive testing
- Redundancy requirements and alternative ways to operate the system fail-safe design philosophy

iii) *Data Quality Assurance and Control*: The data quality should satisfy its designed purpose via

- Data quality assurance and assessment
- Data quality control and continuous data quality monitoring

iv) *Data Analytics Verification*: The quality of the implemented data analytics algorithm should be assessed to assure the algorithm's accuracy and reliability with consideration of the limiation and uncertainty introduced by historical data sets, data quality, and data analytics models. An analytics or simulation based verification in addition to functional verification is recommended.

v) *CyberSafety*: Cyber security should be fully considered and the basic ABS Cybersecurity **CS** Notation is recommended.

2.3 Principles Based on High Risk Level

For Smart Functions with a risk level ranking of High, in addition to the above prescriptive requirements covered in Sections 3/2.1 and 3/2.2, enhanced software quality and cyber safety requirements should be satisfied.

Software Quality Engineering: The ABS **ISQM** Notation is recommended. It is described in the ABS *Guide for Integrated Software Quality Management (ISQM Guide)*, which prescribes the software quality engineering requirements and best practices for the design, construction, and maintenance of integrated computer-based control systems.

CyberSafety: The advanced Cybersecurity **CS** Notation is recommended. This Notation may be issued by ABS to vessels that conform to more rigorous requirements described in the ABS Cybersecurity Guide.

In addition, a comprehensive risk assessment is recommended which considers all potential risks that the Smart Function implementation may impose to the vessel's safety, integrity, and operation. Smart Function risk factors should include, but are not limited to:

- The role of the Smart Function, in terms of decision support
- The integration with other onboard systems and potential failure propagation and performance degradation
- The complexity of the hardware, software, and the models and algorithms employed
- The reliability of the hardware, software, and onboard and vessel-shore communication
- The uncertainty of analytics models, data, and data quality
- Cyber security
- Operation errors and human factors

It should be noted that risk level rankings of High are not commonly seen in Smart Function implementation, as the Smart Functions typically provide passive decision-making support.

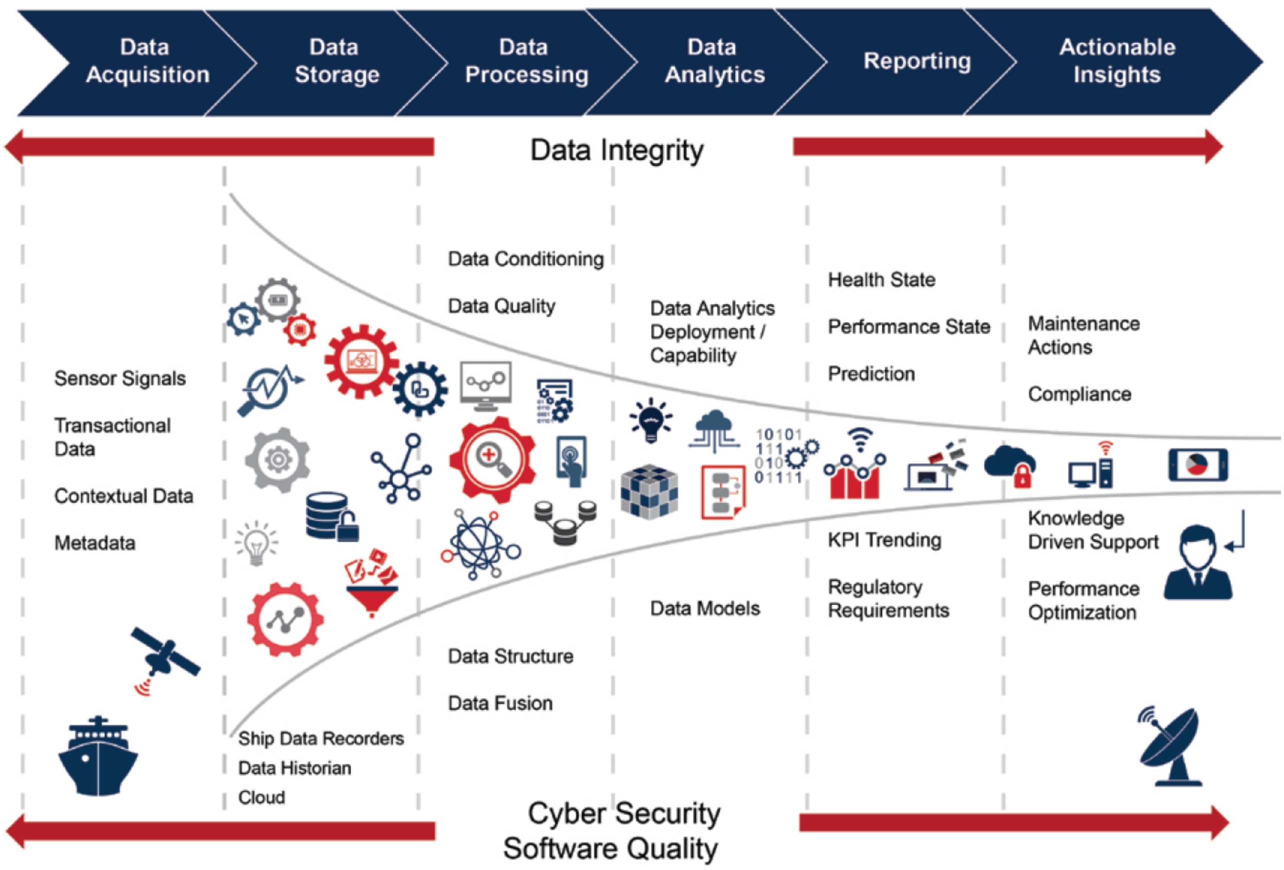
SECTION 4

General Procedure for Smart Function Implementation

1 General

Smart Function implementation typically involves a data flow path as shown in Section 4, Figure 1.

FIGURE 1
Data Flow Associated with Smart Function Implementations



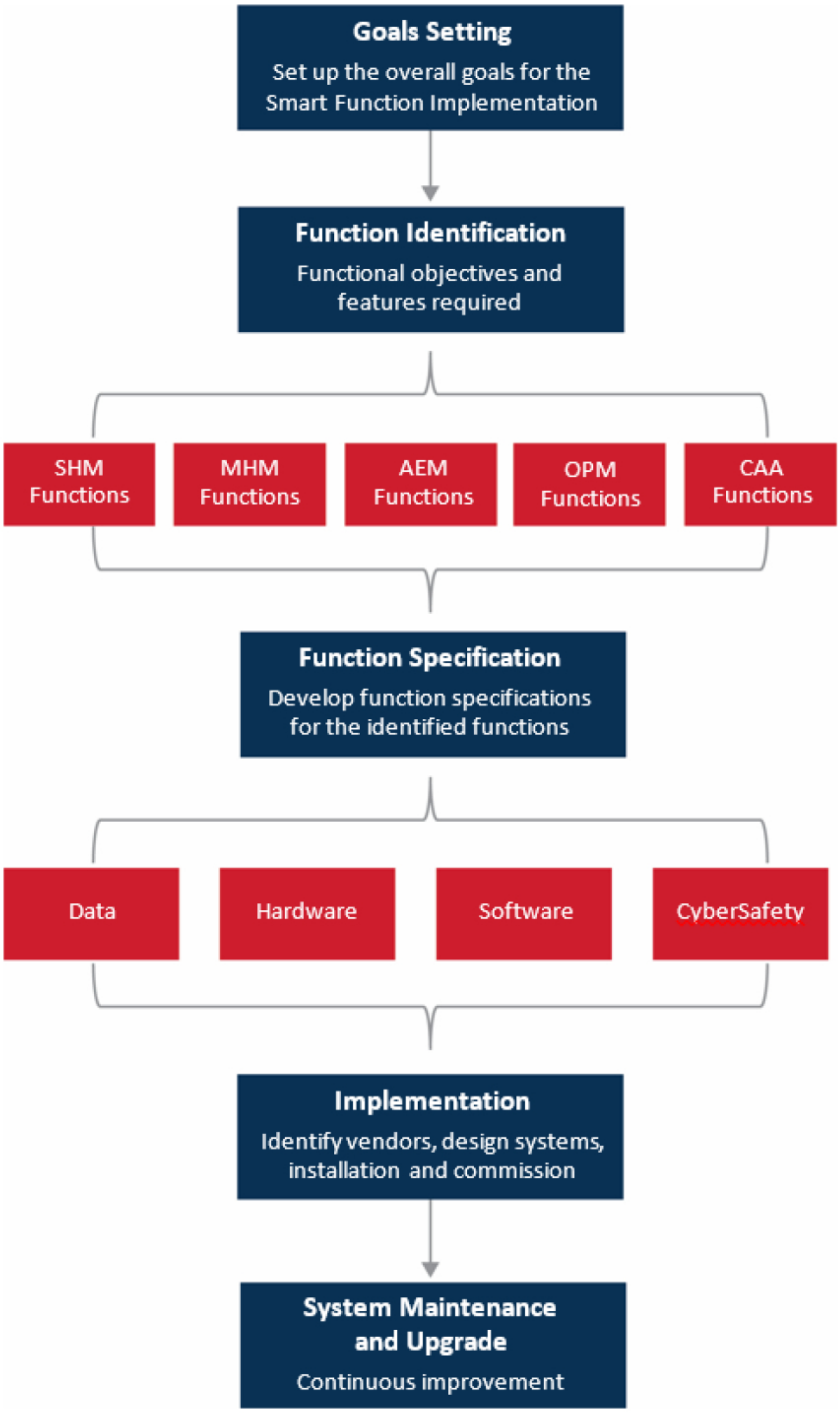
A successful implementation of Smart Functions usually involves the owner, system and service vendor, integrator, shipyard, and Class. The role and capacities of the system and service vendors vary for different implementations, and a typical vendor's scope can be categorized as follows:

- *Full Capability ("Collect – Storage – Process – Analyze – Report")*. Vendors that control the entirety of the data flow process from sensor signal acquisition and processing to decision making support based on data analytics and reporting.
- *Partial Capability ("Collect – Storage", "Process")*. Vendors serve a role of "data aggregator" enabling others to perform processing, analysis, and reporting.
- *Partial Capability ("Process – Analyze – Report")*. Vendors serve a role of health or performance analyst. Such vendors provide systems and services to perform the analytics and reporting, but are not involved in the collection and processing aspects of the data.

The complete data flow path may include a single vendor or organization, a bundling of vendor packages, or a combination of developed functions and vendor packages.

The complexity of Smart Function implementation varies greatly, from a standalone real-time monitoring function to an integrated operational management and optimization system. A well-defined and systematic procedure will help to achieve a smooth and reliable implementation. Section 4, Figure 2 shows recommended stages for Smart Function implementation.

FIGURE 2
Recommended Stages for Smart Function Implementation



2 Goal Setting

Based on the goals for Smart Function implementation defined in Section 2/2, asset owners and operators can set vessel-specific implementation goals in order to identify the appropriate Smart Functions and the data infrastructure to support them.

An example of vessel-specific smart function-related implementation goals may include:

- Enhance structural integrity
- Enhance equipment longevity and systems reliability
- Enhance navigational safety
- Reduce overall Operational Expenses (OPEX)
- Compliance with environmental regulations
- Improve/optimize fuel efficiency
- Optimize inspection and maintenance
- Reduce crew reporting burden and vessel/shore reporting errors
- Reduce system and vessel downtime
- Optimize voyage planning
- Strategic investment planning for new vessel designs and operations
- Strategic investment planning for new technologies (alternative fuel, coatings, or ESD)

Smart Function implementation incurs initial and maintenance costs. When examining the economic viability of such investments, stakeholders should define priorities, adopt a strategic approach and develop an action plan that proves the value of incorporating the function in question.

A techno-economic evaluation, tailored to the vessel's technical specification and in association with the owner's investment and operational strategies, may provide guidance and justification for Smart Function implementation. Results and conclusions from the techno-economic evaluation can support key decisions on selection and configuration of sensor packages and instrumentation, the data infrastructure, communication capacity, and software systems. A number of key considerations for Smart Function project definition may include:

- Expected outcomes and Return on Investment (ROI)
- Initial investment and lifecycle operational cost
- Compliance with applicable regulations, rules, and standards
- Competitive vessel energy efficiency and operational performance
- Environmental awareness
- Corporate enterprise operational strategy
- Corporate cultural challenges

When evaluating the potential outcomes and ROI, the following common factors should be considered:

- For health monitoring: the criticality of the monitored system, equipment, and structures; the potential impact to current maintenance and inspection strategies by the implementation for the monitored machineries and structures; crew competence and training.
- For operational management, efficiency and optimization: the potential impact on the current operational behaviors and the level of crew's confidence on the Smart Functions.

Function-specific outcomes are discussed in Appendix 2 of this document.

3 Function Identification

The main purpose of this stage is to identify the Smart Functions and define their functional requirements to meet the goals identified in Goal Setting stage as described in Subsection 4/2. The commonly applied Smart Function categories are described in Subsection 2/3 and detailed in Appendix 2 and can be served as the starting points. For each identified Smart Function, its functional requirements and features should be described in detail with consideration of the following aspects:

- Target vessel type and design
- Expected operations and environment conditions
- Maturity of the techniques and product availability
- Compatibility with the existing onboard systems and business operations
- Crew readiness and training needs
- System maintenance and upgrade requirements

Examples of the function selection to meet the goal of reducing OPEX and operating the vessel more efficiently for an ocean-going ship are:

- AEM function covering ship hull, propeller, and rudder
- AEM function covering main engine and generators
- OPM function with route, speed, and trim optimization

Refer to Subsection 2/3 and Appendix 2 for detailed description of Smart Function categories and their implemenation considerations.

4 Function Specification

Function specifications should be developed in this stage for the identified Smart Functions and their functional requirements with consideration of the function's risk level and the corresponding requirements as described in Subsection 3/2. Various levels of Smart Function comprehensiveness and integration lead to different levels of specifications but there are some common considerations:

i) *Measurement Plan*: The plan to realize the identified functions including sensor and instrument selection (sensor type, number of sensors, and sensor specification), the installation plan (locations, means of installation, and protection for surrounding environment) or, simply means of access to pre-installed sensors.

ii) *Onboard Data Infrastructure, System Integration, and Onshore Data Exchange*: The specifications for the data linkage from sensors to data acquisition units, onboard data network, hardware and communication protocols, system interface, data volume and bandwidth requirements, onshore data streaming requirements.

iii) *Onboard Data Management, Processing, and Analysis*:

iv) *Cyber Security, Software Quality, and Data Integrity Plan*: The specification covering cyber security, software quality, and data integrity and protection.

v) *User Interface, Visualization and Reporting*: The system specifications for the user interface, covering visualization and reporting.

The specification on the onboard data infrastructure should consider both the current demands and the potential future upgrade and scale-up for a broad coverage and more functionality.

5 Implementation

The implementation includes several sub-stages:

- Identification of the vendors based on the identified functions, functional requirements, and system specifications
- System design and customization and factory function test
- Design review and verification against the defined functional requirements and specifications
- System installation, onboard testing, function validation, and commissioning
- Crew training and relevant organization's operational model changes

Out of the box solutions typically require customization for each implementation due to the uniqueness of marine and offshore vessels and their operations. The Smart Function hardware and software design should be compatible to the existing vessel design, including structures, machineries, onboard communication and control network.

6 System Maintenance and Upgrade

The Smart Function and its relevant hardware and software should be properly inspected and maintained according to vendor recommendations and maintenance schedule. Inspection, maintenance, and re-calibration records should be kept on board for future reference. Hardware and software upgrades should also be conducted according to the vendor's recommendation with due consideration for maintaining both software integrity and cyber security.

During the operation of Smart Functions, gaps between the implementation and the goals may be identified. To maximize the ROI continuous improvement is recommended, in terms of hardware and software upgrade, means to use the Smart Function, crew's skill level and confidence, and incorporation with the vessel and fleet management.

7 Stakeholder's Role

Cooperation amongst all stakeholders and clearly defined roles for each implementation stage are a crucial factor for successful Smart Function implementation. Section 4, Table 1 summarizes a suggested approach for various stakeholders. The descriptions in the table may not apply to all business scenarios.

TABLE 1
Typical Stakeholder Roles for Smart Function Implementation

Stage	*Main Purpose*	*Owner*	*Vendor/ Integrator*	*Shipyard*	*Class*
Goal Setting	Identify the overall goal for the implementation	Lead	Support		Support
Function Identification	Identify the Smart Functions and their objective to fulfill the goals	Lead	Support		Support
Function specifications	Develop technical specification for the functions	Lead	Support	Support	Verify*
Implementation	Identify vendors and provide designs according to the function specification System installation and commissioning	Support	Lead	Support	Verify*
System maintenance and upgrade	Warrant the system's operability and reliability Warrant the achievement of the identified implementation goals	Support	Lead		Verify*

Notes:

* Class verification generally includes:

- Review of the function specification according to the implementation goals
- Verification that the design is in line with the specification through engineering review
- Validation that the implementation meets the functional objectives through witness the system installation and functional test
- Review of the maintenance and upgrade plan(s) and survey system functionality and maintenance

APPENDIX 1
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 (Marine Vessel Rules)*

ABS *Rules for Building and Classing Mobile Offshore Drilling Units (MODU)*

ABS *Rules for Survey after Construction*

ABS *Guide for Hull Condition Monitoring Systems*

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

ABS *Guidance Notes on Equipment Condition Monitoring Techniques*

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*

ABS *Guidance Notes on Novel Concepts*

ABS *Guidance Notes on Qualifying New Technologies*

ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*

ABS *Energy Efficiency Measures, Status and Guidance*

ABS *Energy Efficiency Measures Advisory*

APPENDIX 2
Smart Function Category Descriptions

1 Structural Health Monitoring

1.1 Functional Objective

1.2 Functions

SHM functions vary in terms of both functionality and scope of coverage. In general, the following SHM function features may be implemented to meet the SHM objective as defined in A2/1.1:

- Real-time awareness of environmental and operational loads and the structural responses to avoid overloading and potential structural damage.
- Critical location monitoring for detecting potential structural damages, such as excessive displacement and deformation, yielding, bulking, cracking, and vibration.
- Structural condition tracking to better understand wastage levels, corrosion rates, and trending.
- Data trasnmission of structural loading and response to other onboard systems for operational planning, operational guidance, performance optimization, and vessel control.
- Vessel-specified environmental and operational loading history for structural remaining useful life assessment, life extension, condition and risk-based inspection, fleet wide operation planning, future design enhancement and operation improvement.

1.3 Structural Health Monitoring Techniques

Traditionally, structural health monitoring utilizes sensors such as strain gauges and accelerometers to directly measure vessel motion, loads, and structural response and to provide condition awareness and trending to onboard crew and shore based personnel for decision support. Sensor-based structural health monitoring is particularly valuable for vessels with the following characteristics:

- Unconventional designs and materials including:
  - Non-traditional structural arrangements with less proven service experience regarding to the structural load carrying and load transfer capacity.
  - High-speed vessels, ultra-large or ultra-light designs that push the design limits to the boundary of existing class rules and other design criteria.
  - Adoption of new materials, such as ultra-high-strength steels, lightweight materials and composite materials, such as very-thick plate that may introduce new structural behavior and damage modes that are not covered in existing class rules and design criteria.
- An unpredictable operational envelope and less well-understood working environments that may not be well characterized by the design criteria.
- Hard-to-access structural locations where periodic physical inspection and survey is difficult or costly.

- High-value, high-utilization, and special purpose vessels that require additional assurance for a higher level of confidence on structural integrity and continous operation.

Some references for sensor-based structural health monitoring implementation and commonly applied techniques are:

- IMO MSC/Circ.646, Recommendations for the fitting of hull stress monitoring system for improving the safe operation of ships carrying dry cargo in bulk
- Review of Hull Structural Monitoring Systems for Navy Ships, Defense Science and Technology Organization (DSTO-TR-2818), May 2013
- State of the Art in Hull Response Monitoring Systems (SSC-401), Ship Structure Committee, 1997
- Guidelines for Structural Health Monitoring—Design Manual No. 2. ISIS Canada—the Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures, University of Manitoba, Winnipeg, Manitoba, Canada, Sept 2001
- ABS *Guide for Hull Condition Monitoring Systems*
- 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*

It is impractical to cover all structural details and potential failure modes through direct sensor-based monitoring at a vessel level due to its scale and complexity, and thus a comprehensive SHM approach for Smart Function implementation may integrate sensor-based monitoring with inspection and structural analysis to obtain a holistic picture of the structural conditions. The main constituents and required data for a SHM function typically include the following features:

- Vessel-specified loads
  - Real-time environmental and operational loads
  - Routing history and historical environmental and operational loads
- Structural load-carrying capacity
  - Thickness measurements, coating condition, and corrosion data
  - Structural modifications, identified damage and damaged areas, and repair history
  - Structural digital model with up-to-date structural conditions considering the above changes that affect the load-carrying capacity
- Full-scale vessel motion, structural response and damage monitoring using sensors for
  - Major global structural loads and failure modes
  - Critical local structures and their corresponding failure modes

A multi-scale and multi-physics digital model feeds on this data. The digital model is continuously/periodically updated with the structural survey/monitoring data, loaded with the encountered/experienced loads, and analyzed for structural responses, health condition, damages, and remaining useful life.

The capacity and outcomes of SHM may vary significantly according to different data availability and effort levels. Vessel structures are complex systems and the assessment results should be interpreted fully with respect to both systemic and random uncertainties relevant to construction quality, operational loads, environment, human errors, data quality, and employed analysis methodologies. Due consideration should be given to these uncertainties, when utilizing SHM results for operation, inspection and maintenance decision-makings.

Since the continuous/periodical model updates and structural analysis are commonly conducted in onshore facilities, periodic or continuous data sharing with onshore facilities and onshore domain expert involvement are typically part of a sophisticated SHM function.

1.4 Features

Appendix 2, Table 1 summarizes the common SHM function features.

TABLE 1
Main Features for Structural Health Monitoring

Function	*Capacity*	*Coverage*	*Onshore Support*
SHM	Sensor-based monitoring on structural loads and responses Alarming for overloading and/or potential damages Operational guidance regarding to structural safety and integrity A multiple scale and multiple physics digital model based life-cycle structural integrity management program Condition-based structural inspection and survey	Directly monitored global loads, response, and failure modes Directly monitored identified local critical areas and local failure modes Holistic coverage on the global and local structure and failure modes through integrated program with direct monitoring, data collection, digital model update, and analysis	Continuous/periodical data collection and sharing with onshore facility for analysis, expert support, and decision making

1.5 Outcomes

Appendix 2, Table 2 summarizes the main potential outcomes of implementing SHM functions.

TABLE 2
Outcomes of Structural Health Monitoring

Function	*Operation*	*Life-Cycle Management*	*Inspection/Survey*	*Future Improvement*
SHM	Real-time condition awareness to avoid potential over loading Direct monitoring on hull and critical areas for potential structural damages Holistic structural condition awareness for operational guidance and optimization Fleet-wise planning to balance vessel utilization according to the vessel's loading history and remaining structural life	Structural life assessment and extension based on vessel-specified loading history and structural conditions Cyber-physical model based life-cycle management	Informed, targeted, and vessel-specific inspection and survey	Historical loading and structural performance data for design and operational improvement

2 Machinery Health Monitoring

2.1 Functional Objective

For the purposes of these Guidance Notes, Machinery Health Monitoring (MHM) intends to detect the onset of machinery health degradation and impending function failure at the earliest possible time. This is typically accomplished via continuous monitoring of operational conditions using pre-existing or purposely installed sensors and related condition monitoring instrumentation. Traditional condition monitoring techniques such as vibration and oil analysis as well as data analytics based approaches using trended operational time-series data (e.g. use of machine-learning, or similar approaches) are often employed individually or combined to form a holistic health monitoring package.

2.2 Functions

In general, the following MHM function features may be implemented to meet the MHM objective as defined in A2/2.1:

- Real-time equipment and system health monitoring using traditional condition monitoring techniques and/or data analytics apporaches to detect the condition degradation to guide operations and avoid potential failure and unexpected downtime.
- Health condition diagnosis and prognosis to transition maintenance strategies from a planned or calendar-based approach to a more condition-based and predictive approach.
- Machinery operational and health data sharing in support of other onboard systems for systems and equipment performance management related to optimizing fuel consumption.
- Machinery operational parameters and performance data collection for both design and operational improvement and other future usage such as the training of machinery data-driven models.

2.3 Machinery Health Monitoring Techniques

Traditional condition monitoring techniques for onboard machinery can be organized into the following categories:

- Temperature measurements
- Dynamic monitoring
- Oil analysis
- Corrosion monitoring
- Nondestructive testing
- Electrical testing
- Observation and surveillance

The ABS *Guidance Notes on Equipment Condition Monitoring Techniques* provide detailed technical and implementation considerations relevant to the above listed condition monitoring techniques.

Mechanical and pressure retaining integrity for rotating and static equipment are typically monitored as part of a machinery condition monitoring program. Common techniques employed for static equipment include corrosion monitoring and nondestructive testing. The mechanical integrity of equipment is highly dependent on the equipment arrangement and configuration, materials of construction, welding quality, and loading patterns. Mechanical failure modes typically monitored for various marine and offshore equipment include, but are not limited to:

- Local stress, strain, deformation, pressure, and overload failure
- Hot spot fatigue damage accumulation
- Fatigue crack initiation and propagation
- External source-related vibration damage
- Usage induced wear out and endurance limit related fatigue
- Corrosion and material degradation from a variety of corrosive environments and fluid flow regimes.

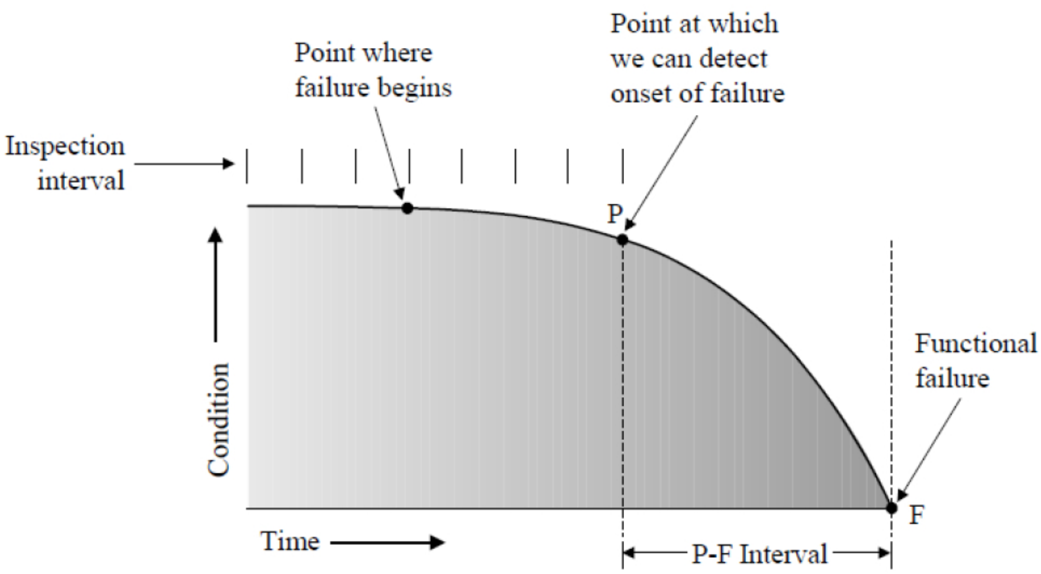
With the advent of a modern data infrastructure using inexpensive sensors, computing power, data storage, and data transmission capabilities, traditional visit-based machinery condition monitoring is increasingly performed via sensors on board the vessel. Operational data is continuously collected and shared between the vessel where initial analysis results can be obtained and onshore facilities where data trending and further assessment may be conducted with subject matter expert support. When faults or condition anomalies are detected, timely notice with instructions/recommendations may be provided to onboard crew for troubleshooting and corrective action. In addition, the machinery condition assessment and prediction can initiate planned maintenance tasks and/or unscheduled corrective maintenance activities (e.g., replacement of a worn-out component that may cause wider performance deterioration or breakdown) for condition-based and predictive maintenance.

Data-driven models, including the use of machine learning and similar approaches, are increasingly prevalent as a health monitoring technique for marine and offshore equipment and systems. Data-driven models enable a more comprehensive approach to health state awareness by:

- Supplementing physical models and traditional condition monitoring techniques when encountering unclear physical relationship and/or over-complicated physical and operational conditions.
- Providing a broader scope of data correlation for the system of systems to catch any early signs of deterioration.
- Use of predictive machinery condition models via historical operational records, machinery condition measurements, functional failure, and inspection and maintenance records.

Comprehensive MHM functions usually combine data-driven models with traditional condition monitoring techniques as well as physics-based models to generate a holistic coverage on failure modes and operational conditions. Data analytics expand upon and boost condition-monitoring capacities to detect failure patterns early in the failure curve by detecting subtle signs of anomalous conditions and degradation, especially for the equipment and systems that are physically and operationally complicated. As shown in Appendix 2, Figure 1, data analytics based approaches potentially are capable to move the point at which we can detect onset of failure (Point P in the figure) further left through broader data correlation and learning from the historical data sets.

FIGURE 1
Potential Failure (P-F) Diagram



The successful construction of a data analytics model requires comprehensive historical data sets, well-defined model acceptance criteria, defined and controlled verification and validation procedures, and domain knowledge and understanding on machinery working principles and operations. In addition to onboard analysis and alarming, vessels with MHM functions usually have established access to onshore technical expert support via real-time communication for better confirmatory data interpretation, anomaly detection, and provision of recommendations.

2.4 Features

Appendix 2, Table 3 summarizes the main MHM function features.

TABLE 3
Main Features for Machinery Health Monitoring

Function	*Capacity*	*Coverage*	*Onshore Support*
MHM	Onboard machinery health condition awareness and alarming Onshore domain support for anomaly detection, condition assessment and prediction, and recommendations Condition-based inspection and maintenance	Comprehensive failure mode coverage via the combination of data-driven models with physical models and traditional condition monitoring techniques	Continuous data streaming to onshore and real-time two-way data communication for recommendations on corrective and preventive actions

2.5 Outcomes

The implementation of MHM functions for machinery health monitoring has a direct linkage to the ABS Preventative Maintenance Program (PMP). The intent of a PMP is for owners/operators to maintain their vessels by applying best-practice maintenance strategies, which may increase a vessel's reliability and operational availability. PMP enrollment allows for crediting the open and examine aspects of a Special Continuous Survey of Machinery (CMS) by way of evidence that the preventative maintenance plan is followed. The current ABS Survey designations within the program include both PM (Planned Maintenance, equipment enrolled in a largely time-based approach to maintenance) and CM (Condition Monitoring, equipment triggering intrusive maintenance tasks by way of visit-based condition monitoring). Refer to Appendix 7-A-14 of the *Marine Vessel Rules* for PMP program requirements. The MHM functions discussed in this document may be accepted as condition monitoring techniques within the ABS PMP to achieving survey credits.

Appendix 2, Table 4 summarizes the potential outcomes of implementing MHM functions.

TABLE 4
Outcomes of Machinery Health Monitoring

Function	*Operation*	*Life-Cycle Asset Management*	*Maintenance / Inspection /Survey*	*Future Improvement*
MHM	Real-time health condition awareness, anomaly detection, and alarming to avoid unplanned shutdown Operation guidance and optimization based on predicted machinery condition	Eligible for ABS PMP and potential for alternate Survey crediting approaches	Condition based and predictive inspection and maintenance	Historical data for design and operational improvement

3 Asset Efficiency Monitoring

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 due to hardware wear and tear, corrosion, material degradation, biofouling, and contaminant deposition. Asset efficiency levels can be maintained through efficiency monitoring and proper maintenance.

3.1 Functional Objective

The objective of Asset Efficiency Monitoring (AEM) is to monitor and/or predict the asset efficiency and to identify the contributors to efficiency degradation in order to optimize maintenance, operation and servicing activities.

3.2 Functions

AEM functions usually target the main energy consumers onboard marine and offshore vessels.

For marine vessels, the following AEM function features are commonly implemented:

- Efficency monitoring of ship hull, propeller and rudder roughness to optimize dry-docking and hull cleaning activities.
- Efficiency monitoring of main fuel consumers such as main engine(s), auxiliary engines, and incinerator(s) to optimize engine tune-up, overhaul, and maintenance schedule.
- Efficiency monitoring of other onboard energy consumers, such as cargo handling, containment system, and HVAC systems.

AEM function features for offshore vessels commonly include the following:

- Efficiency monitoring of drilling system
- Efficiency monitoring of hydrocarbon production system.
- Efficiency monitoring of other onboard marine systems, such as dynamic positioning and power plant management.

3.3 Implementation Considerations

AEM functions are typically implemented through continuous onboard data collection and onshore data analysis, efficiency assessment, and inspection/maintenance planning by subject matter experts. The following should be taken into consideration for the implementation to ensure the functions' applicability and effectiveness:

- *Definition of Key Performance Indicators (KPIs)*. The defined efficiency KPIs should be able to accurately and reliably reflect equipment and systems efficiency. The KPIs should be measurable and can be generated via the recorded data, data statistics or data analytics.
- *Establishment of the Baseline Efficiency*. To assess the efficiency degradation, the efficiency baseline should be established under the design or benchmark conditions. The baseline efficiency can be established through design data, model tests, CFD calculations, shop tests, sea trials or via a period of trial operation following the vessel delivery.
- *Operation Condition Normalization*. The KPIs should be normalized for different operational and environmental conditions to the baseline condition and comparable for various equipments and over time for the same equipment.
- *Sufficient Accuracy*. The efficiency degradation rate may be low, therefore the efficiency monitoring function should have sufficient accuracy to enable reasonable efficiency comparison and trending over a predefined time period.

- *Capability to Identify Efficiency Loss Contributors*. When a system or asset level efficiency is monitored and assessed, the main causes of efficiency losses should be identified at the equipment and component level for proper maintenance and corrective actions.

3.4 Features

Appendix 2, Table 5 summarizes the main AEM function features.

TABLE 5
Main Features for Asset Efficiency Monitoring

Function	*Capacity*	*Coverage*	*Onshore Support*
AEM	Continuous/periodical asset efficiency monitoring through defined efficiency KPIs Asset efficiency degradation and anomaly detection and condition prediction	Equipment, system, or overall vessel level	Continuous/periodical data sharing with onshore facilities for efficiency assessment and maintenance planning

3.5 Outcomes

Appendix 2, Table 6 summarizes the main potential outcomes of properly implementing AEM functions.

TABLE 6
Outcomes of Asset Efficiency Monitoring

Function	*Operation*	*Life-Cycle Asset Management*	*Future Improvement*
AEM	More efficient asset operations and reduced carbon footprint through asset efficiency awareness and optimized maintenance	Condition based and predictive maintenance planning Fleet-wide fuel consumption balancing	Historical data for design and operation improvement

4 Operational Performance Management

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).

4.1 Functional Objective

Operational Performance Management (OPM) is intended to monitor, assess, manage, and dashboard the equipment, system, and vessel's operational performance with or without the provision for crew recommendations to achieve optimum operational performance.

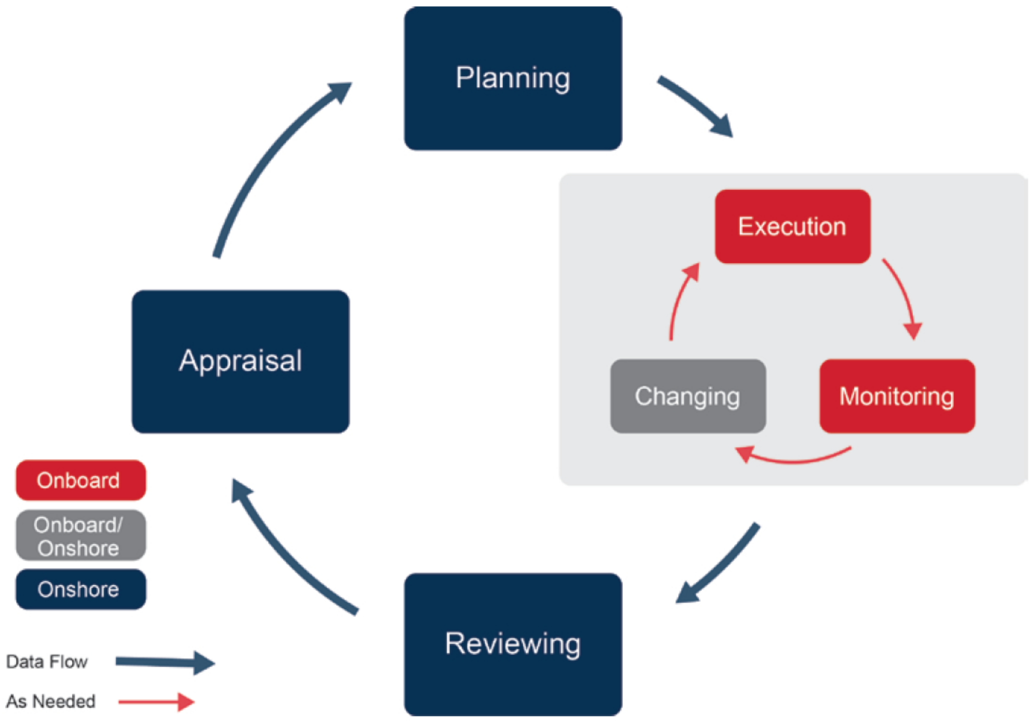
4.2 Functions

OPM functions have a broad scope for marine and offshore vessel operations. Examples of OPM function features implemented for marine vessels are:

- Weather routing to enhance safe and efficient navigation
- Voyage planning and operational monitoring and reporting
- Environmental compliance monitoring and regulatory reporting.
- Vessel and power plant operational performance monitoring and optimization

Appendix 2, Figure 2 illustrates the typical major steps and data flow for achieving marine and offshore operational performance management.

FIGURE 2
Major Steps of Operational Performance Management



As depicted in Appendix 2, Figure 2, the OPM functions described in this section can be implemented as a closed loop procedure from "Monitoring", "Execution", "Changing" for ultimately optimized "Execution". The "Changing" aspect is driven by the deviation from the pre-defined plan and by iterative use of optimized operations to target and enhance the operational performance.

There is significant variance across the range of the OPM functions as described in A2/4.2 in terms of targeted operations, optimization goals, data collection requirements, employed data analytics models, decision support levels, and the execution of corrective actions. This Appendix targets the illustration of typical OPM function features via the description of some typical OPM functions;

- *Weather Routing for Safe and Efficient Navigation*: The weather routing function performs continuous in-voyage evaluation to enhance safe and efficient navigation. The function recommends routing options in consideration of incoming weather system, voyage plan, loading conditions, as well as hull safety and structural and machinery integrity. The function can be fulfilled onboard the vessel with periodical weather forecast feeding and/or using an onshore supporting facility with continuous vessel-onshore communication for routing recommendations.
- *Voyage Planning and Operation Monitoring and Reporting*: The voyage and operation monitoring function monitors and reports the operation status with integrated dashboard for voyage-relevant parameters and pre-defined key performance indicators (KPIs), such as:
  - Weather encountered
  - Speed (log speed, GPS speed, speed over water, etc.)
  - Vessel position
  - Estimated time of Arrival (ETA)

- Sailing in emission control areas (ECA)
- Trim condition
- Main Engine fuel consumption and lubrication oil consumption
- Shaft power
- Propeller performance
- Fuel flow readings for main engines, auxiliaries and other fuel consumers
- Electrical power production

A data collection module is typically integrated with the vessel's automation systems and other computer-based systems for collecting voyage relevant data. In addition, purposely installed sensors and human inputs, such as noon reports, ballast water exchange reports, fuel switching reports, EEOI and emission reports, etc., can also feed data into the OPM functions for consolidated voyage status dashboard and reporting. A reporting module as a crew assistance function is typically implemented in OPM functions.

To take full advantage of the collected data, an onshore voyage monitoring center may be utilized for facilitating post-voyage review and analysis. The analysis targets the assessment of the overall voyage performance and compares individual vessel performance against voyage plans, peer vessels and potentially with competitors. Typically, post-voyage review can include:

- Analysis and trending of key performance measures such as fuel consumption, CO_2 and SO_x emissions, propeller slip and lubricant consumption
- Analysis of compliance with and reporting of a variety of port state and international environmental regulations including ballast water management and fuel switching
- Voyage analyses to identify excessive operational costs related to sub-optimal route or speed increases, RPM setting variations, weather influence, and trim effects

The onshore monitoring and control center may implement an analysis module for reviewing and analyzing the performance of the entire fleet and managing a company-wide SEEMP program.

- *Environmental Compliance Monitoring and Regulatory Reporting*: Regulatory compliance has been a key driver in recent operational planning and optimization approaches. OPM functions are highly sought to address the compliance requirements through data automation. Examples of regulatory monitoring are:

  - Emission Monitoring, Reporting and Verification (MRV)
  - IMO Data Collection System (DCS)
  - ECA and fuel switching
  - Ballast water management
  - EEOI calculation
  - Noise and vibration monitoring

- *Vessel Performance Monitoring and Optimization*: Energy consumption is a major cost of marine and offshore operations. Decision supports and operation recommendations for the purposes of vessel operational performance has a direct impact on commercial viability.

  A variety of operational measures are available for improving operational performance, reducing fuel consumption and lowering emissions, as specified in the ABS *Ship Energy Efficiency Measures Advisory*. A ship owner/operator will adopt those operational measures that best suit their vessel and operations. The OPM functions on board or via an onshore monitoring and control center provide decision assistance on operations considering the planned route, encountered weather, carried cargo, ports to visits, arrival time, etc. and make recommendations on routing, speed, trim, and engine load balance.

The OPM functions for vessel performance monitoring and optimization may include:

– Voyage, speed and trim optimization for minimizing fuel consumption
– Main engine operation monitoring and analyses for engine performance optimization
– Electricity load balancing and power plant optimization
– Cargo handling and supporting system optimization to reduce consumed energy
– Drilling and production operational optimization

4.3 Features

Appendix 2, Table 7 summarizes the main OPM function features.

TABLE 7
Main Features for Operational Performance Management

Function	*Capacity*	*Scope*	*Onshore Support*
OPM	Manage, dashboard, and report system and vessel operations Monitor and optimize system, vessel, and fleet operations Operational parameter recommendation for optimum performance	Main energy consumers and operations	Continuous/periodical data communication onshore Onshore performance monitoring and expert support Onshore fleet benchmarking and performance optimization

4.4 Outcomes

Appendix 2, Table 8 summarizes the main potential outcomes of implementing OPM functions.

TABLE 8
Outcomes of Operational Performance Management

Function	*Operation*	*Future Improvement*
OPM	Operation and performance status awareness Safety enhancement, effective/optimized operations Reduced overall operational cost and emission Fleet wide operational planning and optimization	Historical data for design and operation improvement

5 Crew Assistance and Augmentation

Crew Assistance and Augmentation (CAA) refers to equipment and software applications that provide automated data logging, reporting, enhanced situational awareness, and navigation assistance in support of improving the accuracy of reporting and assisting in navigational bridge management. Vessels with CAA functions are equipped with tools that automate data capture from sensor arrays and onboard sources, provide analysis and visualization dashboards and may align with third party data streams such as weather providers and electronic chart services.

CAA functions can be either integrated with other Smart Functions, such as OPM for regulatory compliance reporting, or be independent crew assistantance and augmentation functions, such as sensor-based object identification for navigation assistance and collision avoidance.

5.1 Functional Objective

The objective of CAA is to reduce crew workload and human error, enhance crew situational awareness and help minimize the risk of potential human oversights. Real-time monitoring of data generated onboard, navigational variables, weather and sea state information aims to automate regulatory/industry reporting and support bridge management practices.

5.2 Functions

CAA functions may have the following features to meet their objectives:

- Data management for regulatory reporting and other stakeholder requirements (e.g., charterers, cargo owners).
- Automated data capture, visualization of metrics and KPI trending to assist in vessel operations and planning.
- Radar, Camera, Lidar (Light Imaging, Detection and Ranging), and other technologies for increased situational awareness, obstacle detection, navigation assistance and collision avoidance
- Overlay of information on electronic charts such as advance notices of upcoming changes, hazards of a temporary nature, etc.
- Animated weather overlay and forecasting

5.3 Features

Appendix 2, Table 9 summarizes the main CAA function features.

TABLE 9
Main Features for Crew Assistance and Augmentation

Function	*Capacity*	*Coverage*	*Onshore Support*
CAA	Real-time and/or continuous situation monitoring and navigation assistance Auto logging and data fusion for integrated dashboard, including auto reporting	Regulatory compliance reporting Voyage and operation statistics and trending Situation awareness and navigation assistance	Onshore communication optional

5.4 Outcomes

Appendix 2, Table 10 summarizes the main outcomes of properly implementing CAA functions.

TABLE 10
Outcomes of Crew Assistance and Augmentation

Function	*Operation*	*Future Improvement*
CAA	Enhanced situational awareness Enhanced navigation bridge support Reduced risk for crew oversights Reduced reporting errors Regulatory reporting compliance Assistance on vessel operation and planning	