Requirements for

Autonomous and Remote Control Functions

ABS

August 2022

REQUIREMENTS FOR

AUTONOMOUS AND REMOTE CONTROL FUNCTIONS
AUGUST 2022

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

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Foreword *(1 August 2022)*

The development and implementation of autonomous and remote control functions in the marine and offshore industry has greatly increased in recent years.

Autonomous Functions are those wherein machines perform each of the four steps in the operational decision loop, i.e. Monitoring, Analysis, Decision and Action without the need for human intervention to perform tasks and achieve the system mission. Autonomous functions do not follow predefined routines and operational scenarios, but rather have the ability to execute the most appropriate actions based on their programming, assigned mission and tasks, operational environment, and the system status.

The autonomous functions covered in this document focus on the functional capabilities which enable the operations of marine vessels and offshore units and do not imply unmanned operations. Besides the autonomous functions, unmanned operations consider other activities and factors, such as system maintenance, incidence handling and manning requirements, which are out of the scope of this document. Fully autonomous and unmanned marine vessels and offshore units will be considered on a case-by-case basis. Please contact ABS for further information.

Remote control functions are functions which allow the system and operation being monitored to be controlled remotely by a human operator who is physically located in a location other than on board a marine vessel or offshore unit where the operations take place.

ABS developed this document to provide the industry with technical and survey requirements for marine vessels and offshore units fitted with autonomous or remote control functions. Marine vessels and offshore units installed with autonomous or remote control functions are to comply with the requirements given in this document. They will be eligible for the class notations **AUTONOMOUS** or **REMOTE-CON**.

The July 2022 version changes the document type from “Guide” to “Requirements”. “Requirements” documents contain mandatory criteria for Classification and issuance of Class Certificates, while Guides contain only requirements for optional Notations (see 1-1-4/1.5 of the ABS *Rules for Conditions of Classification (Part 1)*). The title is changed from "*Guide for Autonomous and Remote Control Functions*" to "*Requirements for Autonomous and Remote Control Functions*". Accordingly, editorial changes are made throughout this document.

The August 2022 edition of this document clarifies the requirements for Remote Control Functions and revises the Risk Category to assign risk levels based on operations supervision level and consequences of failure/category.

This document 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 is the most current.

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

REQUIREMENTS FOR

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CONTENTS

SECTION 1

General *(1 August 2022)*

1 Introduction

1.1 Purpose

The purpose of this document is to

i) Establish a goal-based framework for the implementation of autonomous and remote control functions on board marine vessels and offshore units. This framework also considers the interactions between the operations of autonomous and remote control functions with relevant stakeholders such as Port authorities, other vessels, etc.;

ii) Establish a risk-based approach coupled with a prescriptive set of requirements for the assessment of autonomous and remote control functions;

iii) Provide requirements on the risk-based approval process for the implementation of autonomous and remote control functions.

1.2 Scope

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

This document is intended for use by marine vessel and offshore unit owners, operators, designers, shipyards, equipment and system manufacturers, integrators and regulators.

The autonomous functions covered in this document focus on the functional capabilities which enable the operations of marine vessels and offshore units and do not imply unmanned operations. Besides the autonomous functions, unmanned operations consider other activities and factors, such as system maintenance, incidence handling and manning requirements, which are out of the scope of this document. Fully autonomous and unmanned marine vessels and offshore units will be considered on a case-by-case basis. Please contact ABS for further information.

To keep this document concise, references in this document 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. Contact ABS for clarification on applying these requirements to vessels not covered by the above-mentioned Rules.

This document is not applicable to underwater vehicle systems and hyperbaric facilities.

2 Notations *(1 August 2022)*

The notations in this document are mandatory for vessels and units with permanently installed autonomous or remote controlled functions.

2.1 Autonomous Notations

The class notation **AUTONOMOUS** (*function category, operations supervision level)* is to be assigned to a vessel or unit possessing a permanently installed autonomous function. The implementation is to satisfy the requirements in this document. The function(s) is to be indicated in the vessel records along with its consequences of failure category.

For example, an Autonomous Function related to the vessel's navigation function under periodic supervision with operators located both onboard the vessel and remotely will be notated as:

- Notation: **AUTONOMOUS (NAV, OP2, RO2)**
- Vessel Records: Navigation (Category III), Collision Detection & Collision Avoidance (Category III)

The Autonomous Function can be implemented during vessel construction or during modifications to an existing vessel.

Note:

Each function is to be assigned a consequence of failure category. Refer to 4/2.2.

2.2 Remote Control Notation *(1 August 2022)*

The class notation **REMOTE-CON** (*function category, operations supervision level*) is to be assigned to a vessel possessing a permanently installed remote control function. The implementation is to satisfy the requirements in Section 6. The function(s) is to be indicated in the vessel records along with its consequences of failure category.

The remote control function can be implemented during vessel construction or during modifications to an existing vessel.

An example of the notation for a remote control function related to the vessel's navigation function under periodic supervision from a remote operator (not on board the vessel) will be:

- Notation: **REMOTE-CON** (NAV, RO2)
- Vessel Records: Navigation (Category III)

Another example of the Operations Supervision Levels OP1, OP2 and OP3 may be applied to the notation.

In this case, the notation for a remote control function related to the vessel's navigation function under continuous periodic supervision by both onboard and remote operator will be:

- Notation: **REMOTE-CON** (NAV, OP2, RO2)
- Vessel Records: Navigation (Category III)

Note:

Each function is to be assigned a consequence of failure category. Refer to 4/2.2.

2.3 Maintenance of Notations

To maintain the **AUTONOMOUS** and **REMOTE-CON** notations:

i) The systems carrying out the Function are to be kept properly maintained and operational. The survey after construction requirements described in Section 8 are to be met and the survey is to be conducted to the satisfaction of the attending Surveyor.

ii) The necessary certifications of the Remote Operator Station or Remote Control Station are to be kept up to date.

iii) Records of modifications and upgrades to the systems carrying out the Function, including both hardware and software, are to be kept up to date and onboard, and made available to the attending Surveyor. Modifications to approved systems are to be submitted to ABS for review and approval.

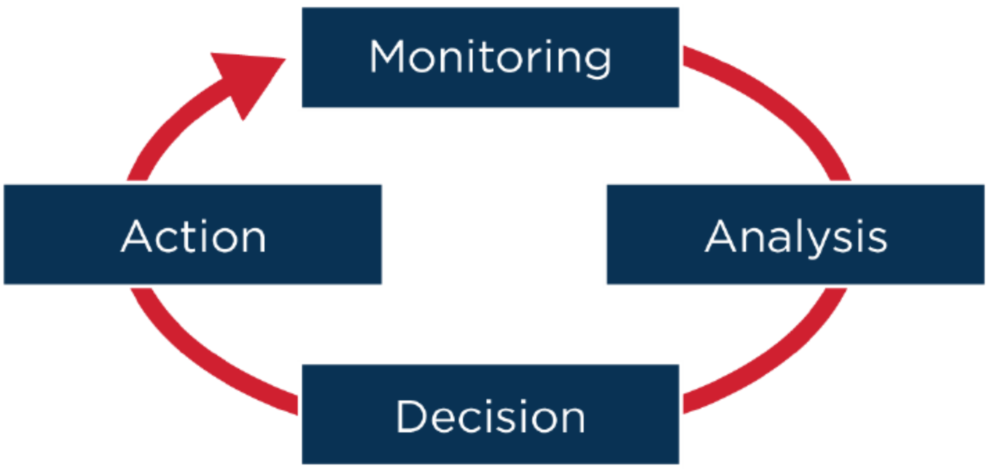
iv) The Concept of Operations document (CONOPS) is to be properly maintained and updated. Amendments to the Concept of Operations document are to be submitted to ABS for review and approval. The CONOPS is to be kept on board the vessel and in the Remote Operator and / or Remote Control Station and made available to the attending Surveyor.

3 Automation vs Autonomous Functions

Automation is the automatic control and operation of a process, system, or equipment by mechanical or electronic devices that take the place of human labor. These are normally routine or repetitious tasks under predefined scenarios and conditions. It is important to also define "automatic control" as the means to control via predetermined orders without intervention by the operator. These systems are common in the marine and offshore industry. Examples include automatic synchronization functions on electrical switchboards, automatic starting/stopping function of standby pumps, dynamic positioning systems, and autopilot controls.

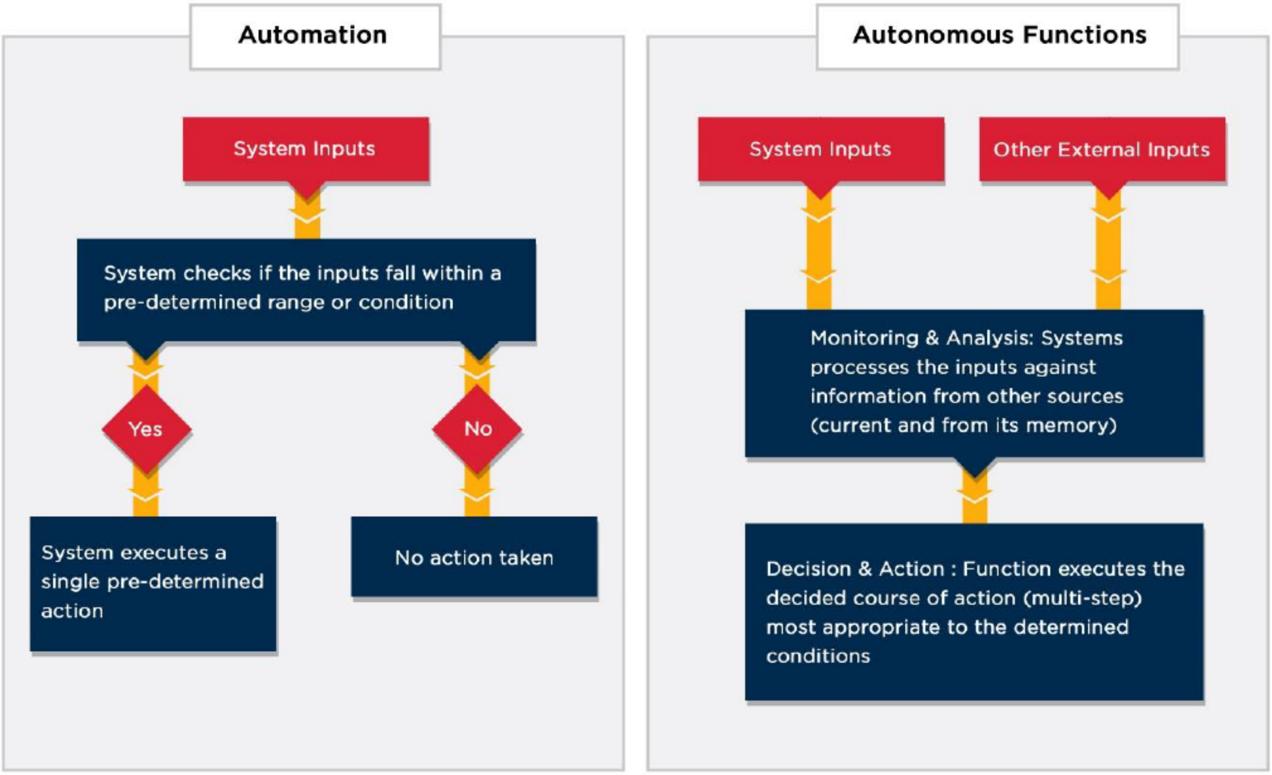
Autonomy differs from automation in that it requires self-governance and freedom from external control or influence. Autonomous Functions are functions where machines perform each of the four steps in the operational decision loop (i.e., Monitoring, Analysis, Decision and Action) without the need for human intervention to achieve the system mission and perform tasks.

FIGURE 1
Operational Decision Loop



Automatic operation and control may be integrated into autonomous functions for routine and predefined tasks. However, autonomous functions have the ability, based on their programming, to execute necessary actions under conditions outside the predefined scenarios based on the mission and tasks, operational environment, and the system status.

FIGURE 2
Automation vs Autonomous Functions



4 Smart-to-Autonomy Levels

In this document, "Autonomous" is defined 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

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

ii) *Semi-Autonomy*: Human augmentation of system functions. System operation builds upon a smart foundation and is governed by a combination of system and human decisions and actions.

iii) *Full Autonomy*: No human involvement in system functions. The system makes decisions and takes actions autonomously. Humans perform a supervisory function solely, and have capability to intervene and override actions made by the system.

The role of the human and systems for the levels described above is summarized and detailed in the Section 1/Table 1 below.

For semi-autonomous functions where there is human dependency on either decision or action, there is a fine-line to differentiate between semi-autonomous and autonomous. For the purposes of Classification, we will categorize such functions as autonomous. These functions will be eligible to request for the notation **AUTONOMOUS** with the Operations Supervision Levels OP1, OP2, RO1 or RO2. See Section 1/Table 2 for descriptions of each Supervision Level.

TABLE 1
Autonomy Levels

Autonomy Levels		*Integration and Application to Decision Loop*				*Typical available notations/Operations Supervision level*
		Monitoring	*Analysis*	*Decision*	*Action*	
1	Smart	S	S	H	H	**SMART**
2	Semi-Autonomous	S	S	S/H	S/H	**AUTONOMOUS** (function category, OP2/OP1/RO2/RO1)
3	Autonomous	S	S	S	S	**AUTONOMOUS** (function category, OP3/RO3)
Note: H – Human, S- System						

5 Autonomous Functions

Function means a group of tasks, duties and responsibilities necessary for vessel operation, safety of life at sea or protection of the marine environment. Autonomous Functions are those in which machines perform each of the four steps in the operational decision loop.

With increasing Autonomy levels, humans are decreasingly involved in the function’s control and operation up to the point where humans take a supervisory role only, with the capability to intervene and override actions made by the autonomous function when necessary.

6 Remote Control Functions

Functions are a group of tasks, duties and responsibilities necessary for individual system, vessel operation, safety of life at sea or protection of the marine environment.

Remote control functions are functions which allow the system and operation being monitored to be controlled remotely by a human operator who is physically located in a location other than on board a marine vessel or offshore unit where the system operation takes place.

The remote location is a location other than the marine vessel or offshore unit where the function takes place. This may be at a location on land or on a vessel other than the vessel where the function takes place.

7 Unmanned Vessels

The autonomous and remote control functions described in this document do not imply unmanned vessels. The vessel manning level is determined with consideration of all onboard activities, system maintenance, incidence handling, and regulation requirements, which are outside the scope of this document.

8 Function Category

The Function Category to be indicated in the notations are to be selected from the following:

i) Navigation (NAV)

ii) Maneuvering (MNV)

iii) Mooring / Unmooring (MOR)

iv) Docking / Undocking (DOC)

v) Propulsion (PRP)

vi) Auxiliary (AUX)

vii) Environmental Protection (ENV)

viii) Cargo Handling (CGH)

ix) Ballast and Trim (BAL)

x) Industrial Processes (IND)

A description of the function is to be provided in the class record comments.

For functions not listed in the above list, they may be considered on a case-by-case basis by ABS.

9 Operations Supervision Levels

The operations supervision level of the function details the supervisory configuration during operations and is dependent on the parameters listed below. The operator is a person who is responsible for the supervision of the function.

a) Operator location

i) Operator located on board vessel

ii) Operator located remotely (away from vessel)

b) Required Attention level

i) Continuous supervision – throughout the operation of the function, continuous (uninterrupted) supervision by the operator is required.

ii) Periodic supervision – throughout the operation of the function, supervision by the operator is required at set intervals. The length of the interval and means of ensuring supervision by the operator are to be determined by the vessel operator and documented in the Concept of Operations document.

iii) As needed basis (per system notification or operational mode) – throughout the operation of the function, supervision by the operator is required on an as needed basis only. This could be dependent on the system notification or required for certain operational modes only. Details are to be determined by the vessel operator and documented in the Concept of Operations document.

The operations supervision levels are as follows:

TABLE 2
Operations Supervision Levels

Operator Location	*Required Attention Level*	*Operations Supervision Level*
Onboard vessel	Continuous supervision	OP1
Onboard vessel	Periodic supervision	OP2
Onboard vessel	As needed basis (System notification or operational mode)	OP3
Remote location	Continuous supervision	RO1
Remote location	Periodic supervision	RO2
Remote location	As needed basis (System notification or operational mode)	RO3

For Autonomous Functions with operators located both onboard the vessel and in a remote location, the function may be assigned with both operations supervision levels.

10 Engagement with Flag State and Port State

The United Nations Convention for the Law of the Sea (UNCLOS) assigns to Flag States the obligation for protection of safety at sea with regards to the construction and equipment of ships. Flag States carry out this responsibility by utilizing a certification and inspection regime in accordance with IMO rules and regulations to govern vessels flying its flag.

Port States have broad jurisdiction over vessels in their ports or domestic waters whether they be foreign or domestic vessels. Domestic vessels generally are not required to comply to IMO regulations. However, these vessels are to comply with domestic regulations which are administered by the Coastal States.

Certain aspects of autonomous functions and remote operations may not be in full compliance with existing Regulations of Flag and Port States. Exemptions and acceptance of alternative arrangements may be required to enable the implementation of autonomous functions and remote operations. Such exceptions to compliance must be documented and considered for safety implications. In the absence of IMO instruments and regulations governing autonomous and remote control functions, it is envisaged that Flag Administrations will consider such requests in accordance with IMO MSC.1/Circ.1455 (Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments).

As such, engagement with the vessel's Flag State, Port State and/or Coastal State(s) together with ABS is necessary and crucial.

11 Definitions

Approval. Confirmation that the plans, reports or documents submitted to ABS have been reviewed for compliance with one or more of the required Rules, Guides, standards or other criteria acceptable to ABS.

Approval in Principle (AIP). The process by which ABS issues a statement that a proposed novel concept design complies with the intent of ABS Rules and/or appropriate codes although said design may not yet be fully evolved (i.e., concept appears to have technical feasibility from both safety (personnel and environment) and functional perspectives), subject to a list of conditions that must be addressed in the final design phase. (The AIP process is governed by the ABS *Guidance Notes on Review and Approval of Novel Concepts*).

Availability. Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.

Boundary. The interface between an item and its surroundings.

Computer Simulation Tests. Control system testing where the equipment under control is partly or fully replaced with simulation tools, or where parts of the communication network and lines are replaced with simulation tools.

Constituent System: An independent task-oriented system integrated into a larger system-of-systems.

Control. The process of conveying a command or order to affect the desired action.

Control System: An assembly of devices interconnected or otherwise coordinated to convey the command or order.

Conventional Technologies. The technologies that are covered within existing Rules and standards.

Event. An occurrence that has an associated outcome. There are typically many potential outcomes from any one initial event that may range in severity from trivial to catastrophic, depending on other conditions and add-on events.

Failure. The loss of the ability to perform the intended function.

Failure causes. Circumstances associated with design, manufacture, installation, use and maintenance that have led to a failure.

Failure mode. The specific manner of failure that the failure mechanism produces.

Function. A group of tasks, duties and responsibilities necessary for vessel operation, safety of life at sea or protection of the marine environment

Functional Description Document (FDD): A description of the functionality of the programmed computer-based system and control actions of connected systems. Contains any modifications requested by the Owner and may describe extra-functional requirements. It is a combination of documents from the Concept and Requirements and Design and Design Phases.

Functional Specification. A document that describes the features, characteristics, process conditions, boundaries and exclusions defining the performance and use requirements of the product, process or service.

Goal Based Standards (GBS). High-level standards and procedures that are to be met through regulations, rules and standards. Goal Based Standards 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.

Hardware. Physical equipment used to process, store, or transmit computer software or data.

Hazards. Conditions that exist which may potentially lead to an undesirable event.

Interoperability. Capability of objects to collaborate, that is, the capability mutually to communicate information in order to exchange events, proposals, requests, results, commitments and flows (ISO/IEC/IEEE 24765).

Maritime Autonomous Surface Ships (MASS). A ship which, to a varying degree, can operate independent of human interaction.

Modeling. The activity of representing some elements of a process, device or concept (ISO/IEC/IEEE 24765).

New Technology. Any design (material, component, equipment or system), process or procedure which does not have prior in-service experience, and/or any Classification Rules, Statutory Regulations or industry standards that are directly applicable. It is possible to categorize the type of "novelty" in one of four categories:

i) Existing design/process/procedures challenging the present boundaries/envelope of current offshore or marine applications

ii) Existing design/process/procedures in new or novel applications

iii) New or novel design/process/procedures in existing applications

iv) New or novel design/process/procedures in new or novel applications

Novel Concept. A marine vessel or offshore unit that with the inclusion of new technologies, the service scope, functionality capability, and/or risk profile is appreciably altered.

Operator. The qualified personnel who is responsible for the supervision and potential intervention for autonomous functions or is responsible for the remote control for remote control functions.

Real-time. Problem, system or application that is concurrent and has timing constraints whereby incoming events must be processed within a given timeframe (ISO/IEC/IEEE 24765).

Reliability. Ability of an item to perform a required function under given conditions for a given time interval (ISO 14224).

Remote. A location which is not located within the vessel where the Function takes place. This may be at a location on land or on a vessel other than the vessel where the Function takes place.

Remote Control Functions: Functions which are controlled from a remote location (i.e., a location on land or on a vessel other than the vessel where the Function takes place).

Remote Control Station: The remote location where the designated operator with responsibility over the remote control function is located.

Remote Operator Station: The remote location where the designated operator with responsibility over the Autonomous Function is located.

Redundancy. Existence of more than one means for performing a required function of an item.

Risk. The product of the frequency with which an event is anticipated to occur and the consequence of the event's outcome.

Robustness. The degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions (ISO/IEC/IEEE 24765).

Smart Function. 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.

Software. Computer programs, procedures, test scripts, and associated documentation and data pertaining to the operation of a computer system.

Software Design Document: A document describing the design of a system or component. Typical contents include system or component architecture, control logic, data structures, input/output formats, interface descriptions, and algorithms.

Software Requirements Specification (SRS): Documentation of the essential requirements (functions, performance, design constraints, and attributes) of the software and its external interfaces.

System-of-Systems. The large-scale integration of many independent task-oriented systems to create a larger, more complex system which offers more functionality and performance than simply the sum of the constituent systems.

Technical Specification. Document that defines technical requirements to be fulfilled by the product, process or service in order to comply with the functional specification.

Validation. The process of evaluating a production unit (or full scale prototype) to determine whether it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or demonstration.

Verification. The process of evaluating a system to determine whether the product of a given development stage satisfies the approved requirements and can be performed at different stages in the product life cycle by test, analysis, demonstration or inspection.

12 Submittal Requirements

12.1 Overall Function

The following documents related to the implementation of the overall Function are to be submitted for review:

i) Description of the function. See 5/2.1 and 6/2.1.

ii) Concept of Operations document (CONOPS). See Subsection 3/2.

iii) Risk category level assignment. See Subsection 4/2.

iv) Risk assessment plan and associated risk assessment report(s). See Subsection 4/3.

v) Test Program. See 7/3.1.

vi) Survey Program. See Subsection 8/2.

vii) Management of Change program. See Subsection 2/6.

12.2 Constituent Systems

The following documents related to the constituent systems which enable the implementation of the function are to be submitted for review:

i) Cyber security. See 5/2.9:

a) OT/IT digital architecture description

b) Cyber security risk assessment

c) Cyber security risk management system (CRMS)

d) For Functions assigned with medium or high risk level, documents required for compliance with the **CS-System**, **CS-1** or **CS-2** notations are to be submitted for review.

ii) Software. See 5/3.3:

a) Software test plan

b) For Functions assigned with low risk level, documents annotated as 'S', 'M' and 'W' for Computer Based System Category II in 4-9-3/Table 2 of the *Marine Vessel Rules*

c) For Functions assigned with medium or high risk level, documents required for compliance with the **ISQM** or **SQM** notations are to be submitted for review.

iii) Data analytics. See 5/3.5:

a) Brief summary of hybrid or data-driven applications – physical principle, assumption and limitation

b) Data sources and data collection steps – sensor configuration and mapping specification

c) Data quality assessment and control plan – describe the method/procedure applied for data quality assessment, assurance and control (e.g., data quality validation and correction rules, measurable data quality metrics and dimensions, and data quality acceptance criteria)

d) Data modeling development procedures – overview of the analytics approaches (e.g., a flow chart), method for key model parameters selection, method for data partitioning, and assumption/limitation prior to model training

e) Model evaluation results – model evaluation methods, processes, model acceptance criteria and results

f) Record of the data model version – procedure for model upgrade and deployment *g)* Data model application performance monitoring plan – model re-training criteria and procedures to better capture equipment maintenance events or change-outs, alarms for model application performance in operation.

h) Risk assessment of data model application

i) Model operation envelope

iv) Where the function is composed of systems or equipment which utilize conventional technologies, engineering and design document as required by the applicable Rules in the *Marine Vessel Rules* or the *MOU Rules* are to be submitted for review and approval.

Note:

Each function is to be assigned a risk level (low risk level, medium risk level or high risk level). The parameters considered in the assignment of the risk levels are the function's operations supervision level and the consequences of failure. Refer to Subsection 4/2.

12.3 Modeling and Computer Simulation Tests

Where modeling and computer simulation tests are permitted to be used as an alternative approach in the overall system-of-systems test of the Function or within individual constituent systems, the following are to be submitted. See Subsection 7/4:

i) Modeling and computer simulation test plan

ii) Model that has been developed in a computer simulation test space that supports the functional mockup interface (FMI) standard, or equivalent, is to be submitted for review upon request

iii) Computer simulation test results report

13 Related Optional Notations

Due to the connected and software intensive nature of autonomous and remote control functions, it is foreseen that there will be a greater focus on data integrity, cybersecurity and software quality in the course of implementing these functions. Additionally, reliability, robustness and inter-operability concerns will also be key foundational requirements.

ABS offers a full suite of optional notations to complement the **AUTONOMOUS** and **REMOTE-CON** notations. The full list of optional notations is available for download from the ABS website at www.eagle.org.

13.1 Prerequisite Notations

Section 1/Table 3 lists the prerequisite notations in the implementation process of the **AUTONOMOUS** and **REMOTE-CON** notations.

While there are no requirements for compliance to the **ISQM**, **SQM**, **CS-System**, **CS-1** and **CS-2** notations for low risk functions, nonetheless, they are recommended.

TABLE 3
Prerequisite Notations

	Risk Level		
	Low	*Medium*	*High*
AUTONOMOUS notation			
Cyber Security (See 5/2.9)	To comply with requirements in section 5/2.9.3(a).	**CS-System** notation is required for cyber-enabled systems necessary for the Function.	**CS-1** or **CS-2** notation requirements are to be satisfied. The notation may be granted upon request.
Software (See 5/3.3)	To comply with requirements in 5/3.3.3(a).	**ISQM** or **SQM** notation requirements, or equivalent, are to be satisfied. If ISQM or SQM notation requirements are satisfied, the notation may be granted upon request.	
REMOTE-CON notation			
Cyber Security (See 5/2.9)	To comply with requirements in section 5/2.9.3(a).	**CS-System** notation is required for cyber-enabled systems necessary for the Function.	**CS-1** or **CS-2** notation requirements are to be satisfied. The notation may be granted upon request.
Software (See 6/3.3)	To comply with requirements in 5/3.3.3(a).	**ISQM** or **SQM** notation requirements, or equivalent, are to be satisfied. If ISQM or SQM notation requirements are satisfied, the notation may be granted upon request.	

Note:

Each function is to be assigned a risk level (low risk level, medium risk level or high risk level). The parameters considered in the assignment of the risk levels are the function's operations supervision level and the consequences of failure. Refer to Subsection 4/2.

14 Abbreviations and Acronyms

The following abbreviations and acronyms are applied to the terms used in this document:

ABS: American Bureau of Shipping

AIAA: American Institute of Aeronautics and Astronautics

ALARP: As Low As Reasonably Practicable

COLREG: Convention on the International Regulations for Preventing Collisions at Sea

CONOPS: Concept of Operations

CRMS: CyberSecurity Risk Management Systems

FDD: Functional Description Document

FMEA: Failure Modes and Effects Analysis

FMI: Functional Mockup Interface

GBS: Goal Based Standards

HIL: Hardware-in-the-loop

HMI: Human Machine Interface

HVAC: Heating, Ventilation and Air Conditioning

I/O:	Input / Output
IEC:	International Electrotechnical Commission
IEEE:	Institute of Electrical and Electronics Engineers
IMO:	International Maritime Organization
ISO:	International Organization for Standardization
ISQM:	Integrated Software Quality Management
IT:	Information Technology
LNG:	Liquefied Natural Gas
LPG:	Liquefied Petroleum Gas
MARPOL:	International Convention for the Prevention of Pollution from Ships
MASS:	Maritime Autonomous Surface Ship
MIL:	Model-in-the-loop
MSC:	Maritime Safety Committee
OT:	Operational Technology
SIL:	Software-in-the-loop
SOLAS:	International Convention on the Safety of Life at Sea
SMS:	Safety Management System
UPS:	Uninterruptible Power Systems

15 References

15.1 ABS

ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)*

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

ABS *Guidance Notes on Review and Approval of Novel Concepts*

ABS *Guidance Notes on Qualifying New Technologies*

ABS *Guide for Smart Functions for Marine Vessels and Offshore Units*

ABS *Guide for Cybersecurity Implementation for the Marine and Offshore Industries – ABS CyberSafety™ Volume 2*

ABS *Guide for Software Systems Verification – ABS CyberSafety®, Vol. 4*

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

ABS *Guidance Notes on Smart Function Implementation*

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

ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification*

ABS *Guidance Notes on Management of Change for the Marine and Offshore Industries*

ABS *Guide for Marine Health, Safety, Quality, Environmental and Energy Management*

ABS *Advisory on Autonomous Functionality*

ABS *Advisory on Data Quality for Marine and Offshore Application*

15.2 Other References

SOLAS: *International Convention for the Safety of Life at Sea*

MARPOL: *International Convention for the Prevention of Pollution from Ships*

COLREG: *Convention on the International Regulations for Preventing Collisions at Sea*

ISM Code: *International Management Code for the Safe Operation of Ships and for Pollution Prevention*

STCW Convention and STCW Code: *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,1978, as amended; and Seafarer's Training, Certification and Watchkeeping Code, as amended*

ISO/IEC/IEEE 24765: *Systems and software engineering - Vocabulary*

ISO/IEC/IEEE 29148*: Systems and software engineering – Life cycle processes – Requirements engineering.*

ISO/IEC 31010*: Risk management – Risk assessment techniques*

IMO MSC.1/Circ.1394*: Generic Guidelines for Developing IMO Goal-Based Standards*

IMO MSC 98/23*: Report of the Maritime Safety Committee on its Ninety-Eight Session,* International Maritime Organization, 28 June 2017

IMO MSC 100/WP.8: *Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS) - Report of the Working Group,* International Maritime Organization, 6 December 2018

IMO MSC 101/WP.8: *Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS) - Report of the Working Group,* International Maritime Organization, 12 June 2019

IMO MSC 101/24: *Report of the Maritime Safety Committee on its 101st Session,* International Maritime Organization, 12 July 2019

IMO MSC.1/Circ.1455: *Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments*, International Maritime Organization, 24 June 2013

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T. B. Sheridan and L. W. Verplank, "Human and Computer Control of Undersea Teleoperators," 1978

A. Kossiakoff, S. Seymour, D. Flanigan, S. Biemer, "Systems Engineering Principles and Practice", 3rd edition.

16 Type Approval Program

Products that can be consistently manufactured to the same design and specification may be Type Approved under the ABS Type Approval Program. When approval of such products and components is requested, applicants should contact ABS for the approval process. For ABS Type Approval Program requirements, refer to 1-1-4/7.7, Appendix 1-1-A3, and Appendix 1-1-A4 of the ABS *Rules for Conditions of Classification (Part 1)*. Alternative certification arrangements are also available in 1-1-A3/5.5 of the ABS *Rules for Conditions of Classification (Part 1)*.

ABS is able to issue a Product Design Assessment (PDA) to components being employed to deliver the autonomous or remote control function(s). These components may reside in a single constituent system or may be distributed amongst multiple constituent systems. The PDA is to cover both functional and applicable system review covering hardware and software utilized to deliver the function.

The PDA is to cover applicable requirements in Sections 5 or 6 for the risk level appropriate to the function and scope. The approved function, scope and risk level are to be recorded in the PDA certificate.

Note:

Each function is to be assigned a risk level (low risk level, medium risk level or high risk level). The parameters considered in the assignment of the risk levels are the function's operations supervision level and the consequences of failure. Refer to Subsection 4/2.

SECTION 2
Implementation Process

1 General

This section describes the implementation process of autonomous or remote control functions. This process can be implemented at the new construction stage or modifications to existing vessels.

2 Autonomous Framework

2.1 General

This sub-section describes a goal-based framework to guide the implementation of the functions. This framework is based on the *IMO Generic Guidelines for Developing IMO Goal-Based Standards (MSC.1/ Circ. 1394)*.

Goal Based Standards (GBS) as defined by the above -mentioned IMO Circular are:

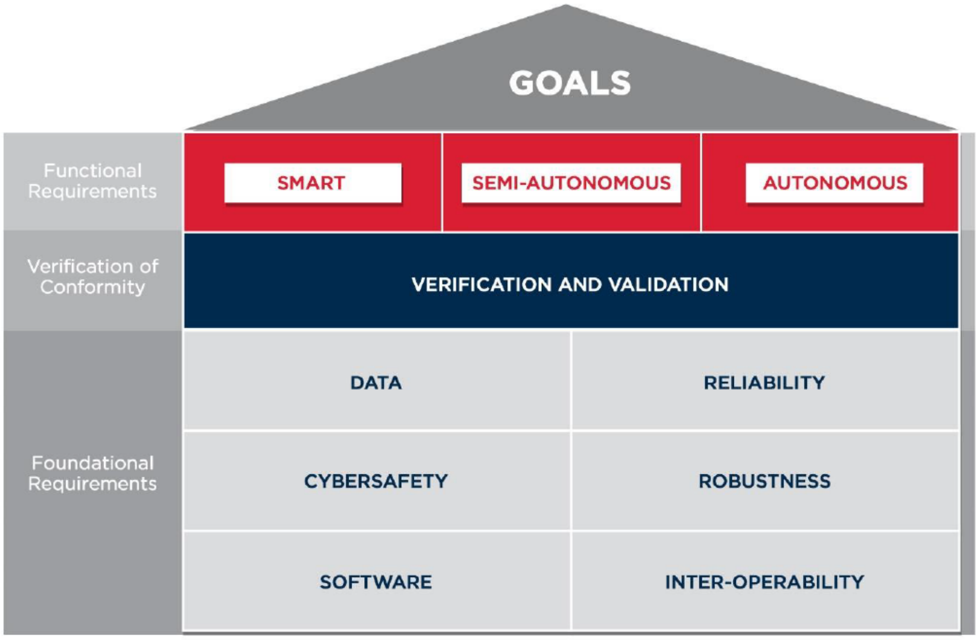
"*High-level standards and procedures that are to be met through regulations, rules and standards for ships. GBS are comprised of at least one goal, functional requirement(s) associated with that goal and verification of conformity that rules/regulations meet the functional requirements including goals*."

The ABS approach to autonomous development builds upon the key principles established in the following publications:

- ABS *Guidance Notes for Smart Function Implementation*
- ABS *Guide for Smart Functions for Marine Vessels and Offshore Units*
- ABS *Guidance Notes on Review and Approval of Novel Concepts*
- ABS *Guidance Notes on Qualifying New Technologies*

This framework is scalable. It can be applied by itself to a single autonomous or remote control function, a system or a system of systems. For more complex functions or for the development project of a fully autonomous vessel with multiple functions and systems, it can be scaled up with multiple functions / systems forming system goals and subordinate goals which support an over-arching goal.

FIGURE 1
Smart to Autonomous Goal Based Approach



2.2 Goals

Goals are high-level objectives to be met. They should address the issues of concern and reflect the required level of safety. In the implementation process during the development of autonomous or remote control functions, a typical over-arching goal would be that the function is to be designed, constructed, operated and maintained for its planned mission safely, reliably and predictably.

2.3 Functional Requirements

Functional requirements provide the criteria to be satisfied in order to meet the goals. Functions being implemented to meet the goals can be categorized into smart, semi-autonomous or autonomous. This categorization is dependent on the functions' capability and its coverage of the different stages in the operational decision loop.

Functional requirements are to support the stated goals and they are developed based on experience, an assessment of existing regulations, manning requirements and/or systematic analysis of relevant hazards.

For Smart Functions, please refer to the ABS *Guidance Notes on Smart Function Implementation* and the ABS *Guide for Smart Functions for Marine Vessels and Offshore Units*.

2.4 Verification of Conformity

Verification of conformity establishes the method and criteria to demonstrate and verify that the function's specifications and implementation conforms to the goals and functional requirements and addresses the safety of the operation of the vessel.

Recognizing that the functions introduced in this document are new and may not yet be comprehensively covered by conventional prescriptive requirements and regulations, the framework is supported by Verification and Validation principles laid out in the ABS *Guidance Notes on Qualifying New Technologies* and the ABS *Guidance Notes on Review and Approval of Novel Concepts*.

2.5 Foundational Requirements

The technologies utilized for autonomous and remote control functions will be highly reliant on connectivity, data and software. Underpinning the framework are the foundational requirements established in the ABS Rules, ABS *Guide for Smart Functions for Marine Vessels and Offshore Units*, ABS *Guide for Integrated Software Quality Management (ISQM)*, and the CyberSafety, Data Integrity and Software series of publications.

These functions rely heavily on software and digital tools. There is also the potential for minimized or negligible human involvement in the operations. In order to maintain or improve the safety of operations with the use of these functions, it is crucial that the functions and systems be designed with reliability, robustness and interoperability in mind, and with consideration for minimal on-board human observation, supervision and intervention.

See Section 2/Table 1 for a list of important foundational requirements.

TABLE 1
Foundational Requirements

DATA	RELIABILITY
CYBERSAFETY	ROBUSTNESS
SOFTWARE	INTER-OPERABILITY

2.5.1 Data

Data will be a core ingredient powering the marine and offshore industries move to a digital future. When implementing autonomous functions utilizing operational data, the availability and integrity of high quality data is essential. The ABS *Advisory on Data Quality for Marine and Offshore Application* addresses concerns and issues related to data quality. Autonomous functions utilizing data analytics techniques are to comply with 5/3.5.

2.5.2 CyberSafety

Cyber security is a key safety concern in the implementation of autonomous and remote control functions. Established cyber security requirements tailored to the marine and offshore industries can be found in the ABS *Guide for Cybersecurity Implementation for the Marine and Offshore Industries*. Autonomous and remote control functions are to comply with the cyber security requirements in 5/2.9.

2.5.3 Software

Verification of software used in the systems, their integration and management throughout the life cycle of the functions is an important element. Autonomous and remote control functions are to comply with the requirements in 5/3.3.

2.5.4 Reliability

Reliability is defined as the "*ability of an item to perform a required function under given conditions for a given time interval*" (ISO 14224).

Conventional vessel operations require constant human-in-the-loop involvement. This will likely not be the case for vessels equipped with autonomous or remote control functions. Therefore, it is likely that the time for on-site monitoring of equipment may be reduced.

This will require increased levels of reliability of the systems and equipment involved in the delivery of the function. In order to achieve this, greater attention on the following factors will be required during the engineering and design stages: redundancy, software reliability and simplicity and system modularity.

This document takes a holistic approach to reliability:

- The V-Model Implementation Process and Management of Change in Subsection 2/4
- Concept of Operations in Section 3
- Risk Assessment in Section 4
- Software quality and reliability

2.5.5 Robustness

Robustness is defined as the "*the degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions*" (ISO/IEC/IEEE 24765It refers to the state or condition where the technology, product or process performance is minimally sensitive to factors that cause variability. As such, the function is to be able to operate in a normal or predictable manner in the event of changes or unforeseen conditions in the operating environment.

Design for robustness is a thread which runs through the approach in this document from the concept phase through the requirements and design phase, engineering phase, verification and validation phase, deployment phase and into the operations and maintenance phase.

2.5.6 Interoperability

Interoperability is defined as the "*capability of objects to collaborate, that is, the capability mutually to communicate information in order to exchange events, proposals, requests, results, commitments and flows*" (ISO/IEC/IEEE 24765). With the increased inter-connectivity and dependency between multiple constituent systems, it is crucial that interoperability between these systems are thoroughly understood and tested. It is also crucial that emergent behavior of these systems working in-concert as a system-of-systems be understood. A key element and focus of the engineering phase and verification and validation phase is to verify the proper integration of the various constituent systems in the function.

3 System-of-Systems

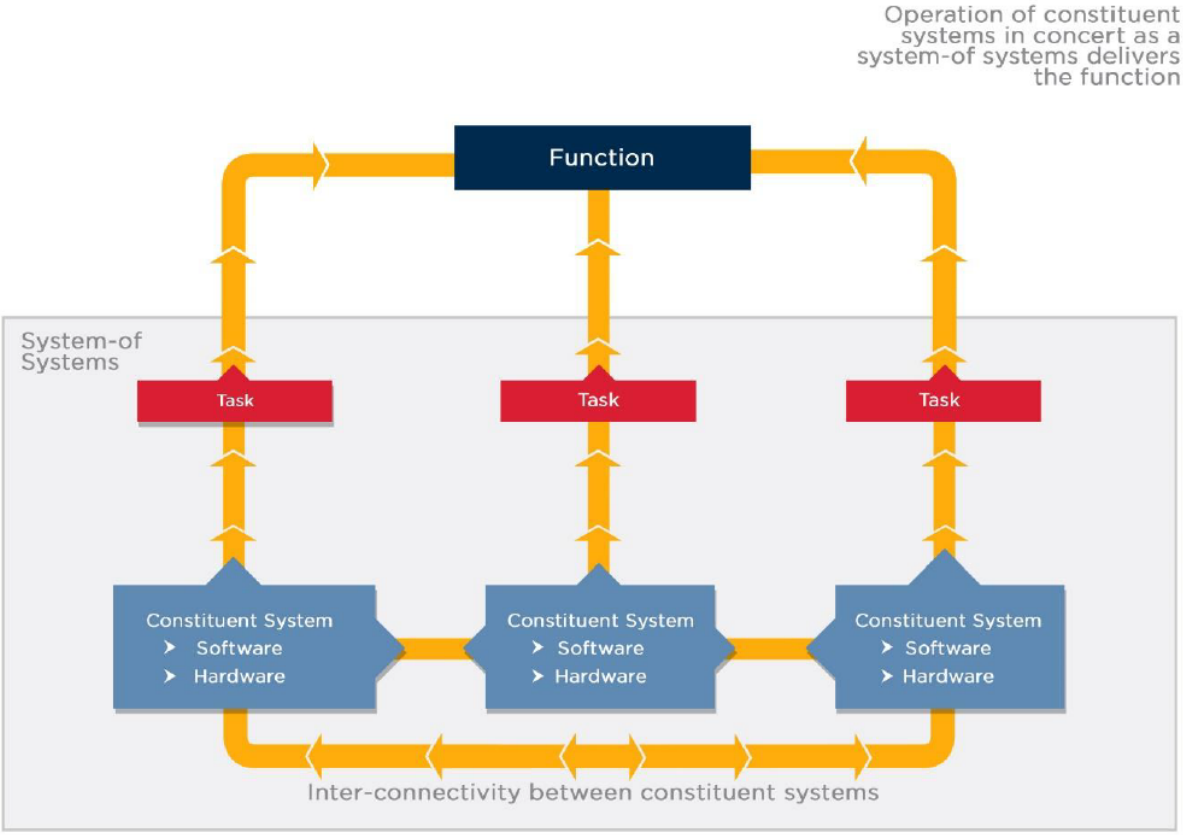
An autonomous and remote control function may be delivered by a single system. However, it is more likely that the function will be delivered by multiple constituent systems working in-concert as a system-of-systems.

While the concept of a system-of-systems is not new, there is no single definition for 'system-of-systems' in the industry. For the purpose of this document, the following definition is adopted:

System-of-Systems: The large-scale integration of many independent task-oriented systems to create a larger, more complex system which offers more functionality and performance than simply the sum of the constituent systems.

Section2/Figure 2 shows the example of a system-of-systems delivering a function.

FIGURE 2
System-of-Systems



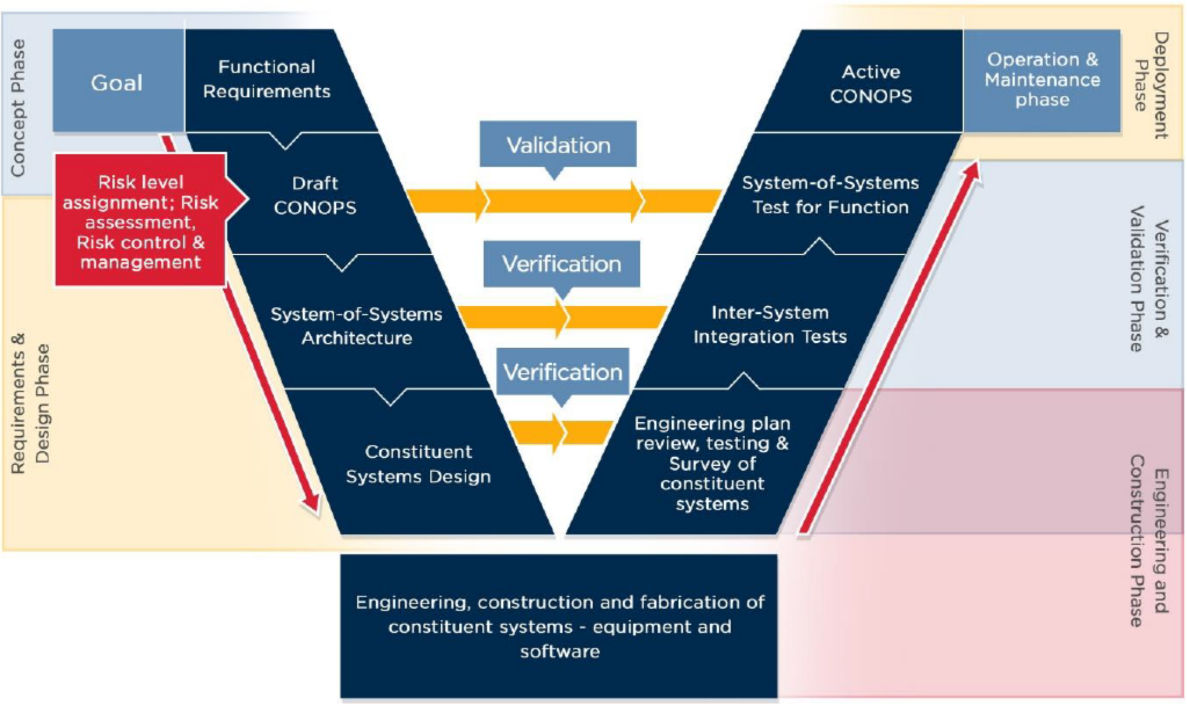
4 Implementation Process

4.1 General

The implementation process for autonomous and remote control functions follows the V-Model Implementation Process seen in Section2/Figure 3, which is an expansion of the standard systems engineering system development model. This model covers the life cycle of the system-of-systems from concept to the operations and maintenance phase. This model can be utilized for the implementation of a new function and also for modification to an existing function.

This V-Model is comprised of a sequence of stages that overlap and are iterative. The V-Model can be divided into two portions i.e. system-of-systems and constituent systems.

FIGURE 3
V Model Implementation Process for Autonomous and Remote Control Functions



4.2 Concept Phase

The concept phase is the first stage which provides the direction, scope and overall picture of the function.

The goals and objectives are to be defined. The function is to be selected and functional requirements providing the criteria to be satisfied are to be drafted.

The main objectives of this phase are to:

i) Define the Goal(s)

ii) Define the functional requirements of the function

iii) Produce a draft Concept of Operations (CONOPS) which will be developed and refined through the course of the implementation process of the function. Please refer to Section 3.

4.3 Requirement and Design Phase

In the requirement and design phase, the Draft CONOPS developed in the concept phase is to be translated to detailed requirements and initial design parameters.

The risk level assignment and risk assessment required in accordance with Section 4 is to be carried out in this phase. The requirements and design of the system-of-system and its constituent systems are dependent on the function's assigned risk level and the results of the risk assessment.

The main objective of this phase is to:

i) Assign risk level to the function

ii) Perform risk assessment

iii) Plan procedures for risk control and management *iv)* Define the system-of-systems architecture

v) Define the requirements for the constituent systems

4.4 Engineering Phase

In the engineering phase, detailed engineering will be carried out for the constituent systems, inter-connectivity between these systems and their integration into a system-of-systems delivering the function. Additionally, test plans are to be prepared and reviewed by ABS in this phase.

The main objective of this phase is to:

i) Produce detailed engineering documents

ii) Prepare required test plans

Please refer to Sections 5 and 6.

4.5 Verification & Validation Phase

The verification and validation phase in the V-Model Implementation Process takes a bottom-up approach.

It starts with the verification that equipment based on conventional technology used in the constituent systems comply with established Rule requirements. This is carried out via engineering plan review, tests and Surveys as required in the applicable Rules. For novel equipment for which there are no existing applicable Rules, verification is to be carried out in accordance with the ABS *Guidance Notes on Qualifying New Technologies* and the ABS *Guidance Notes on Review and Approval of Novel Concepts*.

Software will play an integral part in the implementation of autonomous and remote control functions. Verification is carried out via engineering plan review, tests and Surveys. Please refer to Sections 5 and 6.

Inter-system integration tests between the various constituent systems are to be carried out to demonstrate successful integration.

System-of-Systems Test for Function is to be carried out to validate the performance of the function in its intended operational environment or a simulated environment as close as possible to its intended operational environment.

The Test Program for the Function is to be submitted for approval. Refer to 7/3.1.

The main objectives of this phase are to:

i) Complete plan review, tests and Surveys of constituent systems

ii) Complete inter-system integration and System-of-Systems Test for Function

4.6 Deployment Phase

At the completion of the verification and validation, a final and comprehensive Concept of Operations (CONOPS) document is to be submitted for approval. Please see Section 3.

4.7 Operations & Maintenance Phase

Satisfactory operation and maintenance of autonomous or remote control functions installed on board the vessel will be confirmed by the Surveyor during annual and special surveys in accordance with a Survey Program. See Section 8 for Survey After Construction requirements.

Changes are to be managed in accordance with the approved Management of Change procedures.

5 Integration of Function with Vessel

The implementation process is to consider not only the verification of the autonomous or remote control functions themselves, but also verify the potential impact of the implementation of these functions on the conventional aspects of the vessel and operations.

This verification is critical to confirm:

- There will be no adverse impact on other functions on the vessel and its operations, and
- The application of existing Rules, regulations and standards to conventional equipment and systems will still be valid.

6 Management of Change

An effective Management of Change program is required and is to be reviewed by ABS as part of cybersecurity and overall system reliability reviews.

The 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 to system or vessel operational characteristics, performance or safety.

Change includes the hardware modification and replacement, software patching and version upgrading, data analytics model revision, data source or data structure change, change to the Concept of Operations, changes to staffing levels or operator qualification requirements, etc.

Upon completion of risk assessments and as the proposed function system design proceeds into the 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 function system is commissioned.

Whenever a change is made, the potential consequences of that change are to be assessed before implementation. Risk Assessments are to be re-executed if the change may alter the scope and objectives of the original risk assessment. Related documents such as the Concept of Operations, System-of-Systems Test plan, and Operational Procedures are to be reevaluated and where necessary are to be submitted to ABS for review.

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

7 Statutory Considerations

7.1 Involvement of Flag State, coastal State and/or port State Authorities

Implementation of autonomous and remote control functions which have an impact on satisfying regulatory requirements will require prior authorization of the vessel's flag State Administration. Necessary authorization may also be required from the coastal State and/or port State Authority where the vessel will operate.

Involvement of flag State, coastal State and/or port State Authorities will be critical and consultations with these parties should be carried out early in the project.

Implementation of autonomous and remote control functions is to comply with requirements and regulations imposed by flag State, coastal State or port State, as applicable.

7.2 Compliance

As far as practicable, implementation of the function is to comply with the intent of mandatory IMO instruments.

To determine compliance with the intent of applicable statutory requirements, the following are to be identified:

i) Applicable statutory requirement(s)

ii) Intent of the said requirement(s)

iii) Mitigating measures or alternative methods to enable the intent of the said regulations and requirements to be met

The scope of application of mandatory instruments, including provisions for exemptions and equivalencies should be determined by the flag State Administration in accordance with those instruments.

7.3 Interim Guidelines for MASS Trials (IMO MSC.1/Circ.1604)

The Guidelines in IMO MSC.1/Circ.1604 have been developed to assist relevant authorities and relevant stakeholders with ensuring that the trials of Maritime Autonomous Surface Ships (MASS) related systems and infrastructure are conducted safely, securely and with due regard to the protection of the environment.

These Guidelines provide guidance to:

i) relevant authorities:

a) coastal State;

b) flag State; and

c) port State; and

ii) relevant stakeholders such as shipowners/authorized representatives, operators and other involved parties in the conduct of MASS trials.

All stakeholders should be cognizant of the principles and guidance in this Guidelines. Compliance with the principles in this IMO Guideline is recommended.

7.4 Operator in Remote Location and Remote Control

Existing Rules and Regulations are created based on the premise that the vessel will always be manned by responsible persons or operators located on board the vessel. The Remote Operator and remote control conditions in which certain functions or certain parts of a function are being supervised or controlled from a remote location away from the vessel is a new concept in marine and offshore operations.

The flag State, coastal States and/or port State authorities are to be approached for discussions and where necessary, to obtain required approvals and exemptions. There may also be local requirements governing the operation of remote operator and remote control stations such as shore based work, health and safety regulations. The stakeholders of the project are to be aware of these requirements and address them.

The context of current regulatory guidance differs from the highly automated environment, but the remote operator must meet communications, timeliness of response, safety, and General Prudential Rule and Rule of Good Seamanship requirements at all times.

8 Key Stakeholders

Cooperation among all stakeholders and clearly defined roles for each implementation stage are a crucial factor for successful implementation. The following summarizes a suggested approach for various stakeholders. The descriptions in the Section 2/Table 2 may not apply to all business scenarios.

The key stakeholders include but are not limited to the following:

i) Vessel operator

ii) Vessel builder

iii) Function integrator

iv) Constituent system providers / vendors

v) Crew

vi) Flag Administration

vii) Port Authorities

viii) ABS

TABLE 2
Typical Stakeholder Roles for Autonomous and Remote Control Function Implementation

Stage	*Main Purpose*	*Vessel Operator*	*System Providers / Vendors*	*Function Integrator*	*ABS*
Goal Setting	Identify the overall goal for the implementation	Lead	Support	Support	Support
Function Identification	Identify the autonomous and / or remote control functions and their objective to fulfill the goals	Lead	Support	Support	Support
Description of the Function	Describe the function	Lead	Support	Support	Verify
Concept of Operations	Develop a Concept of Operations document intended to give an overall picture of the operations of the autonomous and / or remote control function and its operational environment	Lead	Support	Support	Verify
Risk Level Assignment	Assign Risk Level to autonomous and / or remote control function	Lead	Support	Support	Verify
Risk Assessment	Carry out Risk Assessment	Lead	Support	Support	Verify
System-of-Systems Architecture	Design system-of-systems architecture. Identify constituent systems necessary to perform the Function.	Support	Support	Lead	Verify
Design and Engineering of Constituent Systems	Carry out design and engineering activities in cognizant of technical requirements due to risk level	Lead	Support	Support	Verify
Installation and Commissioning	Install and commission constituent systems carrying out the function	Support	Support	Lead	Verify
Inter-system Integration	Integration of constituent systems	Support	Support	Lead	Verify
Trials / System-of Systems Test for Function	The installed system-of-systems and function implemented are to undergo trials.	Support	Support	Lead	Verify

Stage	*Main Purpose*	*Vessel Operator*	*System Providers / Vendors*	*Function Integrator*	*ABS*
Deployment	Deploy the function in its intended operational environment	Lead	Support	Support	Validate
Operations and Maintenance	Affirm the function's operability and reliability. Affirm the achievement of the identified implementation goals. Prepare Management of Change plan. Manage changes in accordance with Management of Change plan.	Lead	Support	Support	Verify

SECTION 3
Concept of Operations

1 General

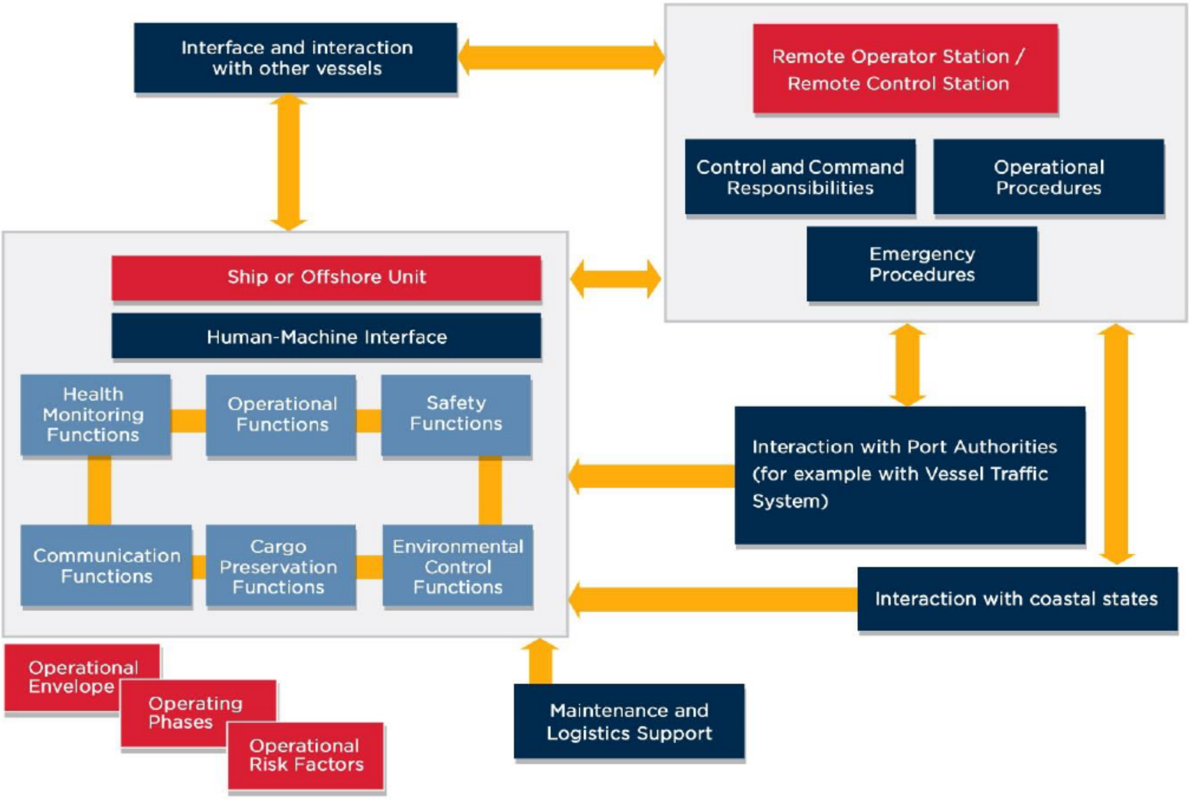
The implementation of autonomous and remote control functions will see greater cross-systems integration, human-system integration and closer interfacing and integration with external systems, for example with the Vessel Traffic Service (marine traffic management system). A system-of-systems approach is necessary for the safe implementation of autonomous and remote control functions.

The Concept of Operations principle used in systems and software engineering can be adapted for use in the implementation of autonomous and remote control functions. It is prepared initially to support the concept and development stages and then maintained throughout the program to support the production, utilization, support and retirement stages of the system life cycle.

The Concept of Operations is intended to give an overall picture of the operations of the autonomous and/or remote control function using one or more specific constituent systems, or set of related constituent systems in the operational environment in which the function operates. The systems mentioned are not limited to the systems on board the asset but may also include systems outside of the asset with which the function relies on or interacts with.

The Section 3/Figure 1 below provides an example of the holistic considerations which will be necessary in the development of a Concept of Operations Document (CONOPS).

FIGURE 1
Considerations for the Development of a Concept of Operations Document



2 Concept of Operations Document

2.1 Goal

The goals of the Concept of Operations Document (CONOPS) are to:

i) provide a clear vision of the intended use and the resulting benefits of the function

ii) facilitate a clear understanding of the system context and the stakeholders' view of the function

iii) present information related to the background, operational concepts, assumptions and requirements of the autonomous and remote control function(s) in a format that can be understood and utilized by all stakeholders

iv) highlight differences between current/conventional operations and desired future operations

v) provide the basis for system validation

To meet these goals, a Concept of Operations Document should:

i) describe the desired function features and characteristics from an operational perspective

ii) provide a description of the operational environment and operational envelope

iii) describe how the function will be used

iv) facilitate understanding of the overall function goals among stakeholders

v) form an overall basis for long-range operations planning and provide guidance for development of subsequent system definition documents such as the function and interface specification *vi)* describe system response to conditions outside the normal operating conditions (ie a component failure, extreme environmental conditions, etc.)

2.2 Content

The list below provides a guidance on the list of content required for the CONOPS.

i) General	*a)*	Objectives of the proposed function
	b)	Scope of the proposed function
	c)	Description and overview of the proposed function
	d)	Expected reliability requirements of the proposed function
ii) Functional integration	*a)*	Operational policies and constraint
	b)	Performance and reliability characteristics
	c)	Capabilities, functions/services and features
	d)	Limitations and boundaries of function
	e)	Integration with related onboard functions
	f)	Major system elements and the interconnection among those elements
iii) Operational environment & scenarios	*a)*	Operational Envelope - Intended Area of Operations and Details/ Limitations/Restrictions
	b)	Defined Planned Voyage and Operation Phases with supportive Methods of Control
	c)	Characteristics of operational environment
	d)	Modes of operation
	e)	Major elements and the interconnection among those elements
	f)	Interfaces to external systems or procedures
	g)	Interface with other stakeholders in the environment for example other vessels/units, port State and coastal State.
	h)	Operational risk factors
	i)	Provisions for safety, security, integrity and continuity of operations in emergencies
	j)	Logistics requirements

iv) Human- systems integration	***a)*** Human-in-the-loop involvement ***b)*** Operator characteristics and required qualifications ***c)*** Organizational structure – onboard asset and in Remote operating center (where applicable) ***d)*** Interactions among users ***e)*** Human-machine interface ***f)*** Alarms ***g)*** Conditions for manual intervention and retaking of control by operator ***h)*** Operational Procedures ***i)*** Communication equipment
v) Summary of impacts	***a)*** Operational impacts ***b)*** Organizational impacts ***c)*** Impacts on operational environment ***d)*** Overall impact on the design and engineering of the asset ***e)*** Regulatory compliance impact ***f)*** Impact on maintenance

2.3 Concept of Operations Version Maintainability

The Concept of Operations Document is to be a version-controlled living document and is to be kept constantly updated. Modifications to the Concept of Operations Document which are material to the conduct and operations of the autonomous or remote control function are to be submitted to ABS for review. This is to include but is not limited to the following changes:

- Changes that impact the overall goal of the function or the vessel
- Performance characteristics
- Limitations and boundaries of the function
- Changes to operational envelope
- Technical/system modifications
- Changes in human-in-the-loop involvement

SECTION 4

Risk Categorization and Assessment

1 General

This document uses a risk-informed approach to set the prescriptive requirements for ABS verification and validation activities. The risk category levels consider the safety related risk factors, potential consequences of autonomous or remote control function failure or under-performance on the vessel's safety and operations, potential impact of failure of associated vessel systems on the autonomous or remote control function and the ability of the Operator to regain control of the Function and vessel in the event of failure of the autonomous or remote control function.

2 Assignment of Risk Category Level

Each function is to be assigned a risk category level based on the approach described below. The risk category level is to be identified in accordance with this Subsection. This is to be documented and submitted to ABS for review.

2.1 Operations Supervision Levels

The Section 4/TABLE 1 below shows the Operations Supervision Levels. See Subsection 1/9 for details.

TABLE 1
Operations Supervision Levels

Operator Location	*Required Attention Level*	*Operations Supervision Level*
Onboard vessel	Continuous supervision	OP1
Onboard vessel	Periodic supervision	OP2
Onboard vessel	As needed basis (System notification or operational mode)	OP3
Remote location	Continuous supervision	RO1
Remote location	Periodic supervision	RO2
Remote location	As needed basis (System notification or operational mode)	RO3

2.2 Consequences of Failure and Category *(1 August 2022)*

Consequences of Failure is defined according to the potential of risk to human safety, damage to the vessel and impact on environment that may be caused by a failure of the Autonomous or Remote Control Function.

TABLE 2
Consequences of Failure and Category (1 August 2022)

Consequence Category	*Consequences of Failure*	*Typical Functions*
Category I	Failure will not lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment	Functions related to non-essential services.
Category II	Failure could eventually lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment.	Functions which are necessary to maintain the ship in its normal operational and habitable conditions
Category III	Failure could immediately lead to dangerous situations for human safety, safety of the vessel and/or threat to the environment.	Functions for maintaining the vessel's propulsion and steering Vessel safety functions

2.3 Risk Matrix *(1 August 2022)*

Risk levels are to be assigned based on the Operations Supervision Level and Consequences of Failure/ Category.

Section 4/TABLE 3 below is to be utilized to assign a risk category level (L: Low, M: Medium, H: High) to each of the Functions implemented on each vessel.

TABLE 3
Risk Category (1 August 2022)

Operations Supervision Levels and Consequence Category		*RO1*	*RO2*	*RO3*	*Without Remote Operator*
Autonomous Functions					
OP1	Category I	Low	Low	Low	Low
	Category II	Low	Low	Low	Low
	Category III	Low	Low	Low	Low
OP2	Category I	Low	Low	Low	Low
	Category II	Medium	Medium	Medium	Medium
	Category III	Medium	Medium	Medium	Medium
OP3	Category I	Low	Low	Low	Low
	Category II	Medium	Medium	Medium	Medium
	Category III	Medium	Medium	Medium	Medium
Without Onboard Operator	Category I	Medium	Medium	Medium	
	Category II	Medium	High	High	
	Category III	High	High	High	
Remote Control Functions					
OP1	Category I	Low	Low	Low	
	Category II	Low	Low	Low	
	Category III	Low	Low	Low	

Operations Supervision Levels and Consequence Category		*RO1*	*RO2*	*RO3*	*Without Remote Operator*
OP2	Category I	Low	Low	Low	
	Category II	Medium	Medium	Medium	
	Category III	Medium	Medium	Medium	
OP3	Category I	Low	Low	Low	
	Category II	Medium	Medium	Medium	
	Category III	Medium	Medium	Medium	
Without Onboard Operator	Category I	Low	Medium	Medium	
	Category II	Medium	High	High	
	Category III	High	High	High	

3 Risk Assessment

3.1 General

As detailed in the framework in Subsection 2/2,the high-level goal in the implementation process of autonomous and remote control functions is that it is to be designed, constructed, operated and maintained for its planned mission safely, reliably and predictably. In this context, the intent of risk management and risk assessment activities are:

i) Safe implementation of autonomous or remote control function on the vessel

ii) Proper integration of the autonomous or remote control function with other onboard systems

iii) Reduction of risks to as low as reasonably practicable (ALARP) and confidence that a failure will not lead to an uncontrollable situation

iv) Control and management of risk throughout the life cycle of the vessel

3.2 Risk Assessment Plan

A risk assessment plan is to be developed and submitted to ABS for review.

The risk assessment plan should describe:

i) Description of proposed Function

ii) Quantitative or Qualitative Risk assessment method(s) to be used and description if using a non-standard method

iii) Scope and objectives of the assessment

iv) Subject matter experts/participants/risk analysts, including their background and area of expertise

v) Proposed risk acceptance criteria or risk matrix

vi) Risk control and management measures

Further guidanceon submitting a risk assessment plan can be found in the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries* and ABS *Guidance Notes on Qualifying New Technologies*.

The risk assessment is to address all interactions between new technologies via the New Technology Qualification (NTQ) process, conventional technologies, system-of-systems integration, role and responsibilities of the human operator, human-machine interface, operational environment and interactions between the Function and external parties.

3.3 Risk Assessment Techniques

The selected risk assessment techniques are to be suitable for the intended function.

Please refer to the ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Industries* for reference.

SECTION **5**

Autonomous Functions

1 General

This section seeks to:

- Provide the requirements which have to be complied with in order to obtain the **AUTONOMOUS** notation
- Provide a method to assess the operations and requirements for the operations of the function in its intended operational environment
- Provide a method to assess and mitigate the risks of the operations of the function in its intended operational environment
- Provide guidance on the implementation process of the function in accordance with Subsection 2/4.
- Provide guidance on the foundational requirements that should be considered in the implementation of the function

2 Requirements

2.1 Criteria

The function is to be clearly identified.

The function may reside within a single system or it may be performed by a combination of multiple constituent systems working in concert to deliver the function.

The function is to be categorized as either Semi-Autonomous or Autonomous in accordance with the Autonomy levels in Subsection 1/4.

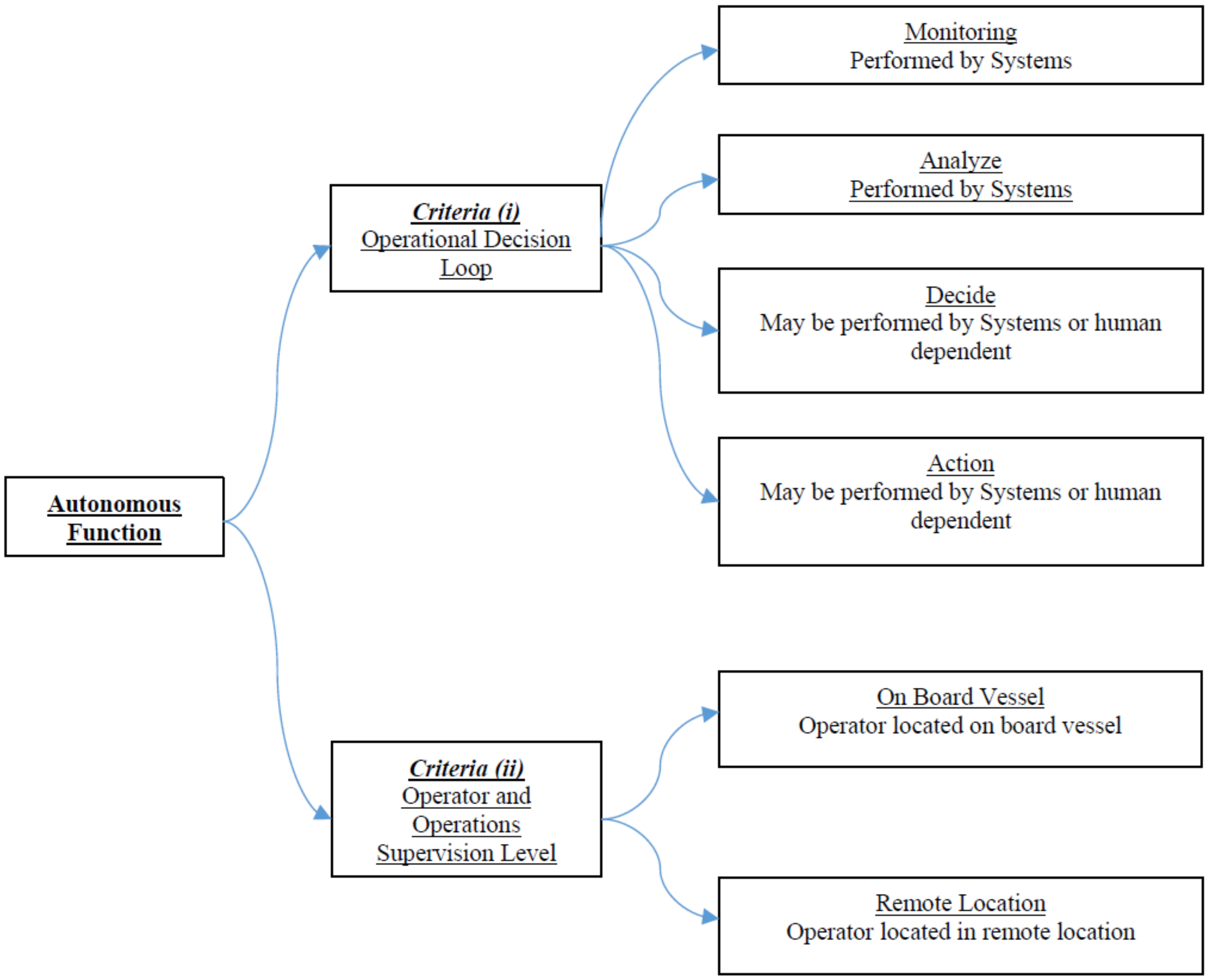
TABLE 1
Autonomy Levels

Autonomy Levels		*Integration and Application to Decision Loop*				*Typical available notations/Operations Supervision level*
		Monitoring	*Analysis*	*Decision*	*Action*	
1	Smart	S	S	H	H	**SMART**
2	Semi-Autonomous	S	S	S/H	S/H	**AUTONOMOUS** (function category, OP2/OP1/RO2/RO1)

Autonomy Levels		*Integration and Application to Decision Loop*				*Typical available notations/Operations Supervision level*
		Monitoring	*Analysis*	*Decision*	*Action*	
3	Autonomous	S	S	S	S	**AUTONOMOUS** (function category, OP3/RO3)
Note: H – Human, S- System						

An operator is to be designated. Responsibility for the performance of the Autonomous Function is assigned to the operator. The operator is to have oversight and capability to intervene and override actions made by the function.

FIGURE 1
Criteria for Autonomous Functions



2.1.1 Operational Decision Loop

The monitoring, analysis and decision stages of the operational decision loop are to be carried out by systems/machines.

The action stage may be carried out by systems/machines or humans.

i) The function is to demonstrate a level of situational awareness of the process it is executing (Monitoring)

ii) The function is to be able to evaluate the inputs which it is receiving (Analyze)

iii) The function is to be able to offer up options for the course of action and decide based on the options provided by the Function (Decision)

iv) The function is to be able to execute the decision (Action). Alternatively, this stage may be carried out by humans.

2.1.2 Operator and Operations Supervision Level

An operator is to be designated and will have responsibility over the Autonomous Function. The operator may be physically located onboard the vessel or in a remote location. The operator station is to be constantly manned.

i) The operator is to supervise the function executions either continuously, periodically or as needed

ii) The operator is to be able to intervene, override, and take over the operation when deemed necessary by the operator

These parameters are to be indicated in the Operations Supervision Level entry of the notation. See Subsection 1/9.

2.2 Concept of Operations Document (CONOPS)

A Concept of Operations document (CONOPS) in accordance with Subsection 3/2 is to be submitted for review.

It is acknowledged that in the implementation process, the CONOPS is an evolving document. A draft CONOPS is to be submitted at the beginning of the project.

At the completion of the verification and validation phase, a final and comprehensive CONOPS is to be submitted for approval.

The CONOPS is to identify and consider, but is not limited to:

- Necessary logistical support for the operation of the autonomous function.
- Maintenance activities of the function and system(s) required for the operation of the autonomous function.
- Operational risk factors and mitigating measures for the autonomous function.
- The limitations and operating boundaries of the autonomous function.
- Procedures for transfer of control are clearly defined and documented.
- Emergency response and rescue procedures.
- Description of the number of personnel, roles and responsibilities, and organizational structure at the Remote Operator location.
- Qualifications and training requirements of the Remote Operator. Any personnel involved in the operations of the function at the Remote Operator location are to be appropriately qualified and experienced to conduct the operations of the Function. This is to be agreed upon with the Flag Administration.
- Interactions and interface between the Remote Operator and external systems and entities. Examples are interactions with Vessel Traffic Systems or other vessels.
- Cybersecurity precautions at the Remote Operator station that affect the location security, and which will prevent potential corruption of the autonomous function through the Remote Operator station.

- The limitations and operating boundaries of the conduct of operations from the Remote Operator location.

2.3 Risk Category Level

The risk category level of the function in accordance with Subsection 4/2 is to be submitted for review.

2.4 Risk Assessment

A risk assessment plan in accordance with Subsection 4/3 is to be submitted for review.

Risk assessment reports carried out in accordance with the risk assessment plan are to be submitted for review.

Risks and effects pertaining to the following are to be assessed:

- Integration of the function with other onboard functions and systems
- Interaction and interfacing between the function with external systems and entities for example with a port Vessel Traffic Systems or other vessels
- Failure of the function on the vessel and its wider environment
- Equipment or system failure
- Operational hazards

The risk assessment(s) are to consider, but are not limited to:

- Impact of implementation of the autonomous function upon related functions carried out by systems or humans. This may be in the form of design modifications of the affected functions or amendments to operational procedures.
- System-of-systems impact of the autonomous function on the overall vessel.
- Impact of failure of the function on the vessel and wider environment.
- Operational risk factors and mitigating measures for the conduct of operations from the Remote Operator location have been identified and considered.
- Impact of failure of the Remote Operator Station on the vessel and wider environment have been identified and considered.

The risk assessment(s) are to show that the vessel is not to descend into an uncontrollable situation in the event of the following:

- Failure of the function
- System-of-systems impact on the vessel
- Impact of failure or other event on the function
- Occurrence of foreseeable hazard

2.5 System-of-Systems and Delivery of Function

2.5.1 Architecture

Where the function is delivered by multiple constituent systems working in-concert, a system-of-systems architecture is to be crafted. This architecture is to take into account the following, amongst others:

- Constituent systems required to enable the delivery of the function.
- Inter-connectivity between these constituent systems

Drawings and documents detailing the system-of-systems architecture are to be submitted for review.

2.5.2 Possibility of Retaking Control

It is to be possible for the Operator to intervene and regain control of the action from the autonomous function at all times.

The risks and impacts of failure to regain control of the function is to be assessed at the risk assessment stage. Measures are to be implemented to mitigate the impacts of this failure.

2.5.3 Visual Awareness

The operator is to have line-of-sight view of the operations being controlled by the autonomous function. Alternatively, live visual feed is to be provided at the operator control station. In case of partial or full failure of video feeds, the operator is to have demonstrably effective backup operational capabilities for situational awareness and decision support.

For functions where visual awareness will not result in an increase of safety, the requirement for visual awareness may be waived.

2.6 Constituent Systems

2.6.1 Conventional Technologies

Where conventional technologies are utilized, they are to comply with applicable existingRules in the *Marine Vessel Rules* or the *MOU Rules*.

2.6.2 New Technologies

Where new technologies are utilized, they are to be qualified and/or approved in accordance with the ABS *Guidance Notes on Qualifying New Technologies*.

2.6.3 Foundational Requirements

In addition to compliance with 5/2.6.1 or 5/2.6.2 (as applicable), constituent systems are to also comply with the Foundational Requirements in Subsection 5/3.

2.7 Remote Operator Station

Remote Operator Stations for autonomous functions with Operations Supervision Levels RO1, RO2 and RO3 are to comply with the requirements below.

2.7.1 Power Supplies

2.7.1(a) Located on Another Vessel

Where the Remote Operator Station is located on another vessel, the power supplies at the Remote Operator Station are to comply with 5/3.2.

2.7.1(b) Located on Shore

Where the Remote Operator Station is located on shore, the power supplies at the Remote Operator Station are to comply with the following.

Computer and communication systems are to be supplied power from uninterruptible power systems (UPS). In the event of a loss of power, the UPS is to have sufficient power for operations of the autonomous function to safely terminate and successfully transfer control to the operator. Calculations and justifications in this regard are to be submitted to ABS for review.

Loss of power and transfer of power to the UPS is to be alarmed at the remote control station and onboard the vessel.

2.7.2 Monitoring and Alarm Systems

2.7.2(a) All Risk Levels

Alarms requiring the attention of the Remote Operator are to be provided with visual and audible alarms.

2.7.2(b) Control Awareness

See 3.4.3(b).

2.7.3 Situational Awareness & Visual Awareness

2.7.3(a) All Risk Levels

The remote operator is to be provided with a sufficient level of situational awareness of the operations being carried out by the autonomous function on board the vessel. The level of situational awareness required is dependent on the nature of the operations.

2.7.3(b) Visual Awareness

Live visual feed is to be provided at the remote operator station. In case of partial or full failure of video feeds, the operator is to have demonstrably effective backup operational capabilities for situational awareness and decision support.

For functions where visual awareness will not result in an increase of safety, the requirement for visual awareness may be waived.

2.7.4 Remote Operator Training and Qualifications

Requirements pertaining to remote operator training and qualifications do not fall under the purview of ABS. The Flag Administration is to be consulted for instructions and guidance on the minimum qualification and training requirements of these operators. The competence requirements of the operators shall be defined and documented in the CONOPS.

2.7.5 Management Systems Certification

The Flag Administration is to be consulted for instructions and guidance on the applicability of the ISM Code to Remote Operator Stations to ensure safety at sea, prevention of human injury or loss of life, and avoidance of damage to the marine environment and property. Where compliance with the ISM Code is required or recommended by the national requirements, a safety management system (SMS) should be developed to ensure compliance with mandatory rules and regulations, applicable codes, guidelines and standards recommended by IMO, Flag Administration, ABS and maritime industry organizations as applicable. The SMS should document the scope and boundaries of any intended certification.

Refer to ABS *Guide for Marine Health, Safety, Quality, Environmental and Energy Management* for additional certifications options.

2.8 Data Communications

2.8.1 Goal

This subsection establishes minimum requirements for the design for reliable and assured data communications systems enabling the delivery of the function.

2.8.2 Functional Requirements

In order to achieve the goal, the following functional requirement is embodied in the provisions of this chapter:

Data communication networks are to be robust and fault resilient.

2.8.3 Requirements – Onboard Vessel Networks

2.8.3(a) Low Risk Level

i) *Integrity of Data*. Means are to be provided to verify the integrity of data and provide timely recovery of corrupted or invalid data.

ii) *Latency*. The network latency is to be sufficient for the required latency of the function.

2.8.3(b) Medium and High Risk Level

In addition to requirements above, the following requirements are also to be complied with.

i) *Single failure*. Upon a single failure, the network is to be robust enough to maintain the performance of critical function tasks.

ii) *Intermittent loss of communications or degradation of network quality*. During intermittent loss of communications or degradation of network quality, performance of critical function tasks are to be maintained.

iii) *Monitoring of the Network.* The data communication network is to be monitored to detect failures on the communication network itself and data communication failure on nodes connected to the network.

2.8.3(c) Wireless Data Communication

Wireless data communication systems are to comply with 4-9-3/13.3.3 of the *Marine Vessel Rules*.

2.8.4 Requirements – Vessel-to-Remote Operator Station

2.8.4(a) All Risk Levels

See 5/2.8.3(a).

2.8.4(b) Medium and High Risk Levels

In addition to the requirements in 5/2.8.3(a) and 2.8.3(b), the following requirements are also to be complied with:

i) *Data flows and data command paths.* Data flows and data command paths are to be protected in both directions, between the vessel and remote operator station.

2.9 Cyber Security

2.9.1 Goal

This subsection establishes minimum requirements for cyber security concerns to be addressed.

2.9.2 Functional Requirements

In order to achieve the goal, the following functional requirements are embodied in the provisions of this chapter:

i) cyber security concerns are to be approached in a holistic system-of-systems manner, at the constituent system level and during operations

ii) cyber security risks are to be assessed and documented

iii) digital architecture is to be documented

2.9.3 Requirements

2.9.3(a) Low Risk Level.

The following documents are to be submitted for ABS review.

i) *OT/IT Digital Architecture Description.* The documented digital architecture of OT systems requiring protection, including the functional description of the systems requiring cybersecurity protection.

ii) *Cyber Security Risk Assessment.* A Cyber Security Risk Assessment in accordance with Appendix 1 of the ABS *Guide for CyberSecurity Implementation for the Marine & Offshore Industries (ABS CyberSafety® Vol. 2)* is to be carried out. The Cyber Security Risk Assessment is to encompass the computer-based and automation equipment/systems used to carry out the function, integration of the function to other systems and equipment on the asset, network connections and remote control or monitoring stations, where applicable.

iii) *Cyber Security Risk Management System (CRMS)*. A Cybersecurity Risk Management System plan in accordance with Appendix 3 of the ABS *Guide for CyberSecurity Implementation for the Marine & Offshore Industries (ABS CyberSafety® Vol. 2)* is to be submitted for review.

2.9.3(b) Medium Risk Level

In addition to 2.9.3(a), the cyber-enabled systems necessary for the Function are to comply with the **CS-System** notation requirements found in the ABS *Guide for CyberSecurity Implementation for the Marine & Offshore Industries* (ABS *CyberSafety® Vol. 2*).

2.9.3(c) High Risk Level

The vessel is to comply with the **CS-1** or **CS-2** notation requirements in the *ABS Guide for CyberSecurity Implementation for the Marine & Offshore Industries* (ABS *CyberSafety® Vol. 2*).

2.10 Voice Communication

Where voice communication between the vessel and remote operator station is required during operation of the function, two channels of voice communication are to be provided between the vessel and remote operator station for medium and high risk level functions.

3 Foundational Requirements

3.1 General

An autonomous function with a higher risk level is to satisfy all relevant requirements from the lower risk levels.

As a baseline, the requirements in the *Marine Vessel Rules* or the *MOU Rules* govern the vessel in all cases. In addition to those requirements, systems and equipment necessary for the autonomous function are also to comply with the foundational requirements listed below.

3.2 Power Supplies

3.2.1 Goal

The goal of this sub-paragraph is the mitigation of the negative impact to the function and its impact on vessel operations in the event of a loss of power.

3.2.2 Functional Requirements

In order to achieve the goal, the following functional requirement is embodied in the provisions of this chapter:

The power supplies to control, monitoring and alarm systems of the constituent systems are to be safeguarded.

3.2.3 Requirements

In order to comply with 5/3.2.2, and taking into account the risk category of the level, the following apply.

3.2.3(a) Medium Risk Level

Electric power for control, monitoring and alarm systems involved in the performance of the function are to be fed from two feeders from different electrical bus sections.

Alternatively, one of the feeders can be connected to a standby power supply from battery and uninterruptible power systems (UPS). The UPS is to have sufficient power for operations of the function to safely terminate and successfully transfer control to the operator. Calculations and justifications in this regard are to be submitted to ABS for review.

The transfer between the power supplies are to be effected automatically. Loss and transfer of power is to be alarmed at the operator control station.

3.2.3(b) High Risk Level

Electric power for control, monitoring and alarm systems involved in the performance of the function are to be fed from two feeders from different electrical bus sections.

For functions categorized under the Maneuvering (MNV) Function Category, electric power for control, monitoring and alarm systems involved in the performance of the function are to be fed from two feeders, one from the main switchboard or other suitable main distribution board and the other from the emergency switchboard or an emergency distribution board.

Alternatively, one of the feeders can be connected to a standby power supply from battery and uninterruptible power systems (UPS). The UPS is to have sufficient power for operations of the function to safely terminate and successfully transfer control to the operator. Calculations and justifications in this regard are to be submitted to ABS for review.

The transfer between the power supplies are to be effected automatically. Loss and transfer of power is to be alarmed at the operator control station. The supply status of these feeders is to be displayed at the operator control station.

3.3 Software

3.3.1 Goal

This subsection establishes minimum requirements for software quality in order to reduce software-related incidents that could negatively affect the performance of computer-based systems.

3.3.2 Functional Requirements

In order to achieve the goal, the following functional requirement is embodied in the provisions of this chapter:

The software development process is to be carried out in accordance with recognized standards.

3.3.3 Requirements

In order to comply with 5/3.3.2, and taking into account the risk category of the level, the following apply.

3.3.3(a) Low Risk Level

Software used in systems performing functions with low risk levels are to comply with the requirements for Computer Based System Category II in Section 4-9-3 of the *Marine Vessel Rules*.

3.3.3(b) Medium and High Risk Level

Software used in systems performing functions with medium and high risk levels are to comply with the requirements in the ABS *Guide for Integrated Software Quality Management (ISQM)* or equivalent. The optional notation **ISQM** or **SQM** may be granted to the vessel upon request.

3.3.3(c) Testing

In addition to the tests required due to the application of the software requirements stated in 3.3.3(a) and 3.3.3(b), software for critical constituent systems involved in the delivery of the function is to be tested in accordance with a test plan approved by ABS. The test plan is to identify all operational situations that the function may encounter, including degradation of sensors. The plan is to outline how these operational situations are to be tested.

For low risk level functions, they are to tested through simulation or physical testing.

For medium and high risk level functions, they are to be tested through both simulation and physical testing.

Where computer simulation test methods are used, please refer to Subsection 7/4.

3.4 Monitoring and Alarm System(s)

3.4.1 Goal

This subsection establishes minimum requirements for monitoring and alarm system(s).

3.4.2 Functional Requirements

In order to achieve the goal, the following functional requirements are embodied in the provisions of this chapter:

- Monitoring and alarm system(s) is/are to be provided.
- The Operator is to be provided with the necessary information and awareness of the operation of the function.

3.4.3 Requirements

In order to comply with 5/3.4.2, the following apply.

3.4.3(a) Monitoring and alarm system(s)

The monitoring and alarm system(s) is/are to comply with 4-9-2/7 of the *Marine Vessel Rules*.

Displays for the monitoring and alarm system(s) is/are to be provided at the operator control station(s).

3.4.3(b) Control awareness

Means are to be provided at all operator stations to identify the system which is having present control over the Function.

3.5 Data Analytics

3.5.1 Goal

This subsection establishes minimum requirements for constituent systems using data analytics techniques.

Data analytics techniques include machine learning, artificial intelligence, data mining and statistics.

3.5.2 Functional Requirements

In order to achieve the goal, the following functional requirement is embodied in the provisions of this chapter:

- The design of data analytics techniques is to comply with recognized industry standards.

3.5.3 Requirements

In order to comply with 5/3.5.2, and taking into account the risk category of the level, the following apply.

3.5.3(a) All Risk Level

i) *A Brief Summary of hybrid or data-driven applications:* The objective of the hybrid (i.e., a combination of physics model and machine-learning based model) or data-driven model is to be clearly defined. The employed data analytics techniques are to be mapped to the autonomous function outcomes and submitted to ABS for review. The physical principles and assumptions, if applicable, are to be documented and submitted to ABS for review.

ii) *Data Sources and Acquisition:* The data source and data collection steps are to be identified and documented. For instance, all the sensors installed on the monitored equipment/system for raw data collection are to be identified through a schematic drawing. Sensor configuration and mapping among the diverse data sources are to be documented.

iii) *Data Exploration*: For model training, data exploration is to be conducted before data quality assessment and data pre-processing to understand the distribution of the key model parameters, correlation between model input parameters and output parameters.

iv) *Initial Data Quality Assessment*: Initial data quality assessment is to be conducted before data analysis to demonstrate that the data set is sufficient for the requirements/purpose. A data quality assessment/inspection plan is to document how to assess data for fitness for autonomous application. The inspection plan is to include the data sampling method based on statistical theory, quality validation rules, data error detection and auto-restoration rules, measurable data quality metrics/dimensions (e.g., to check data consistency, accuracy, timeliness and completeness), threshold values and acceptance criteria to apply to the multi-type and multisource of marine datasets.

v) *Data Correction and Cleansing*: Data correction and cleaning process or rules are to be clearly identified. The specific correction actions (e.g., applied filters, re-formatting operations) against data quality issues are to be provided. For instance, the methods used to address missing data/missing field, duplicated data or peak records are to be described.

vi) *Data Integration*: The minimum required data size for model training is to be identified and documented. Any data aggregating or integration from diverse data sources need to be described.

vii) *Data Storages*: Original data, processed data used for data analytics and output data from the predictive model are to be stored on separate devices or folders.

viii) *Data Modelling*: the following are to be documented and submitted to ABS for review:

- An overview of the analytics approaches (i.e., the selection of the model training techniques, a flow chart to demonstrate the iterative process of model training),
- Method for data partitioning (training and test datasets must be independent and have similar statistical properties),
- Model evaluation acceptance criteria, and
- Assumptions or limitations prior to model training.

ix) *Model Evaluation Results*: the model evaluation methods, process and results are to be provided regarding the predefined model evaluation acceptance criteria. The deviations between predictions and the actual values, and the final trained model parameters are to be provided for review.

3.5.3(b) Medium Risk Level

In addition to the requirements found in 5/3.5.3(a) above, medium risk functions are to comply with the following.

i) *Record of the data model version:* the versioning records of the hybrid or data-driven models are to be documented. The procedure for model upgrade and deployment are to be bound by the Management of Change plan and submitted to ABS for review.

ii) *Monitoring of model applications:* once the model application is tested and deployed, the model performance of the specific autonomous application is to be monitored. A model application performance monitoring plan and the triggers for application retraining are to be clearly defined. Alarms for model application performance in operation are to be generated and visualized at the human-machine interface (HMI).

3.5.3(c) High Risk Level

In addition to the requirements in 5/3.5.3(a) and 5/3.5.3(b) above, high risk functions are to comply with the following.

i) *Risk Assessment of hybrid or data-driven applications:* the risk assessment for a hybrid (i.e., a combination of physics model and machine-learning based model) or purely data-driven application is to be conducted. The risk assessment is to evaluate the risks of how the operation, analysis, reporting, decision-making and execution of the application are impacted by the hybrid or data-driven model development and development process. The risk-based approach for each potential risk (e.g. loss of data, limitations of the algorithm or model assumptions, insufficient sample data size/performance baseline, etc) is to be defined by the application owner/model developer. For the unacceptable effects or high-risk items, the mitigating actions or redundancy plan during operation are to be defined and tested.

ii) *Model Evaluation:* The performance of the data-driven or hybrid models are to be directly evaluated through simulations or equivalent approaches. The simulation scenarios are to be as comprehensive as possible for the operations and environmental conditions. Trials and pilots are to be conducted for model validation, including damage to sensors. The model evaluation, simulation and trial and pilots are to be documented and submitted to ABS for review.

iii) *Model Operation Envelope:* It is not feasible to explore all possible operations and environmental conditions through simulation and trials for data-driven or hybrid models. The model operation envelope is to be defined, in terms of operational and environmental conditions, data and input parameters ranges and quality, reasonable decisions and actions. The model operation envelope is to be implemented to operation monitoring, documented and submit to ABS for review.

iv) *Monitoring of the application of the models:* the input parameters and model performance are to be monitored against the model operation envelope. The monitoring is to be carried out at a suitable frequency. Deviation from the model operation envelope is to be alerted. Necessary mitigating actions, such as a fail-safe action or transfer of control to the operator are to be implemented.

SECTION **6**

Remote Control Functions

1 General

The goal of this section is to provide:

- The requirements which have to be complied with in order to obtain the **REMOTE-CON** notation
- A method to assess the operations and requirements for the operations of the function in its intended operational environment
- A method to assess and mitigate the risks of the operations of the function in its intended operational environment
- Guidance on the implementation process of the function in accordance with Subsection 2/4.
- Guidance on the foundational requirements that should be considered in the implementation of the function

2 Requirements

2.1 Criteria

The function is to be clearly identified.

The function may reside within a single system or it may be performed by a combination of multiple constituent systems working in concert to deliver the function.

The remote control function is to comply with the following criteria:

i) The Remote Control Station is to be constantly manned

ii) The Remote Operator is to be designated and will have responsibility over the Function being controlled in a remote location.

iii) The Remote Operator is to be able to monitor the system and operations under remote control at all times.

iv) The Remote Operator is to be able to control the function in real-time from the remote location.

An operator may be designated as a back-up operator onboard the vessel to be able to intervene and regain control of the function.

A description of the function is to be submitted for review.

2.2 Concept of Operations Document (CONOPS)

A Concept of Operations document (CONOPS) in accordance with Subsection 3/2 is to be submitted for review.

It is acknowledged that during the implementation process the CONOPS is an evolving document. A draft CONOPS is to be submitted at the beginning of the project.

At the completion of the verification and validation phase, a final and comprehensive CONOPS is to be submitted for approval.

The CONOPS is to consider, but is not limited to, the following:

- Necessary logistical support for the operation of the remote control function have been identified and considered.
- Maintenance activities of the function and system(s) required for the operation of the remote control function have been identified and considered.
- Operational risk factors and mitigating measures for the remote control function have been identified and considered.
- The limitations and operating boundaries of the remote control function are to be identified and considered.
- Procedures for transfer of control are clearly defined and documented.
- Emergency response and rescue procedures.
- The number of personnel, roles and responsibilities, and organizational structure at the Remote Control Station are to be clearly identified and described.
- Qualifications and training requirements of the Remote Operator are to be clearly identified and described. Any personnel involved in the operations of the function at the Remote Control Station should be appropriately qualified and experienced to conduct the operations of the Function. This is to be agreed with the Administration.
- Interactions and interface between the Remote Operator and external systems and entities have been identified and considered. Examples are interactions with Vessel Traffic Systems or other vessels.
- Cybersecurity precautions at the Remote Control Station that affect the location security, and which will prevent potential corruption of the remotely operated function through the Remote Control station.
- The limitations and operating boundaries of the remote control function are to be identified and considered.

2.3 Risk Category Level

The risk category level of the function in accordance with Subsection 4/2 is to be submitted for review.

2.4 Risk Assessment

A risk assessment plan in accordance with Subsection 4/3 is to be submitted for review.

Risk assessment reports carried out in accordance with the risk assessment plan are to be submitted for review.

Risks and effects pertaining to the following are to be assessed:

- Integration of the function with other onboard functions and systems
- Failure of the function on the vessel and its wider environment
- Equipment or system failure

- Operational hazards

The risk assessment(s) are to consider, but are not limited to, the following:

- Impact of implementation of the remote control function upon related functions carried out by systems or humans. This may be in the form of design modifications of the affected functions or amendments to operational procedures.
- System-of-systems impact of the remote control function on the overall vessel.
- Impact of failure of the function on the vessel and wider environment.
- Operational risk factors and mitigating measures for the conduct of operations from the Remote Control Station have been identified and considered.
- Impact of failure of the Remote Control Station on the vessel and wider environment have been identified and considered.

The risk assessment(s) are to show that in the event of the following, the vessel is not to descend into an uncontrollable situation:

- Failure of the function
- System-of-systems impact on the vessel
- Impact of failure or other event on the function
- Occurrence of foreseeable hazard,

It is to be possible to transit to a safe state. This may be in the form of redundant systems or alternative means.

2.5 System-of-Systems Architecture

Where the function is delivered by multiple constituent systems working in-concert, a system-of-systems architecture is to be crafted. This architecture is to take into account the following:

- Constituent systems required to enable the delivery of the function.
- Inter-connectivity between these constituent systems

Drawings and documents detailing the system-of-systems architecture are to be submitted for review.

2.6 Constituent Systems

2.6.1 Conventional Technologies

Where conventional technologies are utilized, they are to comply with applicable existingRules in the *Marine Vessel Rules* or the *MOU Rules*.

2.6.2 New Technologies

Where new technologies are utilized, they are to be qualified and / or approved in accordance with the ABS *Guidance Notes on Qualifying New Technologies*.

2.6.3 Foundational Requirements

In addition to compliance with 6/2.6.1 or 6/2.6.2 (as applicable), constituent systems are to also comply with the Foundational Requirements in Subsection 6/3.

2.7 Remote Control Station

2.7.1 Power Supplies

2.7.1(a) Located on Another Vessel

Where the Remote Control Station is located on another vessel, the power supplies at the Remote Control Station are to comply with 6/3.2.

2.7.1(b) Located On Shore

Where the Remote Control Station is located on shore, the power supplies at the Remote Control Station are to comply with the following.

Computer and communication systems are to be supplied power from uninterruptible power systems (UPS). In the event of a loss of power, the UPS is to have sufficient power for operations of the remote control function to safely terminate and successfully transfer control to an onboard operator or to transition to a safe state. Calculations and justifications in this regard are to be submitted to ABS for review.

Loss of power and transfer of power to the UPS is to be alarmed at the remote control station and onboard the vessel.

2.7.2 Monitoring and Alarm Systems

2.7.2(a) All Risk Levels

Alarms requiring the attention of the Remote Operator are to be provided with visual and audible alarms.

2.7.2(b) Control Awareness

See 3.4.3(b).

2.7.3 Situational and Visual Awareness

2.7.3(a) Situational Awareness

The remote operator is to be provided with a sufficient level of situational awareness of the operations being carried out by the function on board the vessel. The level of situational awareness required is dependent on the nature of the operations.

2.7.3(b) Visual Awareness

Live visual feed of the operations being carried out by the function on board the vessel is to be provided at the remote control station. In case of partial or full failure of video feeds, the operator is to have demonstrably effective backup operational capabilities for situational awareness and decision support.

For functions where visual awareness will not result in an increase of safety, the requirement for visual awareness may be waived.

2.7.4 Remote Operator Training and Qualifications

Requirements pertaining to remote operator training and qualifications do not fall under the purview of ABS. The Flag Administration is to be consulted for instructions and guidance on the minimum qualification and training requirements of these operators. The competence requirements of the operators shall be defined and documented in the CONOPS.

2.7.5 Management Systems Certification

The Flag Administration is to be consulted for instructions and guidance on the applicability of the ISM Code to Remote Control Stations to ensure safety at sea, prevention of human injury or loss of life, and avoidance of damage to the marine environment and property. Where compliance with the ISM Code is required or recommended by the national requirements, a safety management system (SMS) should be developed to ensure compliance with mandatory rules and regulations, applicable codes, guidelines and standards recommended by IMO, Flag Administration, ABS and maritime industry organizations as applicable. The SMS should document the scope and boundaries of any intended certification.

Refer to ABS *Guide for Marine Health, Safety, Quality, Environmental and Energy Management* for additional certifications options.

2.8 Data Communications

See 5/2.8.

5/2.8.4 applies for data communications between vessel and Remote Control Station.

2.9 Cyber Security

See 5/2.9.

3 Foundational Requirements

3.1 General

As a baseline, the requirements in the *Marine Vessel Rules* or the *MOU Rules* govern the vessel in all cases. In addition to those requirements, systems and equipment necessary for the remote control function are to also comply with the foundational requirements listed below.

3.2 Power Supplies

See 5/3.2.

3.2.1 Additional Requirements

In addition to the requirements in 5/3.2, the following requirements are to be complied with.

3.2.1(a) Loss of power

Loss of power onboard the vessel is to be alarmed at the Remote Control Station.

3.2.1(b) Transfer between power supplies

The transfer between power supplies onboard the vessel is to be effected automatically. Transfer of power is to be indicated at the Remote Control Station. For functions with high risk levels, the supply status of these feeders is to be displayed at the Remote Control Station.

3.3 Software

See 5/3.3.

3.4 Monitoring and Alarm System(s)

3.4.1 Goal

This subsection establishes minimum requirements for monitoring and alarm system(s).

3.4.2 Functional Requirements

In order to achieve the goal, the following functional requirements are embodied in the provisions of this chapter:

- Monitoring and alarm system(s) is/are to be provided.
- The Operator is to be provided with the necessary information and awareness of the operation of the function.

3.4.3 Requirements

In order to comply with 6/3.4.2, the following apply.

3.4.3(a) Monitoring and alarm system(s)

The monitoring and alarm system(s) is/are to comply with 4-9-2/7 of the *Marine Vessel Rules*.

Displays for the monitoring and alarm system(s) is/are to be provided at both the vessel and the remote control station.

3.4.3(b) Control awareness

Means are to be provided at all operator stations to identify the system having current control over the Function.

3.5 Data Analytics

See 5/3.5.

SECTION 7

Tests, Installation and Commissioning Surveys

1 Goal

This section provides:

- Testing requirements to be complied with for the implementation of autonomous and remote control functions.

2 Functional Requirements

In order to achieve the goal stated in Subsection 7/1, the following functional requirements are embodied in the provisions of this chapter.

i) A system-of-systems approach is to be adopted.

ii) Onboard testing, augmented by simulation and virtual testing is to validate that functionality has been achieved with all constituent systems in operation for the full range of operating scenarios.

iii) The constituent systems performing the autonomous or remote control function and its installation, as appropriate, are to be examined and tested to the satisfaction of the attending Surveyor in accordance with the approved plans.

iv) Operation of the autonomous function shall be demonstrated in its proposed operational setting.

3 Requirements

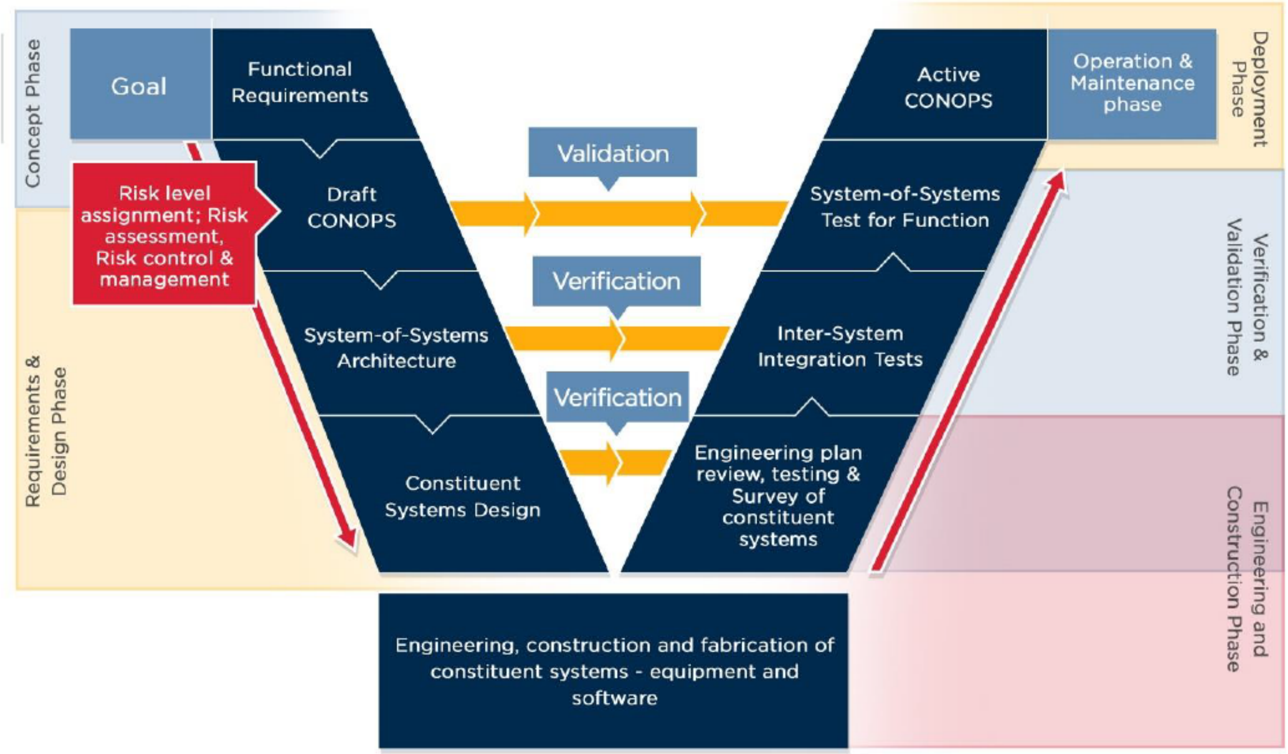
3.1 Test Program

A Test Program for the Function is to be developed to contain test procedures and acceptance criteria. It is to be submitted for review during the plan review process. The test program shall incorporate all operational modes anticipated in normal and also fault/abnormal operation. System fault and failure response and testing shall be tied to the identified hazards from the risk assessments utilized during design.

When deemed necessary by ABS, additional tests to those specified in the Test Program may be required. Tests which require Surveyor attendance will be determined during the review.

The Test Program is to be arranged in the test hierarchy as shown in the V Model Implementation Process (i.e., Constituent Systems' Tests, Integration Tests and System-for-Systems Test for Function).

FIGURE 1
V Model Implementation Process for Autonomous and Remote Control Functions



The Test Program is to include, but is not limited to, the following:

- Identification of all constituent systems and equipment, including details of performance tests and trials for all operational modes laid out in the CONOPS.
- Listing of tests required to be conducted in each level in the hierarchy of tests above.
- Test procedures, methods and acceptance criteria.

The approved Test Program is to be followed and verified by the Surveyor.

3.2 Constituent Systems' Tests

3.2.1 Conventional Technologies

Where conventional technologies are utilized, tests and required Surveyor attendance and witnessing are to comply with applicable existing Rules in the *Marine Vessel Rules* or the *MOU Rules*.

3.2.2 New Technologies

Where new technologies are utilized, tests and required Surveyor attendance and witnessing are to be in accordance with that established during the new technology qualification process carried out in accordance with the ABS *Guidance Notes on Qualifying New Technologies*.

3.3 Integration Tests Before Installation

Intra-system and inter-system integration testing between constituent systems are to be conducted. This activity is carried out according to the Overall Test Plan.

The objective of integration testing is to confirm that functions are properly executed, that the software and the hardware it controls interact and function properly together and that software systems react as designed in case of failures.

Functional performance tests to be carried out in this level are to include, but are not limited to:

- Uninterruptible power supply systems (UPS)
- Input systems, sensors, or signals. They are to be tested and confirmed to be functioning satisfactorily. The alarm systems are to be checked by simulating failures of the sensors and the reference systems.

Faults are to be simulated as realistically as possible to demonstrate appropriate system fault detection and system response. The results of any required failure analysis are to be observed.

Functional and failure testing can be demonstrated by computer simulation tests. See Subsection 7/4.

3.4 Final Integration and Onboard Test

Onboard tests are to confirm that the autonomous or remote control function(s) in its final environment, integrated with all other systems with which it interacts:

i) Integration between various constituent systems and with associated systems have been carried out in accordance with the approved drawings

ii) It is to be possible for the Operator to retake control of the action from the autonomous function at all times

The tests in this level are to include, but are not limited to, the following:

- The operation of the associated monitoring and alarms system is to be tested including operational testing of emergency shutdowns (where provided)
- Operational testing, as applicable, witnessed to demonstrate the system-of-systems has been maintained properly and is in good working order. The test should be carried out to the satisfaction of the attending Surveyor and should demonstrate the risk mitigations, such as redundancy, are in place and operational.
- Operation of protective equipment are to be tested if they are designed to provide essential redundancy of the system-of-systems.
- Input sensors are to be generally examined and confirmed to be functioning satisfactorily
- Changeover to standby equipment or systems are to be tested if they are designed to provide essential redundancy of the system-of-systems.
- Manual Control (for autonomous function)
  - The operation of manual control takeover using human interface systems and controls onboard is to be confirmed to be functioning satisfactorily.
- Manual Control (for remote control systems)
  - The operation of manual controls at the remote controlling station using human interface systems and controls is to be confirmed to be functioning satisfactorily.
- Verification of the autonomous or remote control function automatic resumption following a simulated blackout (if appropriate to the assigned risk level).
- Means of communication between onboard operator station(s) and Remote Operator Station or Remote Control Station (where applicable) are to be tested and confirmed to be operating satisfactorily.

3.5 System-of-Systems Test for Function

A plan for final tests of the function to prove its essential features is to be submitted. The tests proposed in this level are to achieve the following objectives:

i) They are to demonstrate the successful integration of all constituent systems necessary for the performance of the Function.

ii) They are to demonstrate the successful performance of the Function in its intended operational environment or a simulated environment as close as possible to its intended operational environment.

iii) They are to validate all functional scenarios as defined in the Concept of Operations.

iv) Tests are to be carried out to identify unintended effects or emergent behavior resulting from the interactions among the various constituent systems.

v) Tests are to demonstrate the effects of system casualties, proper failover procedures, and low probability – high impact failures that can affect crew (if any), vessel, or environment.

3.6 Remote Operator Station/Remote Control Station

The Test Program is to include tests for the Remote Operator Station (for Autonomous functions with Operations Supervision Levels RO1, RO2 or RO3) and/or the Remote Control Station (for Remote Control functions).

Testing involving the Remote Operator Station or Remote Control Station arrangements are to be conducted in conjunction with the vessel in the presence of attending Surveyors at both the vessel and the Remote Operator Station or Remote Control Station.

The tests proposed for the Remote Operator Station or Remote Control Station are to achieve the following objectives:

i) Integration and installation of the systems and components at the Remote Operator Station or Remote Control Station has been carried out in accordance with the approved drawings

ii) Connectivity between the Remote Operator Station or Remote Control Station and the vessel has been established within the required parameters (latency, integrity of data, etc.)

iii) The ability to transfer control between the vessel and the Remote Operator Station or Remote Control Station (as applicable) is functioning satisfactorily.

iv) Systems providing the Operator at the Remote Operator Station or Remote Control Station with situational awareness (including monitoring and alarm systems) and visual awareness are functioning satisfactorily.

The tests proposed for the Remote Operator Station or Remote Control Station are to include, but are not limited to, the following:

- The operation of the associated monitoring and alarms system is to be tested including operational testing of emergency shutdowns (where provided)
- Operational testing, as applicable, witnessed to demonstrate the systems and components in the Remote Operator Station or Remote Control Station have been maintained properly and is in good working order. The test should be carried out to the satisfaction of the attending Surveyor and should demonstrate the risk mitigations, such as redundancy, are in place and operational.
- Operation of protective equipment are to be tested if they are designed to provide essential redundancy of the system-of-systems.
- Changeover to standby equipment or systems are to be tested if they are designed to provide essential redundancy of systems and components in the Remote Operator Station or Remote Control Station.
- Manual Control (for autonomous function)

  - The operation of manual control takeover using human interface systems and controls onboard is to be confirmed to be functioning satisfactorily.
- Manual Control (for remote control systems)
  - The operation of manual controls at the remote controlling station using human interface systems and controls is to be confirmed to be functioning satisfactorily.
- Means of communication between onboard operator station(s) and Remote Operator Station or Remote Control Station (where applicable) are to be tested and confirmed to be operating satisfactorily
- Impact of loss of data communication, intermittent loss of data communication and degradation of network quality between Remote Operator Station or Remote Control Station on the performance of the function. The test is to demonstrate the resilience and robustness of the connectivity and the ability of the function to resume operations upon resumption of connectivity.

4 Modeling and Computer Simulation Tests

4.1 General

Modeling and computer simulation tests offers the ability to provide the information that would normally be obtained from traditional system studies, physical testing and additional information about operation and configuration.

For model verification and validation, techniques such as these below are acceptable:

- Explore Model Behavior
- Graphical comparison of data
- Confidence intervals
- Hypothesis Tests
- Testing based on simulation of failures

Physical testing requirements may be verified or supplemented by computer-based system simulation testing techniques.

4.2 Documents to be submitted

i) Modeling and computer simulation test plan.

ii) Model that has been developed in a simulation space that supports the functional mockup interface (FMI) standard, or equivalent.

iii) Report of the results of the execution of the simulation of the model depicting steady state operation, transient operation, and operation in the event of occurrence of fault or anomalies. The computer simulation test results are to be provided in a format capable of comparison to any simulation performed independently on alternative simulation software.

4.3 Modeling and Computer Simulation Test Plan

A test plan is to be submitted for review and approval showing which items will be further validated by physical tests and which ones will be validated by simulation tests.

4.4 Computer Based System Testing Approaches

When physical testing requirements are verified or supplemented by computer-based system simulation testing requirements, the following methods are acceptable. The application of these computer-based system simulation test methods is to be described in the test plan.

4.4.1 Model in the Loop (MIL)

Model In the Loop (MIL) testing is to be conducted when both a numerical model of the multi-physics system and a model of its automation and manual control functions have been verified and validated. Based upon the functional description of the system, each test case to be submitted is to be described specifying:

i) test purpose

ii) test setup including models' parameters

iii) expected results and acceptance criteria

4.4.2 Software in the Loop (SIL)

During Software In the Loop (SIL) testing, virtual (emulated) PLCs, with dedicated interfaces to the simulated multi-physics models, are to be considered for deployment of the executable code. Combining the various multi-physics models of connected systems onboard with their actual control and automation logic through SIL can offer a higher fidelity virtual testing. This level is essentially a test of the coding system. Based upon the functional description of the system, each test case to be submitted is to be described specifying:

i) test purpose

ii) test setup including models' parameters

iii) expected results and acceptance criteria

iv) comparison between the same test cases from the MiL testing

4.4.3 Hardware in the Loop (HIL)

During Hardware in the Loop (HIL) testing, the control and automations software is to be fully integrated into the final controller hardware and can only interact with the simulated multi-physics system through the actual I/Os of the controller. The simulated multi-physics system also runs on a real-time computer with I/O simulations to "trick" the controller into believing that it is installed on the actual physical system. In this case, the only difference between the final application and the HIL environment is the fidelity of the simulated multi-physics system model and the test vectors that are being used. Based upon the functional description of the system, each test case to be submitted is to be described specifying:

i) test purpose

ii) test setup including models' parameters

iii) expected results and acceptance criteria

Notes:

1 For software upgrades, regression testing is required to be performed.

2 Regression testing is comprised of re-running functional and non-functional simulation tests to verify that previously developed and tested software still performs as expected after a change.

4.5 Integration Simulation Testing

i) Intra-system and inter-system integration testing are to be performed between system and sub-system software modules and between separate systems before being integrated on board. The objective is to confirm that software functions are properly executed, that the software and the hardware it controls interact and function properly together and that software systems react properly in case of failures.

ii) Functional and failure testing can be demonstrated by simulation tests. The results of any required failure analysis are to be observed.

iii) The simulation tests can follow one of the computer-based systems simulation testing methods mentioned in 7/4.3 above.

SECTION 8
Surveys After Construction

1 General

This section provides requirements for Annual Surveys and Special Surveys of the installed function. Please refer to Part 7, Chapter 2 of the ABS *Rules for Survey After Construction (Part 7)* or Section 7-2-2 of the *MOU Rules* for requirements on the Survey Intervals.

2 Survey Program

Upon consultation with ABS, a Survey Program for the Function is to be developed. The Survey Program is to contain tests and Survey check items for Annual and Special Surveys. It is to be submitted for review during the plan review process.

The Program is to take into consideration the following:

- Critical systems, components or tasks identified in the risk assessment(s)
- Critical operational scenarios and characteristics identified in the Concept of Operations document (CONOPS)

Proposed changes to the Survey Program are to be submitted to ABS for approval.

2.1 Function and System-of-System

2.1.1 Annual Surveys

The annual confirmatory survey for the overall Function and System-of-Systems delivering the function as developed in the Survey Program is to include, but not limited to the following items:

i) Verification that the required documentation is available onboard and at the Remote Operator Station and/or Remote Control Station, including the approved Concept of Operations .

ii) Verification that all documentation is maintained and up to date with records of system modification or maintenance, including any applicable hardware changes or software revisions.

iii) Confirmation with vessel's crew that any modifications or changes made to the constituent systems supporting the autonomous or remote control function have been reviewed, approved, and surveyed by ABS.

iv) Where applicable, input sensors are to be generally examined and confirmed to be functioning satisfactorily

v) Operation of manual control system (including operation for the operator to intervene and regain control) is to be confirmed to be functioning satisfactorily.

vi) Operational testing, as applicable, witnessed to demonstrate the system or system-of-systems has been maintained properly and is in good working order. It should demonstrate the risk mitigations, such as redundancy, are in place and functional. Confirmation that the systems supporting the autonomous or remote control function are functioning, including controls and alarms at the main control/monitoring station or remote control location, controls for functional system, including emergency shut-down procedure, redundant functional systems, and any instrumentation are to be generally examined and confirmed to be functioning. The minimum duration for operational testing is to be defined in the Survey Program.

vii) Verification of the autonomous or remote control function automatic resumption following a simulated blackout (if appropriate to the assigned risk level).

2.1.2 Special Periodical Surveys

The Special Periodical Surveys for the overall Function and System-of-Systems delivering the function as developed in the Survey Program is to include, but not limited to the following items:

i) In addition to the requirements of the Annual Survey, complete performance tests are to be carried out to the Surveyor's satisfaction.

ii) Following tests are to be conducted to the satisfaction of the attending surveyor:

a) Blackout recovery test

b) Redundant equipment/systems failure testing, including worst-case failure, fail-safe test, and network arrangements

c) Standby and Power redundancy survey testing

d) Test functional system power supply, if applicable'

e) Emergency system back-up tests (manual control, alternative control form different remote location, loss of control procedures, etc.)

f) Network storm testing

g) Network latency testing

2.2 Constituent Systems

2.2.1 Conventional Technologies

Where conventional technologies are utilized, Survey requirements are to comply with applicable existing Rules in the ABS *Rules for Survey After Construction (Part 7)*.

2.2.2 New Technologies

Where new technologies are utilized, Survey requirements are to be in accordance with that established during the new technology qualification process carried out in accordance with the ABS *Guidance Notes on Qualifying New Technologies*.

2.3 Remote Operator Station / Remote Control Station

The Survey Program is to include tests and checks for the Remote Operator Station (for Autonomous functions with Operations Supervision Levels RO1, RO2 or RO3) and / or the Remote Control Station (for Remote Control functions).

Testing involving the Remote Operator Station or Remote Control Station arrangements are to be conducted in conjunction with the vessel in the presence of attending Surveyors at both the vessel and the Remote Operator Station or Remote Control Station.

The tests and checks proposed for the Remote Operator Station or Remote Control Station are to achieve the following objectives:

i) Connectivity between the Remote Operator Station or Remote Control Station and the vessel are within the required parameters (latency, integrity of data, etc.)

ii) The ability to transfer control between the vessel and the Remote Operator Station or Remote Control Station (as applicable) is functioning satisfactorily.

iii) Systems providing the Operator at the Remote Operator Station or Remote Control Station with situational awareness (including monitoring and alarm systems) and visual awareness are functioning satisfactorily.

The tests proposed for the Remote Operator Station or Remote Control Station are to include, but are not limited to, the following:

- Checks on the training records and qualifications of the Operator(s) at the Remote Operator Station or Remote Control Station
- Checks on the validity of the management systems certification required by the Flag Administration or Port State Administrations (as applicable)
- The operation of the associated monitoring and alarms system is to be tested including operational testing of emergency shutdowns (where provided)
- Operational testing, as applicable, witnessed to demonstrate the systems and components in the Remote Operator Station or Remote Control Station have been maintained properly and is in good working order. The test should be carried out to the satisfaction of the attending Surveyor and should demonstrate the risk mitigations, such as redundancy, are in place and operational.
- Operation of protective equipment are to be tested if they are designed to provide essential redundancy of the system-of-systems.
- Changeover to standby equipment or systems are to be tested if they are designed to provide essential redundancy of systems and components in the Remote Operator Station or Remote Control Station.
- Manual Control (for autonomous function)
  - The operation of manual control takeover using human interface systems and controls onboard is to be confirmed to be functioning satisfactorily.
- Manual Control (for remote control systems)
  - The operation of manual controls at the remote controlling station using human interface systems and controls is to be confirmed to be functioning satisfactorily.
- Means of communication between onboard operator station(s) and Remote Operator Station or Remote Control Station (where applicable) are to be tested and confirmed to be operating satisfactorily
- Impact of loss of data communication, intermittent loss of data communication and degradation of network quality between Remote Operator Station or Remote Control Station on the performance of the function. The test is to demonstrate the resilience and robustness of the connectivity and the ability of the function to resume operations upon resumption of connectivity.

APPENDIX 1

High Level Goals (Autonomous Vessel)

1 General

To support the design of a fully autonomous vessel, the following goals are possible baseline goals for a fully autonomous vessel:

i) Maintain Steering & Propulsion

ii) Safety of Vessel & Security

iii) Protection Against Flooding / Maintain Stability

iv) Safety of Navigation

v) Communicate Distress

vi) Mitigate Environmental Impacts

vii) Monitoring

viii) Maintain Communication with Shore Control Station

These goals can also be considered in the implementation of autonomous functions in accordance with Section 2.

2 Goals

2.1 Maintain Steering & Propulsion

The propulsion system and supporting auxiliaries are to be designed and constructed to provide

- Continuity of propulsion power,
- Continuity of electrical power, and
- Continuity of position/course.

2.2 Safety of Vessel and Security

To maintain safety of the vessel, the vessel is to:

- Maintain continuity of electrical power
- Manage fire risk
- Maintain the machinery management system
- Prevent unauthorized boarding (in-port or at sea)
- Prevent cyber security intrusions

- Detect and contain flooding (see A1/2.3 below)
- Mitigate risks from hazardous cargo

2.3 Protection Against Flooding/Maintain Stability

Flooding and ship stability is a key concern for overall vessel safety. To align with SOLAS requirements the following areas are to be addressed:

- Bilge system
- Operation of sea valves
- Ventilation openings
- Damage stability
- Watertight doors and automated closures

2.4 Safety of Navigation

The vessel is to navigate based on the principles in COLREG. This includes:

- Maintaining steering capability (refer to A1/2.1 above)
- Communicating with surrounding vessels in accordance with the requirements of the current regulatory regime
- Communicating distress to surrounding vessels
- Weather monitoring and routing
- Notice to Mariners and Navigation reference
- Law of the Seas compliance
- Port Interaction
  - Arrival and departure notification
  - Pilot interaction (entering port waters)
  - Docking
  - Cargo Handling
  - Flag/Coastal State Inspections – management of boarding by vetting, regulatory personnel

2.5 Communicate Distress

In the event of distress or emergency conditions, the vessel is to be capable of communicating distress signals to both:

- shore control station and
- surrounding vessels.

Examples of situations in which the vessel is to communicate distress are

- Loss of propulsion or restricted maneuvering
- Failure of protection against flooding (i.e., when it is taking in water)
- Fire
- Loss of navigation capability
- Loss of communication with shore control station

2.6 Mitigate Environmental Impacts

The vessel is to be MARPOL compliant and therefore requires adherence to all measures defined in MARPOL and respective Flag or Port State requirements.

2.7 Monitoring

Vessel Monitoring is to be provided for remote supervision and autonomous decision making support. The vessel is also to be provided with necessary perception and situational awareness. The following areas are to have integrated monitoring systems:

- Power and Propulsion
- Safety/Damage Control
- Stability and Ballast Control (Intact and Damaged)
- Structural Integrity and Health
- Navigation and position (Geolocation)
- Environmental Regulatory Reporting
- Normal Operations and Restorative Actions
- Cybersecurity
- Voyage data

2.8 Maintain Communication with Shore Control Station

For vessel supervision and safety management, it is critical for the vessel to maintain communication with the shore control station. Additionally, the vessel is to be capable of communication with the following:

- Other vessel traffic
- Pilot/Harbor Control
- Riding Crews/Transport Team

Cyber security concerns are to be addressed.

A plan and actions necessary upon loss of communication is to be developed. This will include:

- Safe state determination (based on operational mode)
- Raise distress signal

APPENDIX 2
List of Major Hazards

1 Marine

1.1 General

Hazards differ depending upon the type of vessel and the operating scenario. The hazards in operating an oil tanker are different from those of a passenger ship. The hazards in the open sea are different from those in a harbor approach.

Hazards of shipping can be classified as External or Internal.

- External hazards originate externally and, if not addressed, can compromise the safety of the ship or marine asset. Examples are tropical cyclones and wave action.
- Internal hazards are internal to the ship or marine asset and, if not addressed, can compromise the safety of the ship or marine asset. Examples are machinery failures and combustible cargo.

The following is a list of some of the major hazards related to shipping. The potential hazards described in this appendix, if not properly controlled, can lead to undesirable and hazardous events.

For marine vessels, all operating modes or combinations should be evaluated considering the applicable hazards listed below. Examples include operations such as cargo handling in port, bunkering operations, approaching port, departing port, transit at sea, passing storms, gas cargo processing and handling, maintenance, data communication, and remote operation.

1.2 External Hazards –Transit

i) Water and associated hazardous states

- Extreme waves
- Wind

ii) Severe weather

- Hurricanes
- Storms
- Squalls
- Tropical cyclones
- Waterspouts
- Lightning
- High ambient temperature

- Icing conditions / ice operations
- Fog
- Snow

iii) Hazards to navigation

- Ship's routing procedures related to heavy weather
- Obstructions such as floating containers
- Geographic hazards such as icebergs, coral reefs, sandbars, etc.
- Vessel traffic or congestion
- Grounding / stranding
- Collision

iv) Terrorism or Military Action

- Cyber threats
- Piracy
- Military conflict

v) Dangerous / anomalous action from other vessels

vi) Hazards related to humans

- Pilot error
- Man overboard
- Unlawful acts threatening the safety of the ship and security of passengers / crew
- Personnel accidents / injuries
- Sailing short or loss of key personnel
- Abandon ship

1.3 External Hazards – Port Operations

i) Natural hazards

- Tides and currents
- Wind
- Earthquakes

ii) Mooring hazards

iii) Hazards associated with cargo operations

- Vessel collision with seawalls, piers, or wharves
- Dropped objects
- Electrical equipment hazards
- Lifting operations hazards
- Moving vehicles and equipment hazards
- Other structural damage (e.g., cryogenic fracturing due to spill of LNG)
- Liquid cargo overflows

iv) Hazardous materials

- Flammable and explosive materials
- Oxidizing materials
- Toxic materials
- Corrosive materials
- Water-reactive materials
- Radioactive materials
- Environmental pollution due to release of hazardous substances (e.g., fuels. oils, hazardous cargo, ballast water, air toxins)

v) Simultaneous Operations

1.4 Internal hazards

i) Design limitations in structural capability

ii) Design limitations in static load distributions and stability

iii) Structural/flooding/heavy weather damage

iv) Equipment hazards

- Propulsion failure
- Steering gear failure
- Electrical power failure
- Automation or Dynamic Positioning failures
- Navigational equipment failure
- Sensor failures
- Loss of system control
- Software failure
- Battery failures

v) Cargo hazards

- Cargo-related accidents/shifting of cargo
- Dangerous cargoes

vi) Fuel Hazards

vii) Fire Risk

viii) Loss of Communications

ix) Ergonomic Hazards

- Inadequate personnel protective equipment
- Improper use of equipment
- Manual materials handling
- Slipping and tripping hazards
- Falls
- Excessive strain/posture
- Exposure to weather
- Fatigue

- Noise
- Lighting
- Vibration
- Extreme ambient temperatures

2 Offshore

2.1 General

Offshore oil and gas production systems present a unique combination of equipment and conditions.

The hazards associated with offshore production facilities can be categorized in different ways but are often grouped by operation. This grouping mirrors the way the supporting engineers, operators, and support personnel are grouped within the organization, since these organizational entities are responsible for identifying and understanding potential hazards and addressing them during the design, construction, and operation of the facilities.

The potential hazards described in this Section, if not properly controlled, can lead to undesirable and hazardous events.

Some of the major potential hazards associated with offshore operations are listed below. This list of hazards is not all-inclusive, but is provided to offer an understanding of the types of hazards encountered offshore. Lists such as this or more specific and detailed lists can be used in hazard identification exercises.

2.2 Production Operations – Topside Production Facilities and Pipelines

i) Equipment-related hazards

- Rotating equipment hazards: Stuck by/caught between rotating equipment (e.g., pumps, compressors, catheads, conveyors, belt wheels)
- Electrical equipment hazards
- Lifting equipment hazards
- Defective equipment
- Impact by foreign objects

ii) Process-related Hazards

- Pressure: hydrocarbons under pressure, non-hydrocarbon liquids (e.g., water) under pressure, non-hydrocarbon gas (e.g., air) under pressure, decompression
- Temperature (High or very low): hot surfaces (e.g., engine and turbine exhaust systems), hot fluids (e.g., cooling oils, power boilers, hot-oil heating systems), cold surfaces (e.g., LNG storage vessels, cold ambient climate, propane refrigeration systems), cold fluids (e.g., LNG).
- Hydrocarbons (e.g., oil, LPG, LNG, condensate, lube oil, hydraulic oil, diesel fuel) and other flammable materials (e.g., cellulosic materials, pyrophoric materials)
- Toxic substances: toxic gas (e.g., H2S, chlorine, SO2, benzene), toxic fluid (e.g., mercury, biocide, methanol, brines), toxic solid (e.g., asbestos, man-made mineral fiber, sulfur dust, oil-based sludges)
- Storage of flammable or hazardous materials
- Internal erosion/corrosion
- Seal or containment failures
- Production upsets or deviations
- Vent and flare conditions

- Ignition sources: Electrical (e.g., sparks and arcs from electrical circuits, motors, switches), Static electrical sparks, naked flame (e.g., flaring, boilers), hot surfaces, mechanical sparks (e.g., dropped object, friction), combustion air intakes for combustion machines, HVAC inlets and outlets, hot exhaust outlets (e.g., turbine exhausts), auto-ignition, high energy radiation, ignition of high-pressure release caused by electrostatic discharges occurring in, or as a result of the release
- Process control failures
- Operator error
- Safety system failures
- Asphyxiates: Insufficient oxygen atmospheres, Excessive carbon dioxide (CO_2), Drowning, Excessive nitrogen (N_2)

iii) Well-related Hazards

- Pressure containment
- Unexpected fluid characteristics (e.g., sand, gas, H_2S)
- Well-servicing activities
- Proximity of wells to other wells and facilities

iv) Environmental Hazards

- Corrosive atmosphere
- Sea conditions
- Severe weather (e.g., storms, hurricanes)
- Earthquakes or other natural disaster

v) Ergonomic Hazards

- Inadequate personnel protective equipment
- Improper use of equipment
- Manual materials handling
- Slipping and tripping hazards
- Falls
- Excessive strain/posture
- Exposure to weather
- Fatigue
- Noise
- Lighting
- Vibration
- Extreme ambient temperatures

vi) Mooring and swivel failures

2.3 Drilling Operations

i) Rig Operations

- Well control: Improper well design (e.g., cement, plugs, casings), failure to detect well kick, functional failure of the primary barriers, functional failure of the secondary barrier, other technical equipment failure in safety-critical equipment

- Well formation fluid: Corrosive or erosive components, toxic components, flammable or explosive components, sour components, formation of emulsion, wax, hydrate deposits, etc.
- Drilling fluid: Chemical reactions, toxic components, explosions, burns
- Lifting operations: Failure of lifting equipment, dropped objects, crane tipping over, crane/ loads hitting facilities
- Geological drilling hazards: abnormal pressure, mud losses, wellbore stability
- Structural damage/failure: ship collision, loads associated with earth movements (e.g., earthquakes, reservoir compaction, tectonic motion with faults), fatigue/corrosion, loss/failure at mooring, loss of stability/buoyancy, dropped objects
- Other equipment-related hazards: rotating equipment hazards, electrical equipment hazards

ii) Materials Handling

- Rig transfers
- Crane operations
- Storage of drilling equipment and supplies
- Chemical/flammable storage
- Radioactive sources
- Explosives

2.4 Construction and Maintenance Operations

i) Marine Transport

- Vessel traffic and mooring
- Sea conditions
- Vessel failures
- Diving operations

ii) Materials and Equipment Handling

- Crane and lifting operations
- Elevated objects
- Storage of equipment and supplies
- Chemical/flammable storage
- Static electricity
- Radioactive sources
- Respiratory hazards (e.g., exhaust, chemicals, confined spaces)
- Active or stored energy sources (electrical and mechanical)

iii) Simultaneous Activities:

- Release of flammable hydrocarbons
- Hot work (e.g., welding, grinding, cutting)
- Proximity of other operations

2.5 Air and Marine Transport

i) Vessel approach and docking or mooring procedures

ii) Sea and atmosphere conditions

iii) Severe weather

iv) Vessel failures

v) Personnel transfer

vi) Helicopter mishaps

2.6 Ergonomic Hazards

i) Inadequate personnel protective equipment

ii) Improper use of equipment

iii) Manual materials handling

iv) Falls

v) Excessive strain/posture

vi) Exposure to weather

vii) Fatigue

viii) Noise

ix) Inadequate lighting

x) Excessive vibration

xi) High humidity

xii) Extreme ambient temperatures

xiii) Improper work planning