**Trusted Autonomous Systems (TAS)**

# Project: Development of an Australian Code of Practice for the Design, Construction, Survey and Operation of Autonomous & Remotely Operated Vessels

**(TAS Code of Practice Project)**

# Deliverable 1: Analysis of available standards and codes for autonomous and remotely operated vessels

**August 2021**

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# Executive Summary

Autonomous systems offer the ability to increase safety and efficiency, while lowering economic and environmental costs. In the last five years, there has been a rapid acceleration in the capacity and availability of uncrewed surface and sub-surface vessels, also called autonomous or remotely operated vessels.

For this rapid acceleration to continue, and to ensure this technology can integrate into commercial and defence operations, autonomous systems need to be trusted by the government, regulators, operators and the broader community. An integral part of gaining trust is having a clear, tailored regulatory framework and consistent assurance requirements.

In order to support the development of a clear, tailored, regulatory framework, Trusted Autonomous Systems (TAS) is developing an Australian Code of Practice for the Design, Construction, Survey and Operation of Autonomous and Remotely Operated Vessels. This Code will represent best practice, and is intended to provide certainty for industry by providing a set of standards that they can use to design, construct, survey and operate autonomous and remotely operated vessels. The Code of Practice will be voluntary, and will be updated periodically.

There are a number of codes, standards and guidelines already available internationally for autonomous and remotely operated vessels. In order to understand current best practice, and provide a benchmark for the development of the Australian Code of Practice, this report analyses three codes currently available internationally:

- the *UK Code of Practice for Maritime Autonomous Surface Ships*[1];
- the *LR Code for Unmanned Marine Systems*[2]; and
- DNV GL's *Autonomous and Remotely-operated Ships Class Guideline*[3].

This report breaks down and compares the requirements of each of the three codes for design and construction; navigation, situational awareness and control; survey and testing; and operations such as crew competencies.

The report finds that each of the available codes is:

- tailored towards larger vessels which travel to international ports, and comply with international conventions or Class Society requirements;
- performance-based; and
- underpinned by a requirement for a risk assessment (for example, a failure mode effects analysis) to be undertaken, in order to identify the risks associated with the autonomous systems and the operation of the vessel.

[1] Maritime UK, *Being a Responsible Industry, Maritime Autonomous Ship Systems (MASS) UK Industry Conduct, Principles and Code of Practice, A Voluntary Code*, Version 4 November 2020. Available at: Maritime Autonomous Surface Ships Industry Conduct Principles & Code of Practice version 4 | Maritime UK

[2] Lloyd's Register, *LR Code for Unmanned Marine Systems*, February 2017. Available at: Unmanned Marine Systems Code (lr.org)

[3] DNV GL, Class Guideline, *Autonomous and remotely operated ships*, Edition September 2018. Available at: DNVGL-CG-0264 Autonomous and remotely operated ships

The context in which the three available codes have been developed – focussing largely on vessels which comply with international conventions or Class Rules – is different to the context for an Australian Code of Practice. Given the constraints posed by international conventions, which apply in full to most vessels operating beyond Australian waters and do not yet accommodate many autonomous or remotely operated vessels, an Australian Code of Practice will focus mainly on commercial vessels operating only in Australian waters. Although some international conventions do apply to these vessels, many do not, or have been modified for the Australian domestic fleet.

This report finds that an Australian Code of Practice for autonomous and remotely operated vessels should align with the regulatory framework that already exists for conventional domestic vessels, as far as possible. For this reason, none of the available codes and standards considered in this report provide a template that could be tailored for use in Australia with only minor modifications.

However, by considering the requirements of each of the codes – which are very similar in many respects – the modifications and additions to the standards that already apply to commercial vessels operating in Australia waters can be developed. In other words, each of the three available codes will significantly influence the content of the Australian code.

Based on the content of the three available codes and standards, in addition to the standards that apply to conventional vessels operating in Australia, standards or requirements will apply to autonomous vessels in the areas of:

- situational awareness;
- control;
- software integrity and testing; and
- safe states.

Similarly, the operational requirements that apply to conventional vessels in Australia would apply to autonomous and remotely operated vessels, with some differences:

- the safety management system requirements need to be tailored to autonomous and remote vessel operations;
- the minimum crew and crew competency requirements will be modified; and
- there will be additional requirements for contingency planning and control hierarchies.

Finally, in line with the available codes, a risk analysis approach, which focuses on the impact of potential failures, should apply to novel systems on the vessel, including the systems for situational awareness and control.

The baseline requirement of each of the available codes and standards analysed in this report is that an autonomous or remotely operated vessel should be ‘as safe’ as a conventional vessel. Whether this is appropriate for the Australian code should be considered as part of the consultation process on the development of the Australian code.

This report is intended to inform the development of the Australian code, by providing the developers and reviewers of the Australian code with a breakdown of three available codes for autonomous and remotely operated vessels, and an understanding of how the codes fit into the Australian regulatory context.

# 1. Introduction

TAS's NASF-P (National Accreditation Support Facility Pathfinder) team have commenced a number of new projects to support the continued development of autonomous systems technology in the maritime sector. One of these projects aims to improve the assurance and accreditation framework for autonomous vessels in Australia by developing a dedicated Code of Practice for Remotely Operated and Autonomous Vessels.

Codes of practice, standards and guidelines have been developed by a small number of jurisdictions and Classification Societies internationally, including:

- the *UK Code of Practice for Maritime Autonomous Surface Ships*;
- the *LR Code for Unmanned Marine Systems*; and
- DNV GL's *Autonomous and Remotely-operated Ships Class Guideline*.

The first step in the development of an Australian Code of Practice involves reviewing and analysing these codes and standards in order to:

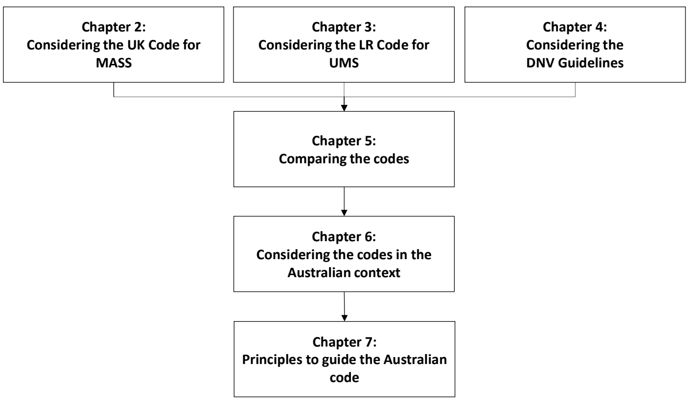
- understand the structure and requirements of each of the codes;
- identify the differences and similarities between the codes; and
- consider the codes in the Australian regulatory context.

This analysis will help inform the approach and content of the Australian Code of Practice.

This report contains the findings of this phase of the project:

- Chapter 2 considers the structure, approach and requirements of the UK Code for MASS;
- Chapter 3 considers the structure, approach and requirements of the LR Code for UMS;
- Chapter 4 considers the structure, approach and requirements of the DNV Guidelines for autonomous and remotely operated ships;
- Chapter 5 looks and the similarities and differences between the three codes;
- Chapter 6 considers the three codes in the Australian regulatory context; and
- Chapter 7 summarises the findings of the report in terms of how the analysis should guide the development of the Australian code.

**Figure 1: Structure of this report**



# 2. UK Code of Practice for MASS

## 2.1 Overview of approach

The UK Code of Practice for Maritime Autonomous Surface Ships (MASS) aims to establish 'initial standards and best practice' for autonomous surface ships less than 24 metres in length. The UK Code is also 'informative' for larger vessels. The UK Code was first published in 2017, and has been re-issued on an annual basis, in 2018, 2019 and 2020.

In the UK Code, MASS are defined as:

> *a surface ship that is capable of being operated without a human onboard in charge of that ship and for which the level of control may encompass any of the levels of control [outlined in the Code – see section 2.3 below].*

The UK Code focusses on the requirements for MASS that are to be registered in the UK. However, it could be applied in other parts of the world where vessels are operating under similar environmental conditions, as it is generally agnostic of national legislation.

The UK Code is very broad in its content – it covers the design, construction, operation, survey, certification and registration of MASS, as well as identifying (in broad terms) pollution and cargo requirements, the application of the obligation to render assistance, and disposal requirements, for MASS.

It is noted that the UK Code has been published with the UK Industry Conduct Principles for MASS. The focus of this report is on the UK Code, and not the industry conduct principles which contain requirements for industry participants, such as customer information and trade restrictions. These issues are outside of the requirements the Australian Code of Practice, which will focus on the design, construction, survey and operation of autonomous and remotely operated vessels.

## 2.2 Structure of the UK Code of Practice for MASS

An overview of the structure of the UK Code is provided in Figure 2 below.

As can be seen in Figure 2, the UK Code includes a number of requirements for the *operation* of MASS – such as safety management systems (SMS), operator competencies, compliance with pollution conventions and obligations to render assistance. These operational requirements are (generally) not included in the LR Code or the DNV Guidelines, which focus on the construction and certification of the vessel and its systems, and not its subsequent operation.

The content of each chapter of the UK Code is summarised below Figure 2.

**Figure 2: Structure of the UK Code of Practice for MASS**

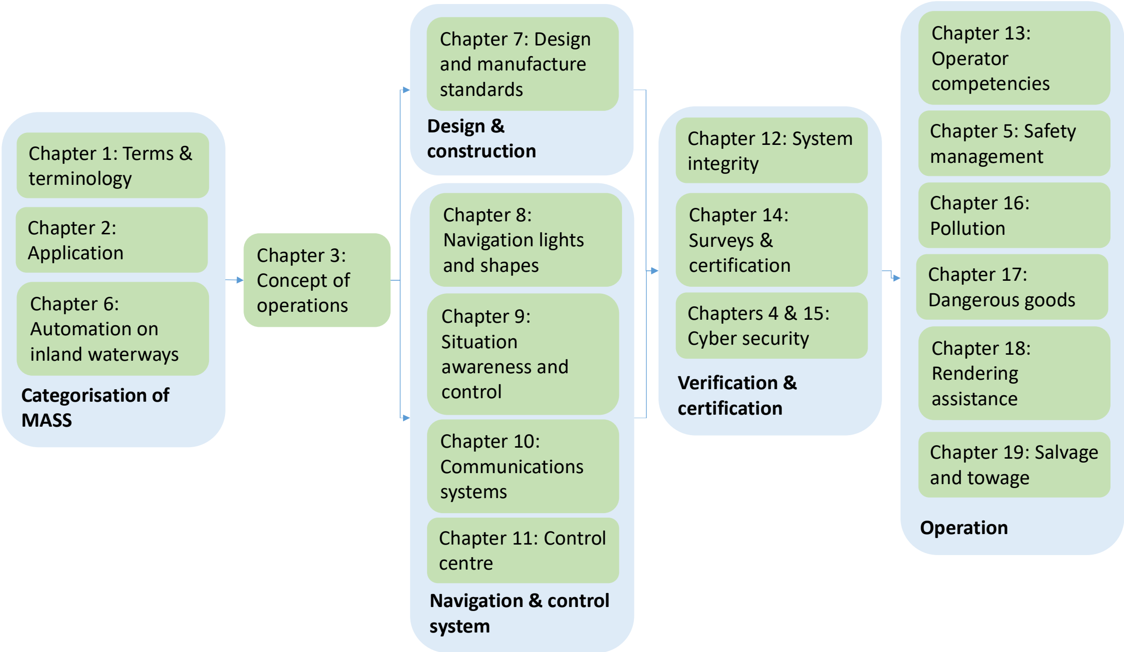



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

<u>Chapters 1 and 2, Definitions and Application</u>

The first two chapters of the UK Code contain the definitions for the UK Code, and outline the application of the UK Code.

The key focus of these chapters is on categorising MASS into:

- design categories;
- levels of control; and
- classes (based on length and speed).

MASS are also categorised under Chapter 5, which is discussed below.

It is noted that the categorising of MASS under Chapters 1, 2 and 6 does not directly link to the application of the requirements of the UK Code.

<u>Chapter 3, Operations</u>

Chapter 3 outlines the requirement to produce a document detailing the intended operations of the vessel, including:

- operation type;
- ship type;
- control method;
- operational area (environmental demands);
- testing / operational deployment plans (noting the approval process required).

This will inform the standards that apply to the vessel.

Chapter 4, Cyber security considerations for MASS

Chapter 4 outlines the threat posed by cybercrime to MASS, the elements of a robust cyber security system, and key cyber security standards or frameworks.

Chapter 5, Safety management

Chapter 5 outlines the requirement for all MASS to be covered by an SMS, and includes guidance on developing an effective SMS for MASS.

Chapter 6, Automation on inland waterways

Chapter 6 reproduces the annex to resolution 2018-II-16 adopted by the Central Commission for the Navigation of the Rhine (CCNR) at its plenary meeting in December 2018. The annex contains a definition of levels of automation in inland navigation.

Chapter 7, Vessel design and manufacture standards

Chapter 7 identifies the standards that apply to the design and construction of the vessel, including structure, stability, propulsion and manoeuvring, electrical systems, fire safety, auxiliary systems and software integrity.

With the exception of the requirements for software integrity, the design and construction requirements are performance-based and stated a very high outcome level. For example, the requirements for stability are:

> *The buoyancy, stability, watertight and weathertight integrity should be sufficient to enable the MASS to be operated and maintained safely as and when required within its design or imposed limitations in all reasonable foreseeable operating conditions.*

Chapter 7 also contains requirements for construction and periodic surveys of the vessel, and for the disposal of MASS.

Chapter 8, Navigation lights, shapes and sounds

Chapter 8 requires compliance with the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), and summaries the COLREG requirements.

Chapter 9, Situational awareness and operation

Chapter 9 addresses the requirements for situational awareness and control, which are central to any autonomous or remotely operated vessel standard.

Chapter 9 contains ‘functional objectives’ for situational awareness and control, being the outcomes that must be achieved by the systems in place on the vessel. These are similar to the ‘required outcomes’ of the National Standard for Commercial Vessels (NSCV – the Australian design and construction standard for commercial vessels which operate domestically) and can also be called ‘performance requirements’.

The functional objectives are stated at a high level, for example:

> *The control system shall be designed and constructed to:*
>
> - *enable its operation in all reasonably foreseeable operating conditions;*

- *operate in a predictable manner with a level of integrity commensurate with operational and safety requirements;*
- *ensure the watertight and weathertight integrity, to meet buoyancy and stability requirements;*
- *minimise the risk of initiating fire and explosion; and*
- *enable the maintenance and repair in accordance with the maintenance philosophy.*

Chapter 9 requires a risk assessment for the MASS to be undertaken using an appropriate risk assessment methodology (such as Failure Mode Effects Analysis (FMEA) – see section 7.2 of this report for a discussion on FMEA). The risk assessment must show that MASS can operate to a level of safety equivalent to an equivalent crewed vessel.

Chapter 9 also identifies the types of sensors that may be used, and outlines the requirements for data interpretation and the control of the vessel. Both of these may be either system-based, or human operator based, or a combination of both.

Chapter 9 also includes requirements for:

- emergency stop;
- propulsion control; and
- steering control,

and requires the control system to be capable of operating to a level of compliance with COLREGS appropriate to the MASS class.

<u>Chapter 10, Communications systems</u>

Chapter 10 contains the requirements for the communications system on the vessel.

In addition, Chapter 10 contains requirements for communications for control system monitoring and input, as well as communication equipment installation requirements (location, electrical supply and redundancy, and protection from flooding).

<u>Chapter 11, Remote control centre operation</u>

Chapter 11 contains requirements for remote control centre operation, including:

- sub-system architecture and the need for human interface;
- tasking cycles for the MASS;
- responsibility of the operator(s);
- protocols for transfers of control;
- data provision to the control centre, including type and quality of data; and
- ability of the operator to take control of the MASS at any time.

Chapter 11 also contains a list of suggested operational requirements for the remote control centre.

<u>Chapter 12, System integrity certification and testing</u>

Chapter 12 contains requirements for the testing and verification of systems on the MASS and supporting the operation of the MASS. Under Chapter 12, system testing is based on a risk assessment.

Chapter 12 contains requirements for:

- testing the impact of power failures;
- use of simulators;
- sensor tests;
- sea trials; and
- emergency stop tests.

Chapter 12 also contains requirements for cyber security measures.

Chapter 13, Operator competencies

Chapter 13 contains guidelines for competencies of operators of MASS. Chapter 13 also contains requirements for ongoing learning (from each operation) and ongoing training.

Chapter 14, Certification, registration and identification

Chapter 14 outlines the identification, survey, certification and registration requirements that apply to MASS and all conventional vessels in the UK.

Chapter 15, Security

Chapter 15 provides guidance on ensuring compliance with the International Ship and Port Facility Security Code (ISPS Code), which applies to ships 500GT and larger. Under Chapter 15, the security measures must be applied on all MASS, including those less than 500GT.

Chapter 16, Prevention of pollution

Chapter 16 covers the applicability of the International Convention for the Prevention of Pollution from Ships (MARPOL) requirements. These requirements are equivalent to those which apply to conventional vessels, although some aspects of MARPOL may not be relevant to some autonomous and remotely operated vessels (such as garbage disposal).

Chapter 17, Cargos and dangerous goods

Chapter 17 covers the applicability of International Maritime Dangerous Goods Code (IMDG Code) requirements to MASS. These requirements are equivalent to those which apply to conventional vessels.

Chapter 18, Rendering assistance

Chapter 18 outlines the requirement to render assistance and how it applies to MASS. A MASS is not obliged to take persons on board if the MASS is not able to do so. However, other obligations associated with rendering assistance will likely apply, such as remaining in proximity of the person(s) in distress in order to provide a reference point for search and rescue authorities.

Chapter 19, Salvage and towage

Chapter 19 contains high level requirements for salvage and towage of MASS, which are the same as apply to conventional vessels.

## 2.3 Categorisation of MASS under the UK Code

The UK Code categorises MASS in five different ways:

- distance from safe haven or land;
- operating conditions – maximum wave height and wind speed;
- size and speed;
- degrees of autonomy; and
- level of automation.

The categories are summarised in the following two tables. The second table includes the degrees of autonomy used by the IMO for categorising MASS, and automation levels agreed by the Central Commission for the Navigation of the Rhine (CCNR), and set out in chapter 5 of the UK Code.

**Table 1: UK Code categorisation of MASS by operational area and size / speed**

| Operational area (distance from safe haven or land) | | Design category (maximum wave height and wind speed) | | Class (vessel size and speed) | |
|---|---|---|---|---|---|
| **0** | Unrestricted | **A** | Ocean | **Ultra-light** | <7m and <4kts |
| **1** | 150 miles from safe haven | **B** | Offshore | **Light** | 7 – <12m and <7kts |
| **2** | 60 miles from safe haven | **C** | Inshore | **Small** | 12 – <24m |
| **3** | 20 miles from safe haven | **D** | Sheltered waters | **Large** | ≥24m and ≥100GT |
| **4** | 20 miles from safe haven in favourable weather and in daylight | | | **High speed** | Determined by speed equation |
| **5** | 3 miles from protected waters and land | | | | |
| **6** | 3 miles from point of departure and land | | | | |

**Table 2: UK Code categorisation of MASS by level of automation**

| Degrees of autonomy of vessels (IMO) | | Level of control | | CCNR automation levels | |
|---|---|---|---|---|---|
| 1 | **Ships with automated processes and decision support** | 0 | **Crewed**<br>(humans on board) | 0 | **No automation** |
| 2 | **Remotely controlled ships with seafarers on board** | 1 | **Operated**<br>(an operator controls all cognitive functionally. Human operator has direct contact with the vessel) | 1 | **Steering assistance**<br>(steering automation system) |
| 3 | **Remotely controlled ships without seafarers on board** | 2 | **Directed**<br>(some degree of reasoning and ability to respond in implemented in the uncrewed vessel. It may report its state and suggest possible actions to the operator. However, the authority to make decisions is with the operator – the vessel will not act unless commanded to) | 2 | **Partial automation**<br>(performance of some functions by a navigation automation system of both steering and propulsion) |
| 4 | **Fully autonomous ships** | 3 | **Delegated**<br>(the uncrewed vessel is authorised to execute some functions. It my sense its environmental and report its intention. The vessel will act as intended unless the operator vetos the action) | 3 | **Conditional automation**<br>(performance by a navigation automation system of all dynamic navigation tasks. Operator receptive to requests to intervene and to system failures) |
| | | 4 | **Monitored**<br>(the uncrewed vessel defines actions, decides, acts and reports its action. The operator monitors the events) | 4 | **High automation**<br>(performance by a navigation automation system of all dynamic navigation tasks and fall-back operation, without expecting a human boatmaster responding to a request to intervene. But human operator may be required to undertake some tasks) |
| | | 5 | **Autonomous**<br>(the uncrewed vessel will make decisions and act without reporting or notifying any external units or operators) | 5 | **Autonomous**<br>(performance by a navigation automation system of all dynamic navigation tasks and fall-back operation, without expecting a human boatmaster will respond to a request to intervene) |

## 2.4 Content of the UK Code of Practice for MASS

A summary of the requirements of the UK Code is provided in Figure 3 and Table 3 below.

## Figure 3: Requirements of the UK Code of Practice for MASS

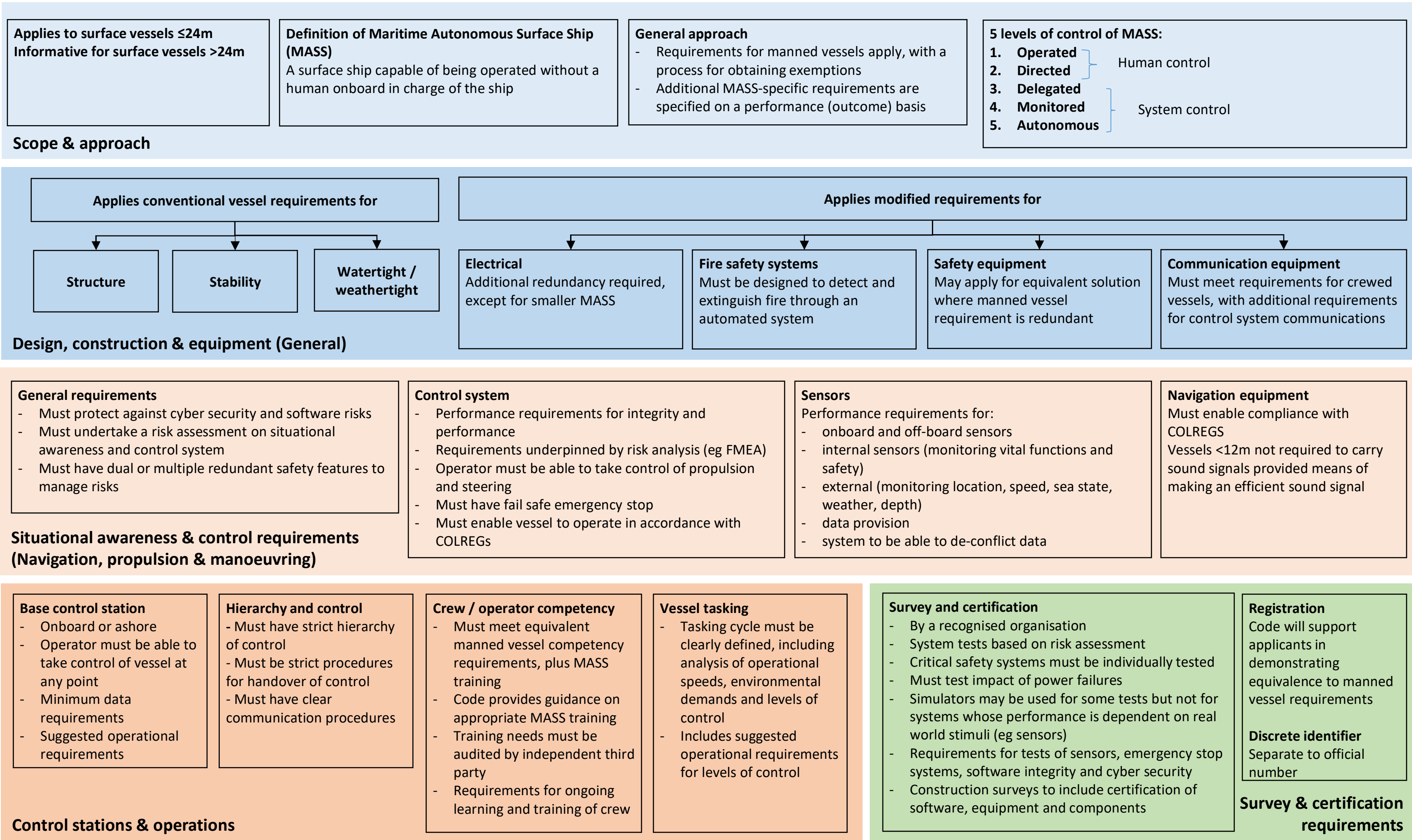



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

**Table 3: Requirements of the UK Code of Practice for MASS**

| Item | Requirements |
|---|---|
| **Design & construction standards** | **General**<br>Vessel must be design, constructed and maintained in compliance with the rules of a Recognised Organisation (RO) or in accordance with the applicable national standards of the administration.<br>Where the MASS design departs from the equivalent crewed vessel standard, there must be justification demonstrating that:<br>- the crewed vessel requirement is redundant (eg removal of crew habitability requirements or lifesaving equipment); or<br>- an alternative solution is required to maintain the same level of performance (eg replacing a manual firefighting system with automatic systems).<br>Departures must not result in an increased risk to other vessels, third parties or the environment. |
| | **Structure, stability, propulsion & manoeuvring**<br>High level performance requirement specified for each aspect, along the lines of:<br>*Should be sufficient to enable the MASS to be operated and maintained safely as and when required within its design or imposed limitations in all reasonably foreseeable operating conditions.* |
| | **Electrical systems**<br>High level performance requirement, plus:<br>- sufficient electrical power should be provided to supply the required services of the MASS during all reasonably foreseeable operating conditions; and<br>- additional redundancy may be required to enable the MASS to conduct its mission. For smaller classes of MASS there may be little or no redundance required. |
| | **Fire safety**<br>Where fire safety systems are required, they must be designed to detect and extinguish a fire with a level of integrity sufficient to enable the MASS to be operated and maintained safely, and to protect the MASS. |
| | **Auxiliary systems**<br>- Should be designed to support mission equipment and mission functions.<br>- If the MASS is to have a payload or carry cargo, these not to have a detrimental effect on the MASS for the duration of its mission.<br>- The MASS is to have sufficient systems to support the embarkation of cargo and equipment for the duration of its mission.<br>- If seamanship systems are fitted to the MASS, they must ensure that the MASS can be recovered safely and undertake any seamanship operations as required (anchoring, mooring, towing etc). |

| Item | Requirements |
|---|---|
| | **Propulsion and manoeuvring**<br>Should enable the MASS to manoeuvre as and when required by the operator but still remain within the designed or imposed limitations. |
| | **Software integrity**<br>- Software risks must be managed.<br>- Software must be protected against viruses, unauthorised installations, changes or deletions, installation of unauthorised software and modifications.<br>- Configuration status of the software on each platform must be captured and recorded, and the record maintained up to date for the life of the platform. |
| | **Navigation lights, shapes & sound signals**<br>- Must comply with COLREGS.<br>- A vessel that operates only between sunrise and sunset is not required to carry navigation lights where it can be demonstrated that the vessel will not be caught in or near an area of restricted visibility.<br>- A vessel <12m is not required to carry sound signalling equipment where it can be demonstrated that some other means of making an efficient sound signal is provided. |
| **Situational awareness and control** | Can include onboard sensors and offboard information sources, communication links and control logic. |
| | **Risk assessment**<br>A risk assessment must be undertaken for the situational awareness and control system in line with an appropriate methodology (such as FMEA) which considers:<br>- risks (such as collision, grounding, flooding);<br>- the probability of a failure occurring to a MASS system or component;<br>- the impact of a failure;<br>- the likelihood of the MASS becoming a hazard or causing environmental damage; and<br>- failure modes of different systems. |
| | **Sensors**<br>- Examples provided of internal sensors for monitoring the platform's vital functions and safety provided (remaining fuel, status of on-board systems, watertight integrity, integrity of hull, pitch roll and heave, vibration, shock).<br>- Examples provided of external sensors (GNSS, heading, sea state, wind speed and direction, depth below keel). |

| Item | Requirements |
|---|---|
| | **Data provision, interpretation and application**<br>- MASS must be able to interpret sensor data on-board or off-board (including by an off-board operator).<br>- Must be sufficient data provided by the sensors to the on-board or off-board system to enable the MASS to be brought away from danger and to a safe haven.<br>- The system must be capable of determining safe operating limits, permitted geographic areas, expected water depth and expected water current speed and direction.<br>- System must be able to de-conflict conflicting data provided by different sources.<br>- System must be capable of making operational decision in accordance with the sensor data interpretation. |
| | **Control system**<br>- Must enable its operation in all reasonably foreseeable operating conditions.<br>- Must operate in a predictable manner with a level of integrity commensurate with operational and safety requirements.<br>- Must ensure the weathertight and watertight integrity of the vessel, to meet buoyancy and stability requirements.<br>- Must minimise risk of initiating fire and explosion.<br>- Must enable the maintenance and repair as required.<br>- Operators must be provided with adequate access, information and instructions for the safe operation and maintenance of the control system.<br>- Control system may be on-board or off-board.<br>- Must have an emergency stop, which must be fail safe.<br>- Must also have propulsion control and steering control (except passive MASS).<br>- Control system must be capable of operating in compliance with the COLREGs and enable the MASS to avoid obstacles. |
| **Communications** | - GMDSS and radio equipment requirements, in accordance with requirements for crewed vessels.<br>- The controller of the MASS must be capable of receiving, interpreting and acting upon information transmitted to the vessel via the radio equipment.<br>- The controller of the MASS should hold a certificate of competence for distress and safety radio communications.<br>- Communications system for the control system may also be required. |
| **Control centre** | **Remote Control Centre**<br>- The Remote Control Centre (RCC) is a set of equipment and/or control units where the control and monitoring of the MASS is conducted.<br>- Operation planning, control and post operation analysis must take place at the RCC. |

| Item | Requirements |
|---|---|
| | - The RCC should be designed to enable the operator to take control of the MASS at any time.<br>- Code identifies minimum data required to be provided to the RCC in order to monitor the vessel (health status, navigational data, etc). Must also assess additional data needs.<br>- Code contains suggested operational capabilities of the RCC (eg planning and executing mission). |
| | **Hierarchy of control**<br>- Must identify the responsibility hierarchy and have strict procedures for transfers of control.<br>- Must specify interactions and methods of communication between the RCC operator and other operators. |
| | **Tasking cycle / phases of operation**<br>- Must clearly define task cycles for the MASS. Code includes a sample tasking cycle.<br>- Phases of operation should be defined – ie loading, departure, voyage, arrival, unloading. Levels of control may differ for different phases of operation.<br>- Operational speeds (not maximum speed) may be used for operational risk assessment.<br>- Environmental demands should be defined, including:<br>➢ sea temperature<br>➢ air temperature<br>➢ humidity<br>➢ atmospheric pressure<br>- Code contains suggested operational requirements for levels of control. |
| **System integrity certification and testing** | **System testing**<br>- Tests must be based on a risk assessment.<br>- All critical safety items covered by failure sensing and remedial action, or by dual or multiple redundancy, highlighted in risk assessment, shall be individually tested by simulating each failure mode of each sub-system or component and verifying that back-up systems are effective.<br>- Effects of power failures shall be checked, including simultaneous power failures on several sub-systems.<br>- Simulators may be used to test autopilot performance and collision avoidance algorithms, but not to test systems whose performance is critically dependent upon real world stimuli, such as optical and inertial sensors. |
| | **Sensor tests**<br>- Sensors critical to performance must be tested.<br>- Sea trials are required where sensor performance is influenced by the platform upon which it is mounted.<br>- Sensors may be certified to be used on many vessels. |

| Item | Requirements |
| --- | --- |
| | **Emergency stop systems**<br>Must be tested, including under datalink failure conditions. |
| | **Cyber security**<br>Code provides details of software integrity testing and cyber-security compliance audits. |
| **Crew and operator competency** | - Must meet requirements for equivalent crewed vessel crew.<br>- Companies must implement training regime for MASS operators and related personnel.<br>- Code provides guidance on qualifications and additional MASS training.<br>- A hazard and operability study (HAZOP) should be completed for each MASS and its expected operations against the knowledge and training of the unit's operators.<br>- Training needs should be audited by independent third party.<br>- Code includes requirements for crew learning from each mission, as well as ongoing training. |
| **Survey requirements** | - Must be surveyed and certificated by an RO.<br>- Construction surveys may include:<br>➢ review of the capability, organisation and facilities of the manufacturer to confirm that acceptable standards can be achieved for the construction and fit out of the hull structure, systems and equipment;<br>➢ certification of software, equipment and components;<br>➢ survey of the material state during build to confirm compliance with the appraised design; and<br>➢ witness of tests and trials to demonstrate functionality.<br>*Note that the wording of these requirements is almost identical to the LR Code.*<br>- Electronic systems must be installed and tested in accordance with the requirements for conventional vessels. |
| **Certification** | - MASS must have a discrete identifier which is separate to their shipping official number. The discrete identifier stays with the vessel.<br>- Outlines registration requirements and processes.<br>- MASS must be surveyed before registration.<br>- Provides advice on the process for obtaining approvals for operation in UK waters, for both trials and operations. |
| **SMS** | Must have an SMS. Code provides guidance on developing an effective SMS for MASS. |
| **Security** | - Must comply with the ISPS Code (as applicable) and SOLAS Chapter XI-2. Compliance must be verified.<br>- All MASS must have:<br>➢ a security alert system; |

| Item | Requirements |
|---|---|
| | ➢ a security assessment; and<br>➢ a security plan.<br>- A company security officer and a security officer for each MASS should be appointed.<br>- The Administration should issue a MASS Security Certificate if these requirements are complied with.<br>- Additional cyber security system requirements:<br>➢ Must have cyber security measures to protect sensors and control systems. Code identifies the key systems to be protected and the key risks to be protected from. It also identifies the security measures that could be used to provide cyber security.<br>➢ Cyber security analysis required to identify vulnerabilities and protection measures.<br>➢ Must have protection from third-party interface with MASS communications.<br>➢ Must have ability to shut down MASS operations if there is a third-party communications interception. |
| **MASS disposal** | Must meet all applicable requirements (as apply to crewed vessels). |
| **Pollution** | Must meet all applicable requirements (as apply to crewed vessels). |
| **Cargo** | Must meet all applicable requirements (as apply to crewed vessels). |
| **Salvage and towage** | Must meet all applicable requirements (as apply to crewed vessels). |

## 2.5 Comments on the approach and content of the UK Code

This section contains some preliminary comments on the approach and content of the UK Code, based on the analysis of the structure and content contained of the UK Code, and on feedback from stakeholders. The suitability of the UK Code for the Australian context is considered in Chapter 6 of this report.

The UK Code is tailored towards vessels which comply with international conventions

The UK Code is tailored towards vessels which comply with international conventions, although the Code acknowledges that local UK standards or requirements might also apply to a vessel (such as the UK MCA Workboat Code). It also assumes that the survey will be undertaken by either a Classification Society or the MCA.

The UK Code is performance-based

The UK Code includes performance requirements for all aspects of the design, construction and operation of the vessel, even those covered by conventional vessel standards (such as construction and watertight / weathertight integrity). These performance requirements are generally stated at a very high level.

For the situational awareness and control requirements, which are key to an autonomous vessel, the performance requirements are underpinned by a requirement for a risk assessment (for example, a failure mode effects analysis) to be undertaken, in order to identify the risks associated with the MASS and its operation. The risk assessment is key to ensuring that those systems are designed and built to enable the vessel to be operated to a 'tolerably safe level' – which is 'ideally' proven to be as safe as an equivalent crewed vessel.

The UK Code moves between operational and design and construction requirements

The structure of the UK Code lacks some coherency, as it jumps between operational and design and construction requirements. However, there are significant interdependencies between the way in which the vessel is operated, and the systems which form part of the design and construction of the vessel, so moving between operational and design and construction requirements is less problematic than it would be in a conventional vessel code.

The UK Code contains many different ways to categorise autonomous vessels

The UK Code contains a large number of different ways to categorise autonomous vessels, many of which overlap. There are:

- two different ways of defining the vessel's operational area;
- two different ways of defining the level of control / level of autonomy of the vessel; and
- categorisation of MASS into classes based on size and/or speed.

None of these categorisations directly link to the requirements of the UK Code. They appear to be provided to assist a designer or operator to conceptualise a vessel and its operations.

# 3. Lloyd's Register Code for Uncrewed Marine Systems

## 3.1 Overview of approach

The LR Code for Uncrewed Marine Systems (UMS) provides a framework for the assurance of safety and operational requirements of UMS.

UMS are defined in the LR Code as:

*A surface or submersible system that can be operated without personnel on-board.*

In other words, the LR Code applies to autonomous and remotely controlled vessels operated on or below the surface.

The LR Code is goal-based and provides a set of performance requirements for each aspect of the vessel. The performance requirements may be met by a range of solutions, not specified in the LR Code, including classification society rules and regulations, recognised national or international standards or risk-based analysis.

The LR Code covers the assurance of safety and operational requirements for UMS. It does not cover:

- risks arising from embarked cargo or mission specific equipment;
- operator training and qualifications; or
- dangerous goods requirements.

## 3.2 Structure of the LR Code for UMS

An overview of the structure of the LR Code is provided in Figure 4. The content of each chapter of the LR Code is summarised in the section below.

**Figure 4: Structure of LR Code for UMS**

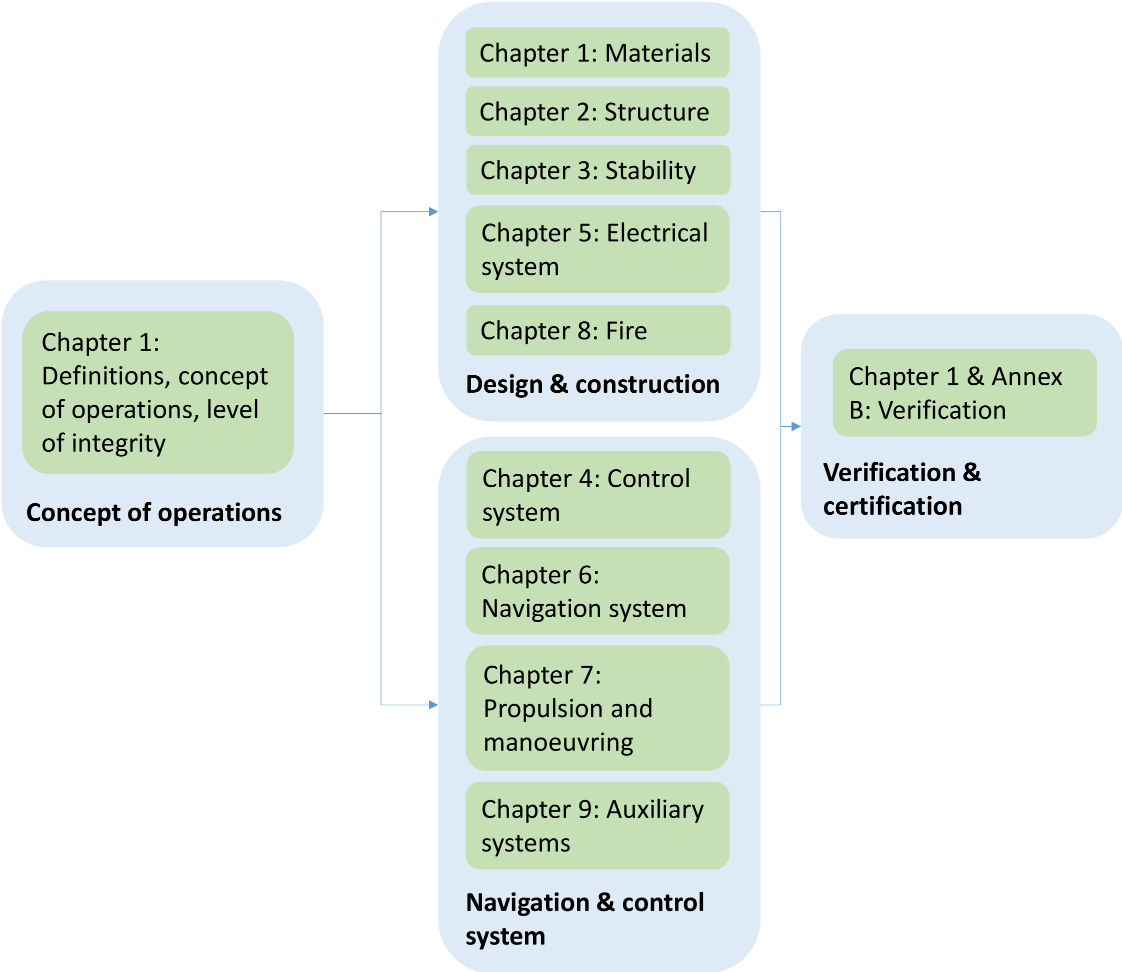



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

<u>Chapter 1, General</u>

Chapter 1 outlines the structure of the LR Code, contains key definitions and categorises UMS into six different autonomy levels (see section 3.3 below).

Chapter 1 also contains:

- verification requirements for UMS, which are based on a verification plan developed for each UMS;
- requirements for materials used on UMS;
- requirements for a ‘concept of operation’, which defines and records the manner in which the UMS will be designed, operated and maintained; and
- details the ‘level of integrity’ requirements, which must be determined for each UMS system.

Chapter 2, Structure

Chapter 2 contains performance requirements for the structure of the UMS. The performance requirements cover the strength of the vessel to carry predicted loads and to operate in the conditions anticipated.

Chapter 3, Stability

Chapter 3 contains performance requirements for the stability of the UMS. The performance requirements cover the watertight and weathertight properties of the vessel, reserve buoyancy, penetrations and fittings, stability of the vessel, displacement checks and other methods of validation, means to remove water, subdivision and arrangement requirements, and stability information.

Chapter 4, Control system

Chapter 4 contains performance requirements for the control system of the UMS. The performance requirements cover:

- provision of feedback to the operator or system on the operating state and potential hazards;
- control of ambient conditions;
- recording of data;
- timing and accuracy of response by control system;
- management of malfunctions, energy failures and other occurrences;
- level of resilience to errors, faults, incorrect sensor inputs, security of communications and security of data;
- human interface; and
- management of changes in control.

Chapter 5, Electrical systems

Chapter 5 contains performance requirements for the electrical system of the UMS. The performance requirements are detailed and cover a large number of issues, including:

- sufficiency and quality of power
- reserve power;
- effects of arc flash;
- protection from lightning strikes; and
- security arrangements.

Chapter 6, Navigation systems

Chapter 6 contains performance requirements for the navigation system of the UMS. The performance requirements cover:

- sufficiency of systems and sensors;
- ability of MASS to identify and analyse hazards;
- means to measure depth;
- means to control illuminated appearance;
- means to communicate with other vessels;
- means to alert other vessels that the UMS is in distress;

- ability to exhibit lights and shapes, and to generate sound signals (for surfaced UMS only); and
- provision of adequate information to operator.

Chapter 7, Propulsion and manoeuvring

Chapter 7 contains performance requirements for propulsion and manoeuvring. The performance requirements cover:

- ability to meet required operating speed and required manoeuvring requirements in all reasonably foreseeable operating conditions;
- energy source and reserve; and
- minimising risk of fire, and protecting against damage by fire.

Chapter 8, Fire

Chapter 8 contains performance requirements for fire safety. The performance requirements cover:

- controlling leaks of flammable liquids, limiting accumulation of flammable gases, vapours and dust;
- minimising use of combustible materials and ignition sources, and separation of combustible materials and ignition sources;
- means for controlling air supply to spaces;
- fire detection systems;
- structural integrity and fire-resistant materials;
- ability to extinguish all foreseeable fires; and
- maintenance of fire systems.

Chapter 9, Auxiliary systems

Chapter 9 contains performance requirements for auxiliary systems. The performance requirements cover the interaction of the auxiliary systems with other systems on the vessel (such as energy sources, watertight and weathertight requirements and fire safety).

## 3.3 Categorisation of UMS under the LR Code

The LR Code defines the level of automation of UMS, as summarised in the following table.

The LR Code notes that a higher level system may use a lower level system as part of its reversionary control, and a complex system may be a combination of multiple systems at different levels.

**Table 4: LR Code categorisation of UMS based on level of automation**

| Level of control | |
|---|---|
| **0** | **Manual**<br>(all action and decision-making performed manually. Systems may have a level of autonomy but humans control all actions) |
| **1** | **On-board decision support**<br>(all actions taken by human operator, but decision support tool can present options or influence actions. Data provided by systems on-board) |
| **2** | **On & off decision support**<br>(all actions taken by human operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board) |
| **3** | **‘Active’ human in the loop**<br>(decisions and actions are performed with human supervision. Data may be provided by systems on or off-board) |
| **4** | **Human on the loop, operator / supervisory**<br>(decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human Operators the opportunity to intercede and override) |
| **5** | **Fully autonomous**<br>(rarely supervised operation where decisions are entirely made and actioned by the system) |
| **6** | **Fully autonomous**<br>(unsupervised operation where decisions are entirely made and actioned by the system during the mission) |

## 3.4 Content of the LR Code for UMS

A summary of the requirements of the LR Code is provided in Figure 5 and Table 5.

## Figure 5: Requirements of the LR Code for UMS

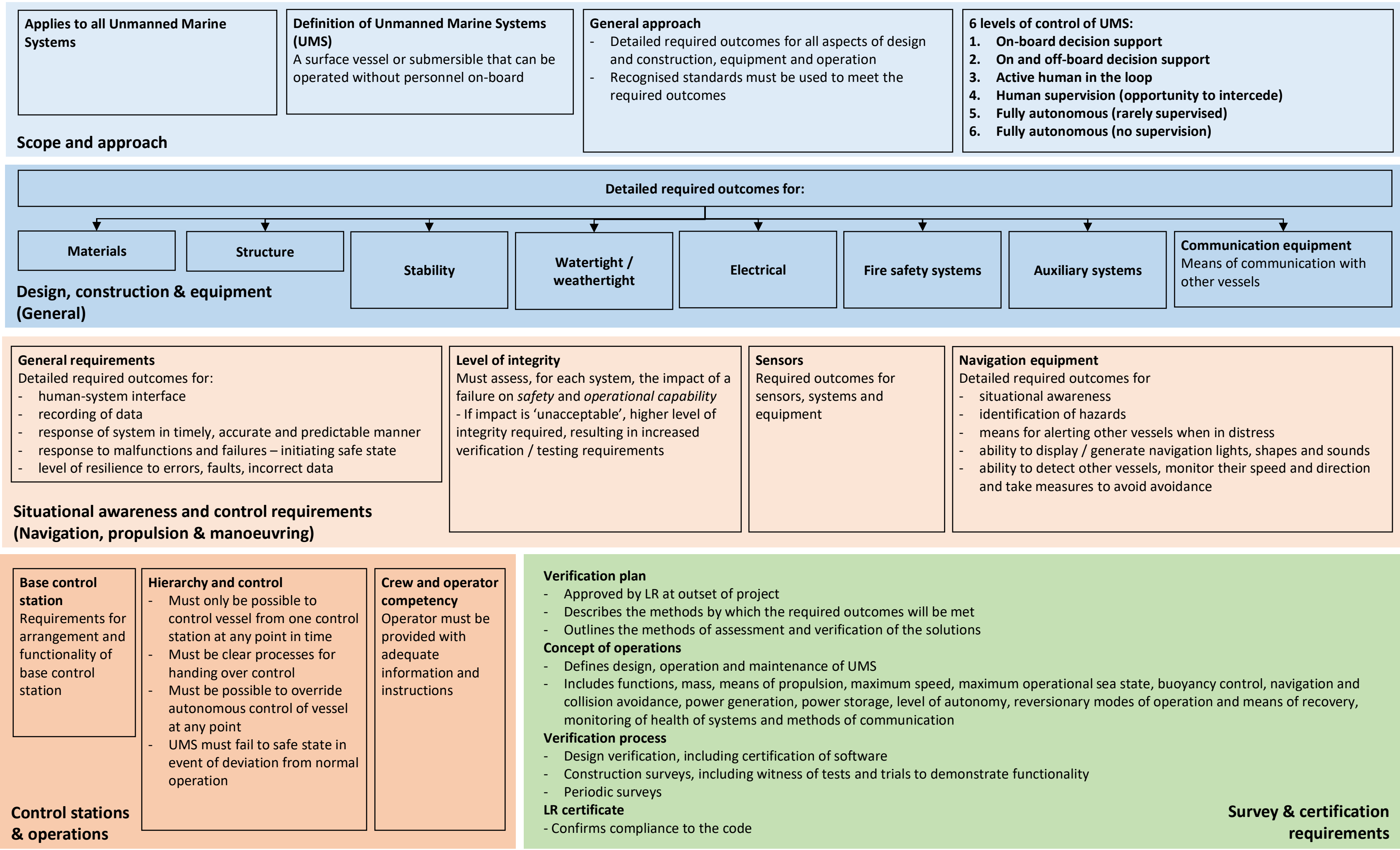



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

**Table 5: Requirements of the LR Code for UMS**

| Item | Requirement |
| --- | --- |
| **Design and construction standards** | **General – materials used**<br>- Materials shall be manufactured and verified in accordance with recognised standards and procedures appropriate for their application and the level of integrity required for the system.<br>- Must be a system in place to identify, record and control hazardous materials and to restrict or mitigate known hazards. |
| | **Structure**<br>- Must be designed to operate in all reasonably foreseeable operating conditions.<br>- Must carry and respond to all foreseen loads in a predictable manner.<br>- Consideration should be given to wind, air temperatures (max and min), ice accretion, solar radiation, waves, green seas, ice navigation, ship motions, hydrostatic (below water).<br>[Very detailed requirements for outcomes for structure] |
| | **Stability**<br>[Very detailed requirements for outcomes for stability] |
| | **Electrical systems**<br>[Very detailed requirements for outcomes for electrical systems] |
| | **Fire safety**<br>Performance requirements for fire safety include requirements for:<br>- controlling risk of ignition;<br>- detection and alerts;<br>- containment and structural integrity;<br>- fire extinguishment; and<br>- maintenance of fire systems. |
| | **Auxiliary systems**<br>Covers auxiliary equipment and components required to support mission equipment and mission functions, and the hazards they create. Does not include the control system.<br>Performance requirements for auxiliary systems include:<br>- ambient conditions shall be controlled, where necessary, to suit the operating environment and auxiliary system requirements;<br>- auxiliary system must be design to meet the mission equipment and mission function requirements in all reasonably foreseeable operating conditions;<br>- energy source must be sufficient and allow adequate reserve;<br>- must have suitable precautions against the build-up of electrostatic charges;<br>- must be designed to minimise risk of initiating a fire and be protected from damage by fire; and<br>- must be designed to not unduly affect other system including under failure |

| Item | Requirement |
|---|---|
| | conditions. |
| **Situational awareness and control** | **Propulsion and manoeuvring**<br>Includes the equipment and components relating to the propulsion and manoeuvring system and the hazards they create. Does not cover the control of propulsion and manoeuvring systems.<br>Performance requirements for propulsion and manoeuvring systems include:<br>- ambient conditions shall be controlled, where necessary, to suit the operating environment and propulsion and manoeuvring system;<br>- propulsion system must be design to meet the required operating speed in all reasonably foreseeable operating conditions;<br>- manoeuvring system must be design to meet the required manoeuvring requirements in all reasonably foreseeable operating conditions;<br>- energy source must be sufficient and allow adequate reserve;<br>- must be designed to minimise risk of initiating a fire and be protected from damage by fire; and<br>- must be designed to not unduly affect other systems including under failure conditions. |
| | **Navigation system**<br>Performance requirements for navigation systems include:<br>- must have sufficient sensors and systems to determine, display and record the UMS' present time position, orientation and movement in relation to the earth and the rate of change of the parameters;<br>- ambient conditions shall be controlled, where necessary, to suit the operating environment and navigation system;<br>- must be able to identify (measure, analyse, assess and display) hazards in the physical environment, measure depth, direction and speed, have means to display its manoeuvring limitations, have means to control its illuminated appearance, have means to communicate with other vessels, and have means to alert other vessels that it is in distress;<br>- must be fitted with systems that can receive, transmit, record and analyse navigation data;<br>- surfaced UMS must be able to exhibit/generate navigation lights, shapes and sounds; and<br>- must be able to detect other vessels the presence of nearby vessels, monitor their speed and direction and take measures to avoid a collision. |
| | **Control system**<br>Performance requirements for the control system include:<br>- must be designed and arranged to meet the required level of integrity;<br>- all aspects of the system must be designed with consideration of the human-system interface;<br>- must record the output of all sensors on which the control system is dependant and all propulsion and manoeuvring system activities at appropriate intervals. This data must be protected from loss;<br>- must respond in a timely, accurate and predictable manner;<br>- must ensure that any serious malfunctions automatically initiate corrective |

| Item | Requirement |
|---|---|
| | actions via a high integrity system to put the UMS in a safe state;<br>- energy source for the control system must meet the level of integrity as the control system;<br>- requirements for the way in which the control system responds to:<br>➢ energy failure; and<br>➢ deviations from normal operations of UMS systems.<br>There are also requirements for level of resilience of control system to errors, faults, incorrect sensor inputs, security of communications and security of data.<br>Must be a process for the management of changes. |
| | **Control station**<br>- Control panel must be designed using human factors methodology. Controls must be easily identifiable and arranged in a logical way to reflect their function, means of operation and hierarchy of importance.<br>- Must only be possible to control the UMS from one control station at any point in time.<br>- Must be clear processes for handing over control.<br>- Where UMS is operating autonomously, it must be possible to override the autonomous control and initiate a corrective action.<br>- UMS must fail to safe state in the event of deviation from normal operation.<br>- Operator must be provided with adequate information and instructions for the safe and effective control of the UMS. |
| | **Sensors**<br>UMS must be fitted with sensors, systems and equipment to provide feedback to the operator or autonomous control system of the operating state and potential hazards. |
| **Survey requirements** | **General requirements**<br>- Independent verification required to provide assurance that the UMS complies with the LR Code and remains compliant throughout its life.<br>- A verification plan must be submitted for acceptance at the commencement of the project which:<br>➢ describes the methods by which the performance requirements will be met;<br>➢ includes details of and justification for the solutions; and<br>➢ outlines the methods of assessment of the solutions and the means of demonstrating conformance.<br>- The verification method will be determined by the 'level of integrity' of each system. Verification methods include design review, independent calculation, equipment and materials certification, audit, inspection, survey, testing and trials. |

| Item | Requirement |
|---|---|
| | **Level of integrity**<br>- The required level of integrity must be determined for each UMS system.<br>- Looking at the UMS as a system of systems, the impact of all foreseeable failures of a system on people onboard, people/objects near the vessel and the environment must be assessed.<br>- The impact of a failure of a system on the operational capability and resilience of the vessel must be assessed.<br>- For each system, the level of integrity shall be characterised as either:<br>➢ High: system failure would have unacceptable consequences;<br>➢ Medium: system failure would have acceptable consequences due to the presence of mitigating factors; or<br>➢ Low: system failure would have acceptable consequences.<br>- The integrity level is assessed for both the safety impacts and the operational capability impacts.<br>- The highest level of integrity required for each system is the one which applies to that system (and is used for determining the verification requirements for that system). |
| | **Concept of operations**<br>A 'concept of operations' is completed first, which defines and records the manner in which the UMS shall be designed, operated and maintained. It should include:<br>- primary and secondary functions<br>- UMS mass<br>- means of propulsion<br>- means of buoyancy control<br>- means of navigation and collision avoidance<br>- means of power generation<br>- means of power storage<br>- maximum UMS speed<br>- maximum operational sea state<br>- maximum operational depth<br>- maximum endurance<br>- level of autonomy<br>- reversionary modes of operation (including recovery)<br>- means of monitoring health of on-board systems<br>- methods of communications/remote operation<br>- means of determining position<br>- details of modularisations/configurations<br>- means of lifting, launch, recovery and transport<br>- launch and recovery environmental limitations<br>- environmental limitations (eg sea state, water quality, water temperature, air temperature) |

| Item | Requirement |
| --- | --- |
| | **Survey process**<br>The verification (survey) process will include:<br>- design verification to justify the solutions and to verify that the design complies with the solutions chosen. This will require:<br>  ➢ a concept of operations and definition of required autonomy and integrity levels;<br>  ➢ construction plans and particulars relevant to hull, equipment and machinery; and<br>  ➢ design calculation and documentation;<br>- certification of software, materials, equipment and components;<br>- details of software integrity testing and cyber-security audits;<br>- maintenance philosophy and survey plan;<br>- construction surveys conducted at a periodicity and scope appropriate to the design and build. These may include:<br>  ➢ a review of the capability, organisation and facilities of the manufacturer to confirm that acceptable standards can be achieved for the construction and fit out of the hull structure, systems and equipment;<br>  ➢ survey of the material state during build to confirm compliance with the appraised design; and<br>  ➢ witness of tests and trials to demonstrate functionality; and<br>- periodic surveys. |
| **Certification and identification** | On completion of survey, a certificate will be issued confirming compliance with the LR Code, which remains valid subject to continued compliance to the LR Code and the periodic survey requirements. |

## 3.5 Comments on the approach and content of the LR Code

This section contains some preliminary comments on the approach and content of the LR Code, based on the analysis of the structure and content of the LR Code and on feedback from stakeholders. The suitability of the LR Code for the Australian context is considered in Chapter 6 of this report.

<u>The LR Code contains detailed performance requirements</u>

The LR Code contains performance requirements for all aspects of the vessel, including those for which an autonomous vessel would be unlikely to differ to a conventional vessel. In this way, the LR Code ‘stands alone’ rather than building on other standards or Codes.

However, in practice, vessels would be expected to meet the LR Class Rules for most aspects of the vessel – the LR Code makes this clear upfront.

Where relevant rules or standards do not exist, the performance requirements must be met by risk-based analysis.

Levels of integrity approach

All UMS systems on and supporting the vessel are subject to a 'level of integrity' analysis under the LR Code. This analysis is similar to a failure mode effect analysis (FMEA), which is referenced in the UK Code. The 'level of integrity' analysis involves assessing the effect on the UMS, considered as a system of systems, of all reasonably foreseeable system failures.

The level of integrity required for a system drives the testing and verification requirements for that system, as well as redundancy requirements.

Structure of the LR Code

The LR Code is structured around the different aspects of the vessel. The structure is clear and easy to follow, but some inter-connected aspects of an autonomous or remotely operated vessel are separated, which can lead to duplication and confusion. For example, the requirements of Chapter 4 (Control systems) and Chapter 6 (Navigation systems) are hard to untangle.

# 4. DNV Class Guideline: Autonomous and remotely operated ships

## 4.1 Overview of approach

The DNV Guidelines recognise the evolving nature of the technology allowing for autonomous and remotely operated vessels, and do not provide detailed rules for all combinations of concepts.

Instead, the DNV Guidelines provide an assurance process for the approval of designs applying novel technologies for autonomous and remote control of ship functions, and for the certification of those novel technologies.

In addition to defining the process required to certify the vessels and the new technologies used on the vessels, the DNV Guidelines also provide guidance on:

- arrangements and technologies supporting remote control of navigation functions;
- the remote control of engineering functions; and
- arrangements in the remote control centre, including the communication link connecting the remote control centre with the vessel, as well as other communication functions for the vessel and the remote control centre.

## 4.2 Structure of the DNV Class Guidelines

An overview of the structure of the DNV Class Guidelines is provided in the following diagram. The content of each chapter is summarised in the section.

**Figure 6: Structure of DNV Class Guidelines for Autonomous and remotely operating ships**

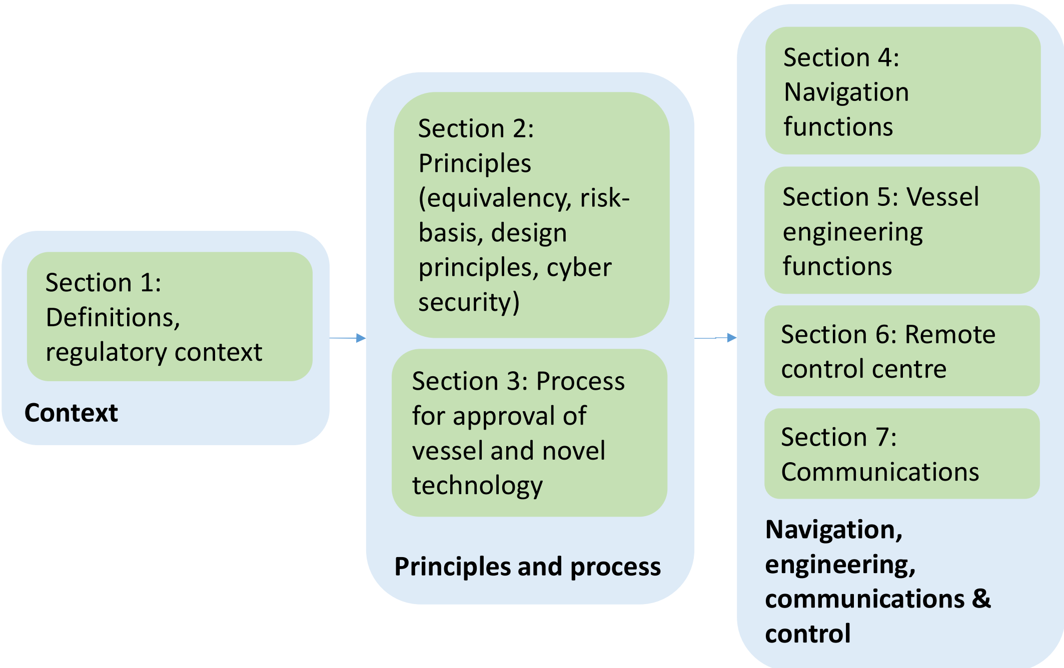



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

Section 1, General

Section 1 outlines the purpose, structure, scope and application of the DNV Guidelines. It includes a description of the regulatory framework and the role of flag administrations and class societies.

Section 2, Main principles

Section 2 contains the main principles against which autonomous and remotely operated vessels, and new systems on the vessel, will be assessed. These principles include:

- autonomous vessels must have an equivalent level of safety to crewed vessels with respect to safeguarding life, property and the environment; and
- when considering safety measures for a vessel, the risks associated with the new operational concepts shall not focus only on consequences for the on-board crew, but also take into consideration consequences for the public, the assets and the environment.

Section 2 also outlines the risk-based approach taken to the assessment of the novel systems and vessels. This approach focusses on identifying and mitigating the risks associated with the new introduced operations, functionality and systems.

A risk analysis must be undertaken which includes:

- risk analysis of the proposed division of responsibility between the automatic systems and personnel in different locations;
- risk analysis on any novel technology focussing on the safe-state, failure modes and fault robustness of the functions and systems; and
- risk analysis associated with the remote supervision and control of a vessel, focussing on the remote control centre and its supporting systems, and demonstrating that any failures of the remote control centre and supporting systems will be managed safely by automation systems or personnel on board.

Section 2 also introduces the concept of 'minimum risk conditions' – the vessel's response when a situation arises that places the vessel outside it's normal operating conditions, but during which time the vessel is still expected to act in some way or another. Deteriorating weather, system failure (eg loss of propulsion) or similar could put the vessel outside its normal operating state. There may be several 'minimum risk conditions' for a specific event.

Section 2 outlines the need to consider all of the functions of the autoremote infrastructure needed to achieve an equivalent level of safety to a crewed vessel. This could include the following functions:

- remote control and supervision
- communication
- navigation and manoeuvring
- propulsion
- steering
- electrical power supply
- control and monitoring
- watertight integrity
- fire safety

- ballasting
- drainage and bilge pumping
- anchoring
- cargo handling
- maintenance.

Finally, section 2 identifies design principles for autonomous or remotely operated vessels, and outlines the requirements for software engineering and testing, and for cyber security.

Section 3

Section 3 is a key chapter of the DNV Guidelines. It contains a detailed process for obtaining approval of autonomous and remotely operated vessels, and of those novel systems in the vessels.

This process involves developing:

- a concept of operation (a description of all the operational tasks that the vessel will undertake that will be fully or partly automated), which will be informed by a preliminary risk analysis;
- developing the high-level design, including the safety philosophy, overall design philosophy, overall maintenance philosophy;
- developing the detailed design, which must be approved by DNV; and
- developing the verification and validation strategy, which must be approved by DNV.

Where novel technology is developed for the autonomous or remotely operated vessel, Section 3 outlines the process involved in assessing and approving that technology. It includes defining what aspects of the technology are novel and which are proven; a detailed risk analysis; simulator-based testing; factory acceptance testing; testing once installed on the vessel; and updates and testing during operation.

Section 4, Navigation functions

Section 4 requires the level of safety achieved by the automation of navigation functions to be equivalent to a conventional vessel.

Under Section 4, the navigation functions or tasks must be defined in terms of how they will be delivered on the vessel, based on the level of autonomy (described in Table 6) for each of the following elements:

- **detection:** acquisition of information relevant to function. May be based on sensors or human perceptions;
- **analysis:** interpretation of acquired information into a situational understanding relevant for control of function;
- **planning:** determination of changes needed in control parameters in order to keep the function performance with the applicable frames; and
- **action:** effectuating the planned changes.

Section 4 details the performance requirements for each of these elements of the navigation functions.

Section 5, vessel engineering functions

Section 5 requires the engineering functions carried out by crew on board a conventional vessel to be automated or carried out by operators in the control centre. Engineering tasks are divided into those needing active involvement by personnel (automatic support) and tasks which will automatically be performed by automation system (automatic operation).

Section 5 includes baseline requirements for the ability of the system to restore key vessel functions.

Section 5 also specifies the response required of the vessel to incidents and failures, so that the degree of redundancies, fault tolerance and automatic functionality can be identified. For example:

- the vessel must be able to continue its planned voyage if an *anticipated failure* was to occur. This means that there must be sufficient redundancies to manage *anticipated failures*, being those caused by wear and tear (such as the breakdown of components on the vessel, failures in rotating machinery, electrical failures such as short circuits, failure of communication networks); and
- the vessel must be able to enter into and maintain a safe state if a *potential failure* was to occur. *Potential failures* include fire and flooding, cyber security incidents (these are *potential failures* only if adequate precautions are implemented), human error and external events.

Section 5 contains guidelines on redundancy requirements for:

- propulsion and steering;
- electrical power supply and distribution; and
- control, monitoring, alarm and safety systems.

Section 6, remote control centre

Section 6 provides guidance as to the technical arrangements in remote control centres, including the physical arrangements, identification and management of hazards and risks within the control centre, vessel situational awareness requirements (including substitutes for all the human senses of crew onboard), contingency planning and data logging.

Section 7, communication functions

Section 7 provides guidance on the systems for communications to and from the vessel. It covers the systems for communication:

- between the vessel and the control centre. These must consider maximum bandwidth, latency requirements, cyber security, interfaces and protocols and prioritisation of data in case of insufficient bandwidth;
- with off-ship systems and sensors, such as shore-based radar, weather forecasts and shore-based cameras (for docking); and
- with other vessels, pilot stations and so on.

Section 7 also contains requirements for cyber security systems.

## 4.3 Classification of autonomous vessels under the DNV Guidelines

The DNV Guidelines focus on classifying the degree of autonomy of *functions* on the vessel, as shown in the following table.

**Table 6: DNV Guidelines – level of automation of functions**

<table>
<tr><th>Functions</th><th>Control element of each function</th><th colspan="2">Level of autonomy for each control element of each function</th></tr>
<tr><td rowspan="5">- Control and supervision<br>- Communication<br>- Navigation and manoeuvring<br>- Propulsion<br>- Steering<br>- Electrical power supply<br>- Control and monitoring<br>- Watertight integrity<br>- Fire safety<br>- Ballasting<br>- Drainage and bilge pumping<br>- Anchoring<br>- Cargo handling<br>- Maintenance</td><td>Detection<br>(acquisition of information relevant to function)</td><td>M</td><td>Manual</td></tr>
<tr><td>Analysis<br>(interpretation of acquired information into a situational understanding relevant for control of function)</td><td>DS</td><td>System decision supported function</td></tr>
<tr><td>Planning<br>(determination of changes needed in control parameters in order to keep the function performance with the applicable frames)</td><td>DSE</td><td>System decision supported function with condition system execution capabilities<br>(human in the loop, required acknowledgement by human before execution)</td></tr>
<tr><td rowspan="2">Action<br>(effectuating the planned changes)</td><td>SC</td><td>Self-controlled function<br>(system will execute the operation, but human can override)</td></tr>
<tr><td>A</td><td>Autonomous function<br>(system will execute the operation, normally without the possibility for a human to intervene on the functional level)</td></tr>
</table>

Looking at the overall control of functions, the DNV Guidelines then consider types of autonomous vessels. The DNV Guidelines also references the degrees of autonomy used by the IMO for categorising MASS. Both of these means for categorising autonomous and remotely operated vessels are shown in the table below.

**Table 7: DNV Guidelines – level of automation of vessels**

| Type of autonomous vessel | Levels of autonomy of vessels | |
|---|---|---|
| **Decision supported navigational watch**<br>(enhanced decision support systems supporting an on-board officer in charge of the navigational watch) | **1** | **Ships with automated processes and decision support** |
| **Remote navigational watch**<br>(the tasks, duties and responsibilities of an officer in charge of the navigational watch being covered by personnel in an off-ship remote control centre) | **2** | **Remotely controlled ships with seafarers on board** |
| **Remote engineering watch assisted by personnel on board**<br>(tasks, duties and responsibilities of an officer in charge of the engineering watch are covered by personnel in an off-ship remote control centre, with crew on board to perform certain defined tasks and assist the remote personnel as needed) | **3** | **Remotely controlled ships without seafarers on board** |
| **Remote engineering watch**<br>(tasks, duties and responsibilities of an officer in charge of the engineering watch being covered by personnel in an off-ship remote control centre) | **4** | **Fully autonomous ships** |

## 4.4 Content of the DNV Guidelines for autonomous ships

A summary of the requirements of the DNV Guidelines is provided in Figure 7 and Table 8 below.

## Figure 7: Requirements of the DNV Guideline for autonomous and remotely operated ships

### Scope and approach

**Guidelines provide a process for DNV to assess and approve novel technologies for the autonomous and remote control of ship functions**

**Covers four autonomous functions**
- Decision supported navigational watch
- Remote navigation watch
- Remote engineering watch, supported by personnel on board
- Remote engineering watch

**General approach**
- A detailed process for assessment and approval of new technologies
- Baseline requirement for all systems is equivalence to the level of safety achieved the crewed vessel requirement
- Risked-based approach, focusing on identifying and mitigating the risks associated with new systems

**4 levels of control of MASS:**
1. **Automated processes and decision support**
2. **Remotely controlled, seafarers on board**
3. **Remotely controlled, no seafarers on board**
4. **Fully autonomous**

### Design & construction – engineering and electrical

**Engineering systems**
Focusses on the management of potential failures:
- Must identify **anticipated failures** (expected to occur through wear and tear) and **potential failures** (less probable than anticipated) (eg flooding, fire)
- Where a failure is anticipated, redundancy is required to allow vessel to continue with planned voyage. In other words, the failure of active components should not cause loss of function
- Additional compensating measures are required to cope with failures and incidents that would, on a conventional vessel, be managed by the crew
- Duplicated or segregated arrangements are required for systems serving key functions
- Any equipment or systems needed for vessel to enter or maintain a safe state require appropriate redundancy and segregation
- Redundancy required for key control systems and safety systems. Need to ensure redundant systems do not fail simultaneously with main systems

**Electrical**
- Must have redundancy and capacity to ensure normal operation can be maintained or restored in event of system or component failure
- Main power supply should be self-contained
- Emergency power system must handle emergency conditions and maintain vessel in safe state
- Emergency lighting might be required to enable remote operators to obtain sufficient situational awareness in an emergency

### Situational awareness and control requirements (Navigation, propulsion & manoeuvring)

**Propulsion**
- Must have redundancy so vessel can maintain a navigable speed in case of failure of single system
- Autoremote vessels may require increased separation and redundancy
- Infrastructure providing remote control should be single fault tolerant
- Compliance with COLREG 6 is required. If safe speed is planned and executed by a system, there must be sufficient information provided to the remote navigator for independent supervision

**Manoeuvring**
- Detailed requirements for information on vessel systems and surroundings
- Identifies potential sensors (CCTV, radar, laser based and other detection technology)
- May need systems that do not require a lot of data to be transferred to the control centre
- Identifies the tasks to be undertaken when docking

**Navigation**
A preliminary risk analysis must define the division of functions between systems and officers
Detailed performance requirements for:
- achieving COLREG 5
- determining vessel position
- accuracy of navigational charts
- image transmission
- view of the sea, field of vision
- detection and recognition of lights and shapes and sounds in accordance with COLREGs
- object detection and recognition / classification
- vessel type recognition
- remote situational awareness must be based on real time information

**Control of navigation functions**
Four areas of navigation control:
1. Detection
2. Analysis
3. Planning
4. Action

For each of these elements, the level of autonomy can be:
- Manual
- System decision supported
- System decision execution with human acknowledgement
- Self controlled (human can override)
- Autonomous

Performance criteria provided for collision avoidance

### Control stations and operation

**Main control station**
- Main controls for speed and direction must be at location of responsible officer
- Main controls for propulsion and machinery must be at location of responsible engineering watch
- Guidelines contain performance requirements for alert management and the technical arrangements in the control station
- Must consider risks to control station and redundancies
- Must be able to respond to failures with manual actions by operator in control centre

**Voyage planning**
Deviation from planned route:
- must be possible to plan and validate an amended route before execution of the deviation
- remote operator must always be able to intervene and initiate an MRC at minimum

Contingency plans:
- must be contingency plans to place vessel in deep water or proceed to a port of refuge
- emergency events include loss of communication to control centre
- Minimum risk conditions (MRCs) must be identified for whole of voyage
- Automation system must be able to bring vessel to MRC without intervention from control centre

### Survey and approval requirements

**Traditional surveys** for physical and mechanical aspects of vessel, unless substituted or supplemented by more sophisticated monitoring capabilities
**Autoremote systems** may be subject to:
- Remote surveys, simulator testing, built-in testing
- Fewer calendar-based surveys, with surveys based on reporting, monitoring, verification and risk-based
- Condition monitoring
- Change management process (including notifying DNV of changes)
- Cyber security measures

**Process for approval of new system or concept**
1. Concept of operation
2. Preliminary risk analysis
3. High level design
4. Safety philosophy – gap analysis against current rules
5. Overall design philosophy – overall functions and constraints, redundancies and fault tolerance
6. Overall maintenance philosophy
7. Detailed design (must be approved by DNV)
8. Build and integrate
9. Commissioning and testing (test evaluation report provided to DNV)
10. Operation – ongoing data provided to DNV to inform future survey regime

**Software engineering and testing**
- Quality assurance in development and delivery
- Cyber security requirements

Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

**Table 8: Requirements of the DNV Guidelines for autonomous and remotely operated ships**

| Item | Approach |
|---|---|
| **Design principles** | - Maintain a safe state (no incidents should cause an unsafe mode).<br>- Maintain normal operation where anticipated failures occur.<br>- Redundancy and alternative control must be provided to the extent required to maintain a safe state.<br>- Independent barriers (systems which are designed with redundancy should be mutually independent and segregated in accordance with fire/flooding scenarios).<br>- Self-contained capabilities on board (failure of remote systems should be mitigated by systems or personnel on-board).<br>- Self-diagnosis and supervision (enhanced diagnostic functions and advanced alert management functions should be implemented to prevent undetected failures and ensure sufficient supervision). |
| **Navigation system** | - Must ensure a level of safety equivalent to a conventional vessel;<br>- Preliminary risk analysis of navigation system required as part of the concept of operations.<br>- Must define navigational functions / tasks intended to be covered by autonomous systems, and those which will be covered by a human operator. A mix of human and system operated tasks is assumed.<br>- Control of each function is divided into detection, analysis, planning and action.<br>**Detection**<br>- COLREG 5 (maintaining proper lookout) must be achieved through:<br>➢ a continuous state of vigilance by sight and hearing, as well as detection of significant changes in the operating environment;<br>➢ fully appraising the situation and the risk of collision, grounding and other dangers to navigation; and<br>➢ detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.<br>- Must comply with horizontal field of vision requirements, vertical field of version requirements and requirements for blind sectors, pitching and rolling, field of vision for docking.<br>- Must be able to detect and recognise lights and shapes as described in COLREG Part C, and sounds and light signals as described in COLREG Part D.<br>- Must be able to determine vessel position, based on at least two independent methods.<br>- Must be able to comply with operational requirements for position fixing as specified in IMO circulars, and with the required accuracy of electronic nautical charts.<br>- Image transmission in an autoremote detection system must be continuous, with resolution, frame-rate, colour depth and field of view providing an equivalent level of detection capability compared to a crewed bridge. This may be a challenging solution for the whole voyage, |

| Item | Approach |
|---|---|
| | but may be feasible for parts of the voyage, such as docking.<br>- Guidelines contain performance requirements for an object detection system, including ability to detect other vessels visually in line with requirements of COLREG 22.<br>**Analysis**<br>- Must be able to distinguish between vessel types in accordance with COLREG 18.<br>- Must be able to classify objects that are hazards (eg ice, small boats, containers).<br>- When navigation is performed from a remote location, the sensor data should be presented to the remote navigator in a way that allows the remote navigator to obtain an equivalent situational understanding to a navigator on-board. The guidelines include options and outcomes for:<br>➢ image transmission;<br>➢ virtual models; and<br>➢ object classification.<br>**Deviation from planned route**<br>- Must be possible to plan and validate an amended route before execution of the deviation.<br>- Planning may also be done by a human or by a system. Where completed by a system, the planned action may require verification (acknowledgement) by a remote navigator before execution (DSE). The system may also have limitations regarding what navigational complexities it is capable of handling, and may ask the remove navigator to plan certain actions. Where there is human acknowledgement or intervention, the remote navigator must have the situational awareness and information required for independent verification.<br>- Remote navigator should always have the ability to intervene and initiate an MRC (safe state) at the minimum.<br>- Performance criteria for collision and grounding avoidance is also provided.<br>**Contingency plans**<br>- Must be contingency plans for alternative action to place vessel in deep water or proceed to a port of refuge.<br>- Emergency events include the loss of communication between control centre and vessel.<br>- For vessels under the responsibility of remote operation from the control centre, the automation system on board the vessel should have the capabilities to autonomously bring the vessel to a minimum risk condition (MRC) without intervention from the control centre. This should be based on the system's own detection of loss of communication with the control centre, including detection of loss of passive supervision by the control centre.<br>- Operators in the control centre must also have the option of bringing the vessel into MRC.<br>- A list of potential MRC, depending on where and how the vessel is operating, are provided. MRCs for the whole of the voyage must be |

| Item | Approach |
|---|---|
| | planned and implemented in the vessel's autonomous system prior to departure.<br>**Safe speed**<br>- Must comply with COLREG 6 (proceed at a safe speed at all times).<br>- Requires situational awareness based on traffic, weather and sea conditions, and area of navigation.<br>- If safe speed is planned and executed by a system, the remote navigator should be provided with sufficient information for independent supervision.<br>**Manoeuvring**<br>- Must have proper visual near vessel information.<br>- Must have information on the effects of deadweight, draught, trim, speed and under-keel clearance on turning circles and stopping distances, rudder angle, propeller revolutions, thrusters.<br>- Equipment used may be a combination of sensors (eg CCTV, radar and laser) and other detection technology that either give true images or electronic reproduction of the surrounding area in real or near real time.<br>- May need systems that do not require a high amount of data to be transferred from the vessel to the control centre, but which still provide a good situational awareness.<br>**Docking**<br>- Must have situational awareness of the field of vision for docking.<br>- The following tasks must be supported:<br>➢ supervision of docking operations;<br>➢ monitoring of the vessel's heading, rudder angle, propeller revolutions, propeller pitch, thrusters;<br>➢ release of sound signals;<br>➢ monitoring of the relevant mooring operations;<br>➢ two-way communications with mooring stations on board and ashore; and<br>➢ two-way communication with other parts of the vessel organisation.<br>**Alert management**<br>- Navigation related alerts should be managed in accordance with the BAM concept (IMO). |
| **Engineering functions** | - All engineering functions traditionally carried out by crew on board must either be automated or carried out by operators in the control centre.<br>- <u>Automatic support</u> = operation of the function by systems and personnel.<br>- <u>Automatic operation</u> = operation of the function by systems with no requirement for intervention. Personnel will supervise and can intervene.<br>**Redundancy and function restorations**<br>- Crew on conventional vessels are able to restore functions within a specified period. Because this may not be possible on an autonomous vessel, there will need to be additional compensating measures to cope with failures and incidents, in order to achieve an equal level of safety |

| Item | Approach |
| --- | --- |
| | (eg additional redundancies).<br>- Personnel onboard can be given tasks in certain circumstances.<br>- Automation systems must be located onboard and not affected by communication failures.<br>**Incidents and failures**<br>- Failure of active components (eg pumps, fans motors, generators) should not cause the loss of functions.<br>- Any failures of components must be compensated for by redundancies, fault tolerance and automatic functionality.<br>- Failures are categorised as either:<br>➢ Anticipated: expected to occur eg through wear and tear. Must be mitigated by redundant design and vessel must be able to continue planned voyage (possibly at reduced speed / capability).<br>➢ Potential: less probable than anticipated. Vessel must be able to enter into and maintain a safe state / MRC during an anticipated failure.<br>- Guidance provided on the effects of a single failure. More rigid definition of safe state is required for autoremote vessels.<br>- Autoremote vessels need more sophisticated diagnostic functions (eg condition / health monitoring).<br>- Fire: is a potential failure. Any compartment or space containing electronic equipment that impose a risk of fire must be addressed in risk assessment. Risk of fire would normally lead to duplicated and segregated arrangement of systems serving key functions.<br>- Flooding: is a potential failure. Any equipment or systems needed for vessel to enter and maintain a safe state should be arranged with appropriate redundancy and segregation.<br>- Failures in rotating machinery: are anticipated failures, unless confidence can be obtained that the component is healthy through well proven diagnostic functions. If they are an anticipated failure, then redundancy is required to allow for continuation of normal planned voyage.<br>- Failures in other mechanical components: may be anticipated or potential, depending on risk assessment.<br>- Electrical failures: some are anticipated (short circuits, failure of power generating equipment, failure of power converter), some are potential (complete black out, fire or flooding).<br>- Failure of control systems and safety systems: redundancy required for key systems. Safe states should be designed and demonstrated.<br>- Failure of data communication networks / links: are anticipated failures.<br>- Cyber security incidents: potential failures, provided adequate precautions are implemented.<br>- Human error: potential failures.<br>- External events: potential failures. |

| Item | Approach |
| --- | --- |
| | **Propulsion and steering**<br>- Propulsion machinery must be able to be sustained or restored even if one of the essential auxiliaries becomes inoperative.<br>- Must be arranged with redundancy so that vessel can maintain a navigable speed in case of failure of single system.<br>- Autoremote vessels may require increased separation, increased redundancy and adequate remote operator interface.<br>- Infrastructure providing remote control / supervision should be redundant / single fault tolerant.<br>- Main controls for speed and direction should be at the location of the responsible navigating officer.<br>- Main controls for propulsion and machinery should be at the location of the responsible engineering watch.<br>**Electrical power supply and distribution**<br>- Must have redundancy and capacity to ensure normal operation can be maintained or restored in event of system or component failures.<br>- Main power supply should be self-contained.<br>- Emergency power supply system, including generation and distribution, should be arranged with sufficient capacity to handle emergency conditions and maintain the vessel in a safe state.<br>- Emergency lighting may still be required to enable remote operators to obtain sufficient situational awareness in an emergency.<br>**Control, monitoring, alarm and safety systems**<br>- Must be able to observe real-time operational status, readiness and capacity of vessel function or system from control centre.<br>- Must be possible to respond to failures with manual actions by operator in control centre.<br>- Effect of failure of integrated control should be limited. |
| **Communication system** | - Communication link between vessel and control centre must consider maximum bandwidth, latency requirements, cyber security, interfaces, and prioritisation of data in case of insufficient bandwidth.<br>- Guidance provided on arrangements for communicating with off-ship systems and sensors (eg shore-based radar, weather forecasts, shore-based cameras eg for docking).<br>- Must be able to communicate with external stakeholders, including other vessels, pilot station etc. May be achieved through relaying task to personnel in control centre, or by automatic systems onboard.<br>- Vessels must have a DNV Class notification Cyber Secure (Advanced), or cyber security assessments must be performed on the total system. |
| **Survey requirements** | - The physical and mechanical aspects of the vessel will be subject to traditional survey requirements, unless substituted or supplemented by more sophisticated monitoring capabilities.<br>- Autoremote systems may be subject to:<br>➢ remote surveys, simulator testing, built-in test capabilities;<br>➢ less calendar-based surveys, more based on the above aspects for reporting, monitoring and verification, and other |

| Item | Approach |
|---|---|
| | risk-based surveys;<br>➢ condition monitoring;<br>➢ software change management processes; and<br>➢ cyber security measures.<br>- Provides guidelines on the technical and organisational arrangements in a remote control centre.<br>- Guidelines include a change management process – DNV must be notified of changes to the target system. |
| **Survey, approval and certification** | - Process for approval of alternative designs to current class rules and regulations.<br>- Where there is a new operational concept, the process is between the developer of the technology, DNV and the administration.<br>- DNV supports the project by documenting and verifying that the proposed concept achieves and equivalent level of safety as a conventional vessel. The process involves:<br>- Concept of operation<br>➢ A description of all the operational tasks that the vessel will undertake that will be fully or partly automated.<br>➢ Each operational task should be divided into sub-tasks to clearly articulate when a human is in charge, and when a system is in charge of decision making.<br>➢ When a human is charge of decision making, the location of the decision-maker should be described, and the timing aspects and ability of the decision maker to establish sufficient situational awareness to be make the decision should be considered.<br>- Preliminary risk analysis<br>➢ May result in changes to the concept of operations.<br>- High level design<br>➢ Contains key elements including propulsion arrangement, fire-fighting capability and system architecture.<br>➢ The degree of novel vs conventional technology planned to be used should be investigated.<br>- Safety philosophy<br>➢ Gap analysis against current rules, and what exemptions will be required.<br>➢ Minimum Risk Conditions should be detailed.<br>➢ Crewing arrangements should be detailed.<br>- Overall design philosophy<br>➢ Overall functions of autoremote infrastructure, requirements and constraints.<br>➢ Redundancies and fault tolerance for the systems.<br>- Overall maintenance philosophy<br>➢ How each autoremote system will be monitored, maintained and repaired. |

| Item | Approach |
|---|---|
| | - Documentation<br>➢ Safety philosophy, design philosophy and maintenance philosophy are provided to DNV for information.<br>- Detailed design<br>➢ Vessel design and off-ship design.<br>➢ Detailed risk analysis of autoremote systems (eg using FMEA).<br>➢ Provided to DNV for approval.<br>- Build and integrate<br>➢ Review, analysis and testing of autoremote systems.<br>➢ Verification and validation strategy sent to DNV for approval.<br>- Commissioning and testing phase<br>➢ Test reports, failures and test evaluation report sent to DNV for approval.<br>- Operations<br>➢ Data collected and provided to DNV to inform future survey schemes.<br>- Convention technology used on the vessel will be subject to standard approval processes (type approval, application design approval, product certification test, on-board tests).<br>- Novel technology will be subject to an approval process which involves defining what aspects of the technology are novel and which are proven, a detailed risk analysis, simulator based testing, factory acceptance testing, testing after installation, and updates and testing during operation. |
| **Software engineering and testing** | - Quality assurance of the development, delivery and modification of software-based systems.<br>- Quality of software is managed through:<br>➢ inspecting and testing end products for defects; and<br>➢ control software and configuration processes to prevent mistakes being made.<br>- Cyber security – must have type approval for programs and cyber security class notation. |
| **System engineering and integration** | - Must have a focus on system engineering and integration.<br>- One organisation that is responsible for system integration on the project. |
| **Remote control station** | - Guidance as to technical arrangements in control centres.<br>- A dedicated physical area for the tasks necessary to remotely operate vessel is required.<br>- Must consider the hazards and failure risks within the control centre (eg black out, fire and evacuation).<br>- *Anticipated failures* in the control centre must not result in loss of normal control, supervision and situational awareness of the vessel functions under remote operation from the control centre.<br>- *Potential failures* in the control must not prevent the vessel from |

| Item | Approach |
| --- | --- |
| | entering and maintaining MRC.<br>- Power supplies must be considered as part of risk assessment and redundancies provided.<br>**Remote situational awareness**<br>- Should be based on real-time information.<br>- Substitutes for the human senses of crew onboard a vessel must be provided by sensor technology, including sight (visual presentations), hearing (hazards that may be detected by sound information), and other senses (eg of vessel movements, visibility, ambient conditions (eg strong wind), fire, temperature, vibrations).<br>- Some sensor information should be recorded to allow for playback (not sensor information all will be monitored at all times).<br>**Remote vessel supervision**<br>- When independent supervision is required, there must be sufficient information to allow remote personnel to do independent analysis.<br>- Contains requirements for intended action control and pre-warnings.<br>- Contains requirements for alter management, functional status, consequence analysis and decision support.<br>- Contingency plans should be displayed at all times at the control centre. Personnel in control centre must be able to select and initiate any MRC at any times.<br>- Requirements for data logging. |

## 4.5 Comments on the approach and content of the DNV Guidelines

This section contains some preliminary comments on the approach and content of the DNV Guidelines, based on the analysis of the structure and content of the guidelines and on feedback from stakeholders. The suitability of the DNV Guidelines for the Australian context is considered in Chapter 6 of this report.

<u>The DNV Guidelines focus on the different requirements for autonomous vessels</u>

The DNV Guidelines do not contain requirements covering the whole of the autonomous or remotely operated vessel. Rather, they focus on how novel systems on an autonomous and remotely operated vessel would be verified and approved as meeting the same level of safety as a conventional vessel.

<u>The DNV Guidelines are process driven</u>

The DNV Guidelines establish a detailed process for assessing the novel aspects of an autonomous or remotely operated vessel.

<u>The DNV Guidelines break down functions and control</u>

The DNV Guidelines contain very detailed breakdowns on how navigation and control systems on the vessel can be executed by humans or systems. This functional approach allows for many different systems of control, and is a more accurate way of considering autonomous and remotely operated vessels than arbitrary categories of autonomous and remotely operated vessels.

For example, it may be difficult to categorise a vessel as ‘directed’ (operator-controlled), ‘delegated’ (operated-monitored, with option of veto) or ‘monitored’ (operator-monitored), if the approach on the vessel is different for different systems and/or situations.

The DNV Guidelines require an analysis of potential failures

Th DNV Guidelines require potential failures of the engineering and electrical systems to be identified and categorised as either ‘anticipated’ or ‘potential’. Redundancies must be in place for ‘anticipated failures’, and the vessel must revert to a safe state for a ‘potential failure’.

Under the DNV Guidelines, the ‘autoremote’ systems on the vessel must also be subject to a detailed risk analysis that ensures that the ‘autoremote’ infrastructure as a whole is able to deal with relevant failures and situations in a safe manner. This risk analysis should be performed using an established risk analysis method such as fault tree analysis (FTA), event tree analysis (ETA) or failure mode and effects analysis (FMEA). The DNV Guidelines contain guidelines on the expected response of the systems to various hazards, incidents and failure modes.

The DNV Guidelines are very detailed

The DNV Guidelines contain a high level of detail, as compared to the other available codes, on the expectations for the ‘autoremote’ systems on the vessel.

# 5. Comparing the available codes

## 5.1 Overview of requirements

The following three tables:

- provide an overview of the content of the three available codes and standards;
- compare the technical requirements of the available standards and codes for vessel design, construction and operation; and
- compare the requirements of the available standards and codes for surveys and testing.

**Table 9: Comparing the available standards – overview of content**

| | UK Code | LR Code | DNV Guidelines |
|---|---|---|---|
| **Design and construction requirements (general)** | Designed, constructed and maintained in compliance with the requirements of a classification society or in accordance with applicable national standards.<br>Justifications for departures | Detailed performance requirements | Process for approval of new approach or new technology |
| **Engineering** | Some additional requirements (eg redundancies) | | Performance requirements and detailed guidance |
| **Communications equipment** | In accordance with the requirements for conventional vessels. | | |
| **Navigation equipment / situation awareness** | Must enable the vessel to comply with COLREGS. | | Must enable the vessel to comply with COLREGS.<br>Detailed performance requirements |
| **Control** | Risk assessment / FMEA | Risk assessment / FMEA | Risk assessment / FMEA |
| **Safe states / contingency plan** | ✓ | ✓ | ✓ |
| **Control centre** | ✓ | ✓ | ✓ |
| **Control hierarchy** | ✓ | ✓ | |
| **Competencies** | ✓ | | |
| **Software integrity & cyber security** | ✓ | ✓ | ✓ |

**Table 10: Comparing the available standards – technical standards and requirements for vessel design, construction and operation**

<table>
<tr><th>Aspect</th><th>UK Code</th><th>LR Code</th><th>DNV Guidelines</th></tr>
<tr><td>Arrangement, accommodation and personal safety</td><td rowspan="7">- The MASS should be designed, constructed and maintained in compliance with the requirements of a classification society or in accordance with applicable national standards.<br>- Where the MASS design departs from the equivalent crewed vessel standard, there must be justification demonstrating that:<br>➢ the crewed vessel requirement is redundant (eg removal of crew habitability requirements or lifesaving equipment); or<br>➢ an alternative solution is required to maintain the same level of performance (eg replacing a manual firefighting system with automatic systems).<br>- The departure must not result in an increased risk to other vessels, third parties or the environment.<br>- The standards of the vessel aspect or system must be sufficient to enable the MASS to be operated and maintained safely, and protected, in all reasonably foreseeable operating conditions.</td><td>Not directly addressed in code.</td><td rowspan="6">Not directly addressed.</td></tr>
<tr><td>Watertight and weathertight integrity</td><td rowspan="3">Detailed performance requirements.<br>May be met through compliance with Class Rules or national standards.</td></tr>
<tr><td>Construction</td></tr>
<tr><td>Stability</td></tr>
<tr><td>Anchoring equipment</td><td>Not directly addressed in code.</td></tr>
<tr><td>Safety equipment</td><td>Not directly addressed in code.</td></tr>
<tr><td>Fire safety</td><td rowspan="2">Detailed performance requirements.<br>May be met through compliance with Class Rules or national standards, or risk-based analysis.</td><td>Must be addressed in the risk assessment.</td></tr>
<tr><td>Engineering – electrical</td><td>As above (for other vessel aspects), possibly with additional redundancy in the electrical systems to enable the MASS to conduct its mission.</td><td>Performance requirements and detailed guidance on arrangements and redundancies.</td></tr>
</table>

| Aspect | UK Code | LR Code | DNV Guidelines |
|---|---|---|---|
| **Engineering – propulsion & manoeuvring** | As above (for other vessel aspects), with a requirement for the MASS to be able to be manoeuvred as and when required by the operator, but still remain within the designed or imposed limitations. | Detailed performance requirements.<br>May be met through compliance with Class Rules or national standards, or risk-based analysis. | |
| **Communications equipment** | In accordance with the requirements for conventional vessels. | Performance requirements. | Detailed performance requirements. |
| **Navigation equipment / situation awareness** | Must enable the vessel to comply with COLREGS. | Detailed performance requirements and requirements for sensors. | Must enable the vessel to comply with COLREGS.<br>Very detailed performance requirements. |
| **Control system** | Risk assessment must be undertaken focussing on potential failures (eg through Failure Mode Effects Analysis)<br>Guidance on sensors.<br>Requirements for data interpretation (analysis) and decision making, either by a system or human.<br>Requirements for vessel control (execution of decisions).<br>Must be able to operate in compliance with COLREGS. | Control system must be designed and arranged to meet the required level of integrity.<br>The required level of integrity is determined by assessing the effect of all reasonably foreseeable system failures and by considering their consequence of those failures on safety and on the operational capability of the vessel.<br>Detailed performance requirements for the control system, for example:<br>*control system is to respond in a timely, accurate and predictable manner commensurate with the equipment limitations and manoeuvring capability of the UMS.* | Must enable the vessel to comply with COLREGS.<br>Control is broken down into analysis, decision and execution. Requirements apply to each of these aspects of control, and depend upon whether a human or system is responsible for the control element.<br>Any novel technology used as part of the control system is subject to an approval process, which involves a failure mode risk assessment (eg through an FMEA). |

| Aspect | UK Code | LR Code | DNV Guidelines |
|---|---|---|---|
| **Safe states and contingency planning** | Requirements for contingency planning and 'safe states'. | Requirements for contingency planning and 'safe states'. | Detailed requirements to identify the 'minimum risk conditions' for each foreseeable event. |
| **Control station** | Vessel must be monitored from control centre at all times.<br>Operator in control centre must be able to take control of the vessel at any time.<br>Guidance on control centre operational capabilities and tasking cycles for the MASS. | Must only be possible to control vessel from one control station at any one time.<br>Operator in control centre must be able to take control of the vessel at any time.<br>Requirements for:<br>- level of integrity of the control station;<br>- control panels; and<br>- operational arrangements and processes. | Operator in control centre must be able to initiate an MRC at any time.<br>Detailed performance requirements and guidance on:<br>- risk controls and redundancies at the control centre;<br>- minimum data to be provided to the control station;<br>- alert management; and<br>- data logging. |
| **Crew / operator competencies** | - Must comply with competency requirements for crewed vessels, plus additional training.<br>- Detailed guidance on the additional training required. | Not addressed in code. | Not addressed in code. |
| **Software integrity & cyber security** | Includes requirements. | Software integrity testing and cyber security audit included as part of verification processes. | Includes requirements. |

**Table 11: Comparing the available standards – technical requirements for survey and testing**

| Aspect | UK Code | LR Code | DNV Guidelines |
|---|---|---|---|
| **Concept of operations** | Must be prepared. | Must be prepared. | Must be prepared. |
| **System testing and approval** | - Testing is based on a risk assessment.<br>- Critical safety items must be individually tested.<br>- Impact of power failures to be tested.<br>- Sensors critical to performance must be tested.<br>- Emergency stop systems must be tested, including under datalink failure conditions. | Step 1: Identify level of integrity required for each UMS system. This is based on the impact of the failure of a system.<br>Step 2: Develop verification plan. The level of testing and verification required will depend on the level of integrity required for each system. | Detailed process for the approval of novel technology, including testing requirements. |
| **Surveys** | Surveys may include:<br>- a review of the capability, organisation and facilities of the manufacturer;<br>- certification of software, equipment and components;<br>- survey of the material state during build; and<br>- witness of tests and trials to demonstrate functionality.<br>Vessel will also be surveyed periodically. | Survey process includes:<br>- design verification<br>- construction surveys, including:<br>➢ review of the capability, organisation and facilities of the manufacturer;<br>➢ certification of software, equipment and components;<br>➢ survey of the material state during build to confirm compliance with the appraised design; and<br>➢ witness of tests and trials to demonstrate functionality; and<br>- periodic surveys. | - Detailed process for approval of design, including the documentation required.<br>- Traditional survey requirements apply to the physical and mechanical aspects of the vessel, unless substituted or supplemented by more sophisticated monitoring capabilities.<br>- Autoremote systems may be subject to:<br>➢ remote surveys, simulator testing, built-in test capabilities;<br>➢ quality assurance of the development, delivery and modification of software;<br>➢ inspecting and testing software; and<br>➢ control software and configuration processes to prevent mistakes being made.<br>- Vessel will be surveyed periodically. |

## 5.2 Comparing the requirements for navigation systems and situational awareness

### 5.2.1. The UK Code for MASS

The UK Code for MASS requires compliance with COLREGs. (The vessel 'must be capable of operating to a level of compliance with COLREGs appropriate to the MASS class').

In addition, the vessel must achieve the same level of situational awareness as an equivalent crewed vessel. Guidance is provided on sensors which may be used to achieve this.

### 5.2.2. LR Code

The performance requirements in the LR Code for the navigation system includes requirements to determine position, identify hazards, detect other vessels, display navigation lights and shapes, generate navigation sounds and avoid collisions.

### 5.2.3. DNV Guidelines

The DNV Guidelines contain a broad category of 'navigation functions' within which falls detection (situational awareness), analysis, planning and execution. In the UK Code and the LR Code, 'navigation systems and situational awareness requirements' are predominantly those which fall into the category of 'detection' in the DNV Guidelines.

The DNV Guidelines contains performance requirements for the 'detection' aspect of navigation. These performance requirements include the requirements that apply to conventional (crewed) vessels as a 'baseline' – compliance with COLREGS, SOLAS Chapter V Regulation 22 (navigation bridge visibility) and relevant IMO Resolutions (position fixing requirements) must be achieved. Guidance is provided on how 'autoremote' systems can be used to achieve these outcomes. For example, the systems used must compensate for the lack of a human look-out on board by accounting for all human senses.

## 5.3 Comparing the requirements for control systems

For the purposes of this section, 'control systems' covers all the systems that support the vessel being controlled in a safe and compliant manner. Using the terminology of the DNV Guidelines, control includes:

- analysis of navigational information and data;
- decision making (action planning); and
- execution of the decision (action control).

Across the three available codes, the requirements for control systems are similar. They include a performance requirement (or performance requirements), together with a requirement to undertake a risk assessment of the proposed control systems, focusing on the consequences of failures.

### 5.3.1. Performance requirements for control systems

The DNV Guidelines require compliance with conventional vessel requirements as a 'baseline' – which in short requires the vessel to comply with COLREGS.

The DNV Guidelines also include significant guidance on how these outcomes are met through autoremote systems, or through a combination of systems and humans. For the execution or action control element, the DNV Guidelines include specific performance requirements for safe speed, manoeuvring and docking.

The UK Code also requires the control system to enable the vessel to comply with COLREGS. The other performance requirements of the UK Code for control systems are relatively brief and cover:

- data interpretation (analysis);
- capability to exert timely and accurate control;
- propulsion control; and
- steering control.

The LR Code includes high-level performance requirements for the control system, covering the ability of the system to respond in a timely, accurate and predictable manner.

### 5.3.2. Control system design, integrity and testing requirements

Control systems on autonomous and remotely operated vessels will rely – at least in part – on novel technology and approaches.

All three codes require a failure-mode risk analysis to be conducted on the control system and/or any new technology on the vessel.

UK Code for MASS

The UK Code requires the control system to ensure that the vessel, and/or the control centre, has sufficient information, interpretation and control of its position and systems, to enable it to be as safe as an equivalent manned vessel operating in similar circumstances. Any decision making that impacts safety and is performed by the MASS must have been adequately demonstrated to be commensurate with that which a competent seafarer would correctly perform in the same circumstances.

Under the UK Code, a risk assessment must be undertaken using an appropriate method, such as FMEA. The analysis in the risk assessment must be supported by trials.

The risk assessment must identify potential failures which could impact on safety through:

- collision with fixed or floating objects;
- grounding;
- becoming a significant obstruction or hazard to other traffic;
- leakage of noxious substances or other forms of pollution; and
- other potentially hazardous events or situations, which may depend on the type of MASS and how it is deployed and operated.

The risk assessment must consider the vessel's systems, sub-systems, and components, and take into account:

- the probability of a failure occurring in measurable units (eg probability per 10,000 hours of operation) and the direct and indirect effects of the failure;
- whether the MASS is capable of inflicting significant damage in a collision, by reason of its kinetic energy or its mass. Even at zero hull speed, a significant mass may cause damage by drifting onto, being blown by wind or thrown by waves onto another object or vessel;
- whether the MASS is liable to become a significant obstruction to other traffic, if left to drift without propulsion or steering. This is governed by size and weight and operating area; and
- whether the MASS carries significant quantities of hazardous or pollutant substances.

Failure modes to be considered in the risk assessment must include:

- power generation, control, distribution;
- propulsion systems including the control of thrust and its direction;
- steering systems including actuators and their control;
- propulsion;
- electrical connectors;
- fuel and hydraulic systems (potential fire, pollution, loss of control);
- individual sensors and their power supplies;
- individual actuators and their power supplies;
- communication systems;
- the platform control system (including autopilots and Collision Avoidance systems);
- the autonomy processor(s), i.e. the interpretation and decision-making system which takes in sensor data and takes decisions on what control actions to take. This may be done on board, off-board, or as a combination of these;
- signaling and lighting; and
- data quality or inconsistency.

All potentially critical failure modes which are mitigated using failure sensors and/or “defence in depth”, dual or multiple redundant safety features, need to be identified for the purpose of test and accreditation of the vessel.

If the consequence of failure identified in the risk assessment are deemed acceptable then the single point failure modes need not be analysed further.

The risk assessment must show that the vessel is able to be operated to a tolerably safe level, ideally proven to be as safe as an equivalent crewed vessel.

LR Code for UMS

Under the LR Code, the ‘required level of integrity’ must be determined for each UMS system. The level of integrity is determined by assessing the effect on the vessel, considered as a system of systems, of all reasonably foreseeable system failures and by considering their consequences.

Consequences of reasonably foreseeable system failures are categorised as *safety* (to people onboard, to people and objects in the vicinity of the vessel and to the environment) or *operational* (capability) consequences. The consequences are further categorised as high (unacceptable), medium (acceptable with mitigating factors) or low (acceptable). The highest level of integrity for each system applies to that system.

The control system must be designed with a level of integrity sufficient to enable the UMS to be operated and maintained safely (as and when required within its design or imposed limitations, in all reasonably foreseeable operating conditions).

Higher verification / testing requirements apply to systems with a higher required level of integrity.

DNV Guidelines

The DNV Guidelines require three different risk analysis:

- a preliminary risk analysis (HAZID) to take place to evaluate the vessel's ability to operate safely and reliably;
- a detailed risk analysis to evaluate the vessel's ability to operate safely and reliably using an established method, such as fault tree analysis (FTA), event tree analysis (ETA) or failure mode and effects analysis (FMEA).
    - If the operational concept includes remote operations from a remote control centre, this should be analysed through a separate risk analysis which focuses on human aspects (such as crisis intervention and operations analysis (CRIOP) and operating and support hazard analysis (O&SHA)); and
- for all novel technology used on the vessel, a detailed risk analysis must be undertaken which assesses threats and identifies failure modes and their risks. This risk analysis of the system should show how the system design maintains the functionality in question and keeps the risks to life, environment and property equivalent to (as safe or safer) current conventional solutions. Recognised risk analysis methods like FTA, ETA, and FMEA should be used. Probability categories should be limited to:
    - failure is not expected;
    - failure may be expected within the lifetime of the product/vessel (potential failure); or
    - failure may be expected several times a year for a product (anticipated failure).

Specific conclusions of the FMEA for the different systems should be verified by tests when redundancy, fail safe response, or independency is required. The test selection should cover all specified technical system configurations.

## 5.4 Comparing the requirements for the control centre

Each of the available codes includes requirements for the control centre. The following table provides an overview of the issues covered in the codes for the control centre.

**Table 12: Comparing the requirements for control systems**

| | UK Code | LR Code | DNV Guidelines |
|---|---|---|---|
| **Arrangements of control centre** | | ✓ | ✓ |
| **Management of risks to control centre and redundancies** | | | ✓ |
| **Remote situational awareness, including data provided & timing of data** | ✓ | ✓ | ✓ |
| **Remote vessel control / supervision requirements** | ✓ | ✓ | ✓ |
| **Hierarchy of control** | ✓ | ✓ | |

## 5.5 Comparing the requirements for safe states and contingency planning

All three codes contain requirements for contingency planning and 'safe states'.

The DNV Guidelines provide significant detail on this issue – under the DNV Guidelines, the 'minimum risk conditions' must be defined for each foreseeable 'event'. The 'minimum risk condition' is the state in which the vessel would enter when unexpected situations arise which poses the least risk to life, the environment and property.

All three codes also include requirements that:

- the remote operator (or supervisor) must be able to enter the vessel into a safe state at any time; and
- where contact is lost with the remote operator (or supervisor), the vessel automatically enters into a safe state.

**Table 13: Comparing the safe states and contingency planning requirements**

| | UK Code | LR Code | DNV Guidelines |
|---|---|---|---|
| **Safe states** | Must have an 'emergency stop', whereby the vessel is operating in a manner that is unlikely to cause damage either directly or indirectly. | Must have a 'safe state' to minimise the risk to people, environments or assets. | Minimum risk conditions (MRCs) must be defined for every possible situation.<br>There will be different MRCs for different situations, including the MRC of 'last resort' (equivalent to the 'emergency stop'). |
| **Initiating contingency arrangements** | Must be automatic in response to some conditions. For example, on sensing failure of datalinks, the vessel must enter a 'render safe' procedure which culminates in the emergency stop.<br>Must be able to initiated at any time by remote controller. | Automation system must ensure that any serious malfunctions shall result in the initiation of corrective actions to put the vessel into a safe state.<br>It must be possible to override the autonomous control system to initiate a corrective action or activate a safe state at any time. | Automation system must initiate an MRC in response to some conditions – for example, loss of communication with control centre.<br>Operator must be able to select and initiate any MRC at any point. |

## 5.6 Comparing the requirements for engineering systems

The requirements for engineering systems on autonomous and remotely operated vessels are presented differently across the three codes. However, at their core, each code requires an assessment of the impact of the potential failure of each engineering system to be undertaken, and the redundancies and fault tolerances required to manage that impact to be identified, given the lack of personnel on the vessel.

The DNV Guidelines focus on the need for additional fault tolerance and redundancies to compensate for failures and incidents that would, on a conventional (crewed) vessel, be handled by crew on board. The DNV Guidelines are structured around the potential incidents and failures, how these would affect different engineering systems, and the resulting redundancies required.

In the UK Code for MASS, this issue is mainly addressed through the risk assessment that must be completed to identify all potential failures that could impact on safety, including failures in the following systems:

- power generation, control, distribution;
- propulsion systems including the control of thrust and its direction;
- steering systems including actuators and their control;
- propulsion;
- electrical connectors; and
- fuel and hydraulic systems (potential fire, pollution, loss of control).

Finally, the LR Code requires the electrical and engineering systems to be design with to meet the required 'level of integrity' for that system (see discussion on the level of integrity requirements at 5.3 above). The level of integrity determines the redundancies required for the electrical and engineering systems.

## 5.7 Comparing the survey and certification processes

The LR Code and DNV Guidelines were developed to support the survey and certification process undertaken by Lloyd's Register and DNV respectively, and as a result contain more detailed requirements on these issues. Both of these codes outline the documentation requirements for the vessel, and the DNV Guidelines include very detailed information on the approval process.

However, the survey process set out in each of the three codes contains the same fundamental elements:

1. Design verification. The design verification process begins with a concept of operations. Design approval is on the detailed design of the vessel, including the standards to which each aspect of the vessel will be constructed and the verification processes.
2. Surveys during construction. This will likely include certification of software and tests and trials to demonstrate compliance, as well as conventional construction surveys.
3. Periodic surveys. Throughout the life of the vessel. Different processes may apply to software-based systems, the health of which may be monitored constantly.

# 6. Considering the available codes in the Australian regulatory context

## 6.1 Domestic commercial vessels, regulated Australian vessels, and recreational vessels

The regulatory requirements applicable to a vessel operating in Australian waters depend on whether the vessel is a:

- domestic commercial vessel;
- regulated Australian vessel; or
- recreational vessel.

Domestic commercial vessels are vessels for use in connection with a commercial, governmental or research activity, that operate only within the Exclusive Economic Zone of Australia – which is approximately 200nm from the Australian shore. Domestic commercial vessels are subject to the *Marine Safety (Domestic Commercial Vessel) National Law Act 2012* (National Law Act).

Commercial vessels that operate beyond 200nm from the shore are regulated Australian vessels and are subject to the *Navigation Act 2012* (Navigation Act). Vessels that are not used in connection with a commercial, governmental or research activity are recreational vessels, and are subject to the marine safety laws in place in the State or Territory in which they are operating.

The Australian Code of Practice will be focussed on the requirements for commercial vessels, not recreational. However, commercial vessels which operate internationally must comply with international conventions, including the Convention for the Safety of Life at Sea (SOLAS). Under current international conventions and agreements, autonomous vessels can only be operated in trials, or through the issue of exemptions and equivalences by the flag state administration.[4]

Vessels which operate only within Australia (such as domestic commercial vessels) are subject to local requirements (noting that some international conventions do apply to these vessels – such as MARPOL and COLREGS). This means that there is more flexibility for autonomous and remotely operated vessels to be approved to operate within Australia's exclusive economic zone.

Given that RAVs are generally certified to operate internationally, and must therefore comply with all applicable international requirements including SOLAS, it is assumed that an Australian Code of Practice would largely apply to domestic commercial vessels. As a result, this chapter considers the available standards against the regulatory context for domestic commercial vessels.

However, the Australian Code of Practice would also be informative for other vessels, such as RAVs.

[4] As at date of this report – June 2021. It is noted that this is a rapidly evolving space, and IMO committees are considering the requirements for autonomous and remotely operated vessels.

## 6.2 The regulatory framework for domestic commercial vessels

### 6.2.1. Overview

As outlined above, domestic commercial vessels are subject to the National Law Act.

The National Law Act establishes the Australian Maritime Safety Authority (AMSA) as the National Regulator, empowers AMSA to regulate domestic commercial vessels in Australia, and creates duties and offences for all owners, masters, crew, passengers and other persons whose actions impact on the safety of domestic commercial vessels. It also identifies the three certificates to be issued as part of the administration of marine safety for domestic commercial vessels.

The National Law Act is supported by the *Marine Safety (Domestic Commercial Vessel) National Law Regulation 2013* (National Law Regulations), six Marine Orders, three main general exemptions and national standards, in particular the National Standard for Commercial Vessels (NSCV). The structure of the National Law is shown in Figure 8.

The National Law Act regulates, for domestic commercial vessels:

- design, construction and equipment requirements, and the survey and certification of vessels;
- vessel operations, such as safety management systems, and the certification of operations;
- the certification of crew competency and minimum crewing requirements; and
- inspection, compliance monitoring, investigations, auditing and other ancillary powers over vessels.

Requirements under the National Law are applied on a risk basis. Three main vessel schemes are established through the Marine Orders and Exemptions: vessels in survey, restricted C vessels, and non-survey vessels. As shown in Figure 9:

- vessels in survey include all vessels 12 metres and longer, all vessels that operate offshore, all vessels which are more than four passengers, and all vessels which have a higher risk element (carriage of dangerous goods, are required to obtain a certificate of survey in order to operate);
- restricted C vessels include vessels less than 12m in length, which operate close to shore (in restricted C waters) and which do not have a higher risk element; and
- non-survey vessels include vessels less than 12m in length, which operate in sheltered waters, carry four or less passengers and which do not have a higher risk element.

### Figure 8: Legislative framework for domestic commercial vessels

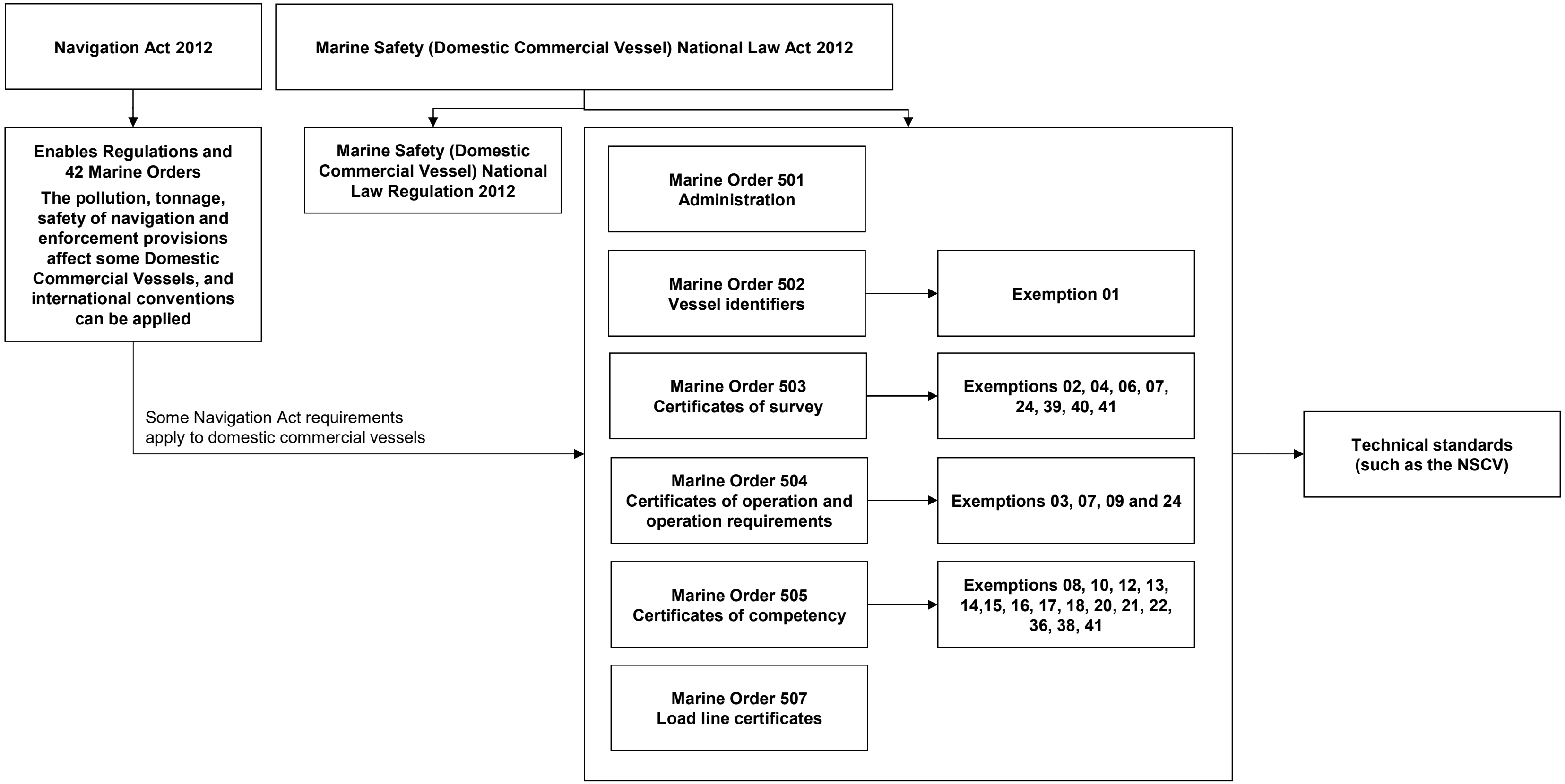



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

**Figure 9: Vessel schemes under the National Law**

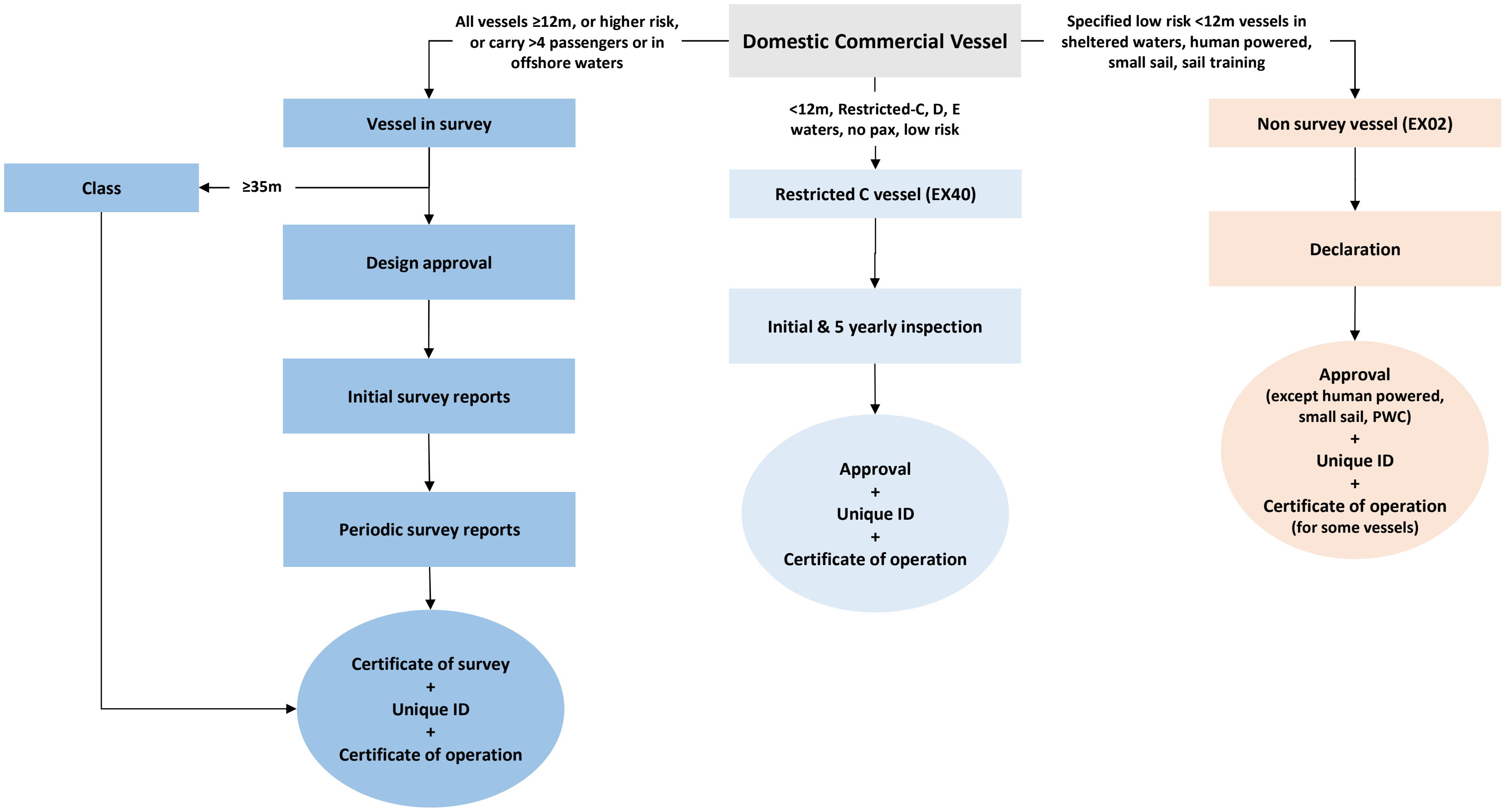



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

### 6.2.2. Regulatory requirements for domestic commercial vessels

The standards, survey requirements and certification requirements that apply to a newly constructed domestic commercial vessel depend on the scheme the vessel is in. The requirements for each scheme are set out in Table 14 below.

Note that Class 1 vessels are passenger vessels (vessels which carry more than 12 passengers), Class 2 vessels are non-passenger vessels (work boats, cargo vessels and small passenger vessels which carry up to 12 passengers), Class 3 vessels are fishing vessels and Class 4 vessels are hire and drive vessels.

**Table 14: Regulatory requirements for newly constructed domestic commercial vessels**

| Scheme | | Design, construction & equipment standard | Survey standard | Operating standard (including crewing) | Crew competencies standard | Certification |
|---|---|---|---|---|---|---|
| **Vessels in survey** | **Class 1, 2 & 3** | NSCV Part C | MO503 and the Marine Surveyor Accreditation Guidance Manual, Part 2, Surveys of Vessels (SAGM) | MO504 | MO505 and Part D | Certificate of survey<br>Certificate of operation<br>Certificates of competency for crew<br>Load Lines Certificate for some vessels ≥24m in load line length |
| | **Fast craft** | NSCV Part F1 | | | | |
| | **Class 4** | NSCV Part F2 | | | Local recreational boating licencing requirements generally apply | Certificate of survey<br>Certificate of operation |
| **Restricted C vessels**<br>**(Class 2 and 3 vessels only)** | | Exemption 40 | Exemption 40 and the SAGM | MO504 | MO505 and Part D | Vessel approval<br>Certificate of operation<br>Certificates of competency for crew |
| **Non-survey** | **Class 2 & 3** | NSCV Part G | N/A – surveys are not required | MO504 | MO505 and Part D | Vessel approval<br>Certificate of operation for some vessels<br>Certificates of competency for crew |
| | **Class 4** | | | | Local recreational boating licencing requirements generally apply | Vessel approval<br>Certificate of operation for some vessels |

### 6.2.3. The standards that apply to domestic commercial vessels

Vessels in survey

As shown in Figure 9, the majority of vessels which operate offshore are ‘vessels in survey’. As shown in Table 14, the NSCV Part C (Design and construction) applies to these vessels. NSCV Part C contains the following subsections:

- Section C1: Arrangement, accommodation and personal safety;
- Section C2: Watertight and weathertight integrity (under development – the relevant requirements of the Uniform Shipping Laws Code (USL Code) continue to apply until NSCV C2 is complete);
- Section C3: Construction;
- Section C4: Fire safety;
- Section C5: Engineering, including:
    - Subsection C5A: Machinery;
    - Subsection C5B: Electrical;
    - Subsection C5C: LPG systems for appliances;
    - Subsection C5D: LPG systems for engines;
- Section C6: Stability, including:
    - Sub-section C6A: Intact stability requirements;
    - Subsection C6B: Buoyancy and stability after flooding;
    - Subsection C6C: Stability tests and stability information;
- Section C7: Equipment, including:
    - Subsection C7A: Safety equipment;
    - Subsection C7B: Communications equipment;
    - Subsection C7C: Navigation equipment;
    - Subsection C7D: Anchoring systems.

This means that, under the current regulatory framework, the assessment of new entry domestic commercial vessels that are intended to be operated offshore, including those which are autonomous or remotely operated, will be conducted against these sections of the NSCV.

Restricted C vessels

Smaller (<12m) vessels which operate close to shore are subject to the Restricted C requirements. The Restricted C requirements include:

- some NSCV Part C requirements (such as NSCV C5B – Electrical);
- some NSCV Part F2 requirements (such as for flotation); and
- for some aspects of the vessel – such as construction and watertight integrity – the vessel must be ‘fit for purpose’.

The Restricted C requirements are tailored to vessels operating offshore but in lower risk operations, near land. Restricted C vessels are subject to initial survey and five yearly periodic surveys by an accredited marine surveyor, but the survey requirements are far less extensive than those for a vessel in survey.

Non-survey vessels

Smaller, lower risk vessels (such as those <12m, operating only in sheltered waters) are subject to NSCV Part G (Non-survey vessels). Under the NSCV Part G, vessels can comply with a range of Australian and international standards for small craft, such as ISO standards, ABYC standards and Australian Standard AS 1799.

Non-survey vessels are not required to be surveyed by an accredited marine surveyor, however AMSA may request evidence of compliance to the NSCV Part G (for example, through an Australian Builder's Plate).

### 6.2.4. Are autonomous and remotely operated DCV required to comply with the rules of a Classification Society?

The NSCV Part B (General requirements) includes the following requirement for 'novel vessels':

> ***3.2 Novel vessels***
>
> *(1) If the National Regulator considers that a vessel does not have the shape, form, function or propulsion of most vessels of a similar kind, the National Regulator may categorise the vessel as a novel vessel.*
>
> *Note 1 A vessel that is similar to another vessel of its kind may be considered to be a novel vessel.*
>
> *Note 2 See the AMSA website at http:www.amsa.gov.au for information about vessels the National Regulator considers to be novel.*
>
> *(2) A novel vessel must be constructed and maintained in accordance with the class rules of a recognised organisation.*

Autonomous and remotely operated vessels may be novel vessels simply because the current standard – the NSCV – does not contain standards for some aspects of the vessels and their systems. This means that AMSA could require autonomous and remotely operated vessels to meet the standards of, and be surveyed by, a Classification Society that is a Recognised Organisation.

Generally, however, a domestic commercial vessel that is surveyed by a Recognised Organisation is still subject to the NSCV standards for arrangement, accommodation and personal safety, watertight and weathertight integrity, fire safety, stability, equipment (except anchoring equipment) and associated systems. Only the construction, machinery, electrical and anchoring systems on the vessels must be built to Class Rules.

In addition, it is understood that AMSA is accepting survey reports of autonomous and remotely operated vessels completed by accredited marine surveyors, which means that AMSA is not currently requiring all autonomous and remotely operated vessels to be in Class.

### 6.2.5. Survey requirements for domestic commercial vessels

Domestic commercial vessels in survey (those vessels required to have a certificate of survey – see Figure 9 above), as well as Restricted C vessels, are subject to the survey requirements of the Marine Surveyors Accreditation Guidance Manual (SAGM). Part 2 of the SAGM contains the detailed process for design approval, initial surveys and periodic surveys for domestic commercial vessels.

Under Marine Orde 503 and the SAGM, surveys must be conducted by an accredited marine surveyor or a Recognised Organisation. For vessels 35m and longer, some aspects of the vessel (construction, machinery, electrical systems and anchoring equipment) must be surveyed by a Recognised Organisation in accordance with the organisation's Class Rules. This means that, even for an autonomous vessel 35m or longer that is required to be surveyed by a Recognised Organisation, many of the NSCV standards still apply.

The SAGM also contains requirements for novel vessels or novel aspects of a vessel, as follows:

> ***2.8 Reporting obligations and unsafe vessels***
>
> *(1) Section 33 of the National Law Regulation requires Accredited Marine Surveyors to report to the National Regulator where:*
>
> > *(a) corrective action is required to the vessel, or a thing on the vessel, due to a defect or non conformity in the vessel or thing; and*
> >
> > *(b) a matter, or an aspect of a matter, being surveyed is complex or novel, and is not covered by an applicable standard.*
>
> *(2) If, during the conduct of a survey, a surveyor becomes aware of a defect, non-conformity or novel matter relating to the vessel or a thing on the vessel, then the surveyor must report the matter to the National Regulator as soon as practicable.*
>
> *(3) Details of the deficiencies or novel matters are to be:*
>
> > *(a) notified in writing to the owner of the vessel;*
> > *(b) provided to the National Regulator; and*
> > *(c) retained by the surveyor.*

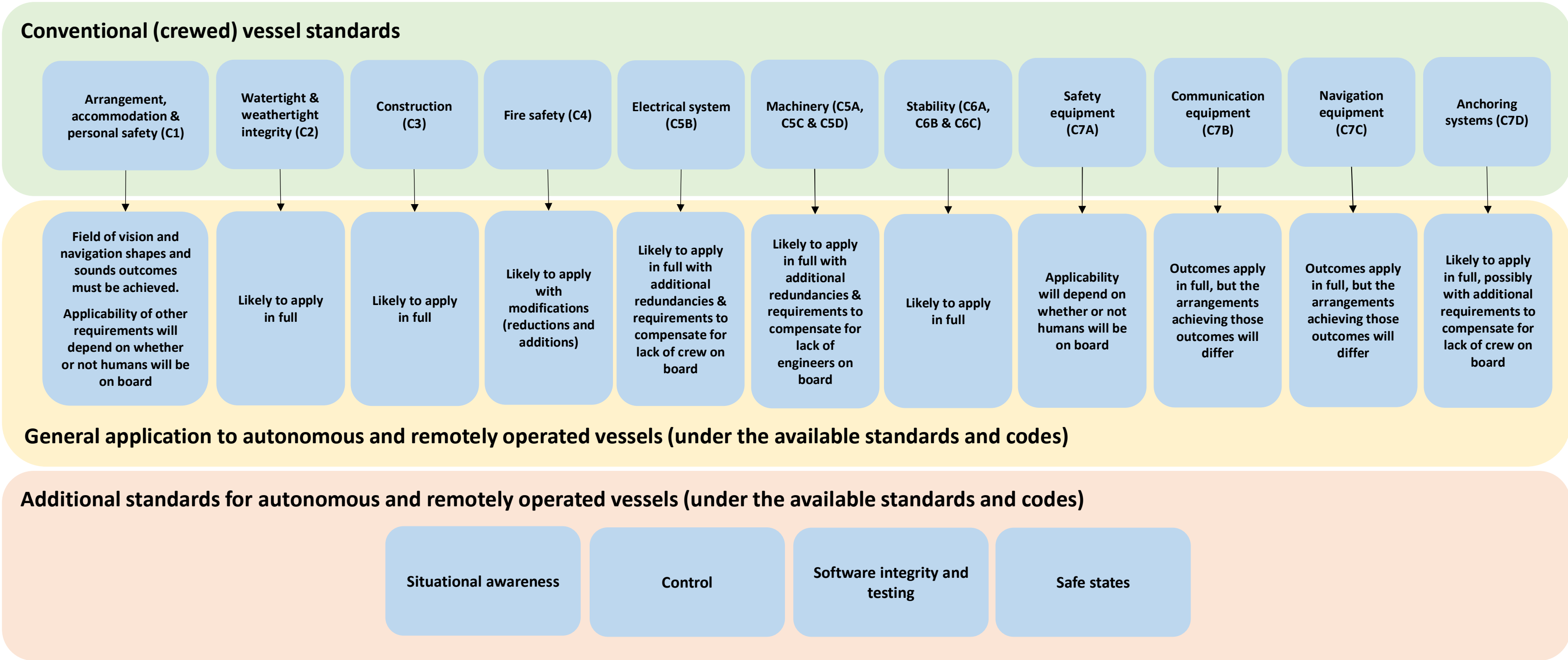
## 6.3 Comparing the standards for autonomous and remotely operated vessels to conventional vessel standards

### 6.3.1. Design and construction standards

Based on the content of the available codes and standards considered in this report, there is a significant overlap between standards for the design and construction of conventional vessels (such as the NSCV), and the requirements for autonomous and remotely operated vessels.

Figure 10 below illustrates how the conventional vessel standards generally apply to autonomous and remotely operated vessels in the available codes and standards, and the additional requirements or standards that apply.

**Figure 10: Application of conventional vessel design and construction standards to autonomous vessels in the available codes**




*This diagram sets out how the NSCV sections would apply if the approach used in the codes and standards reviewed in this report was applied in the Australian Code of Practice.

Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

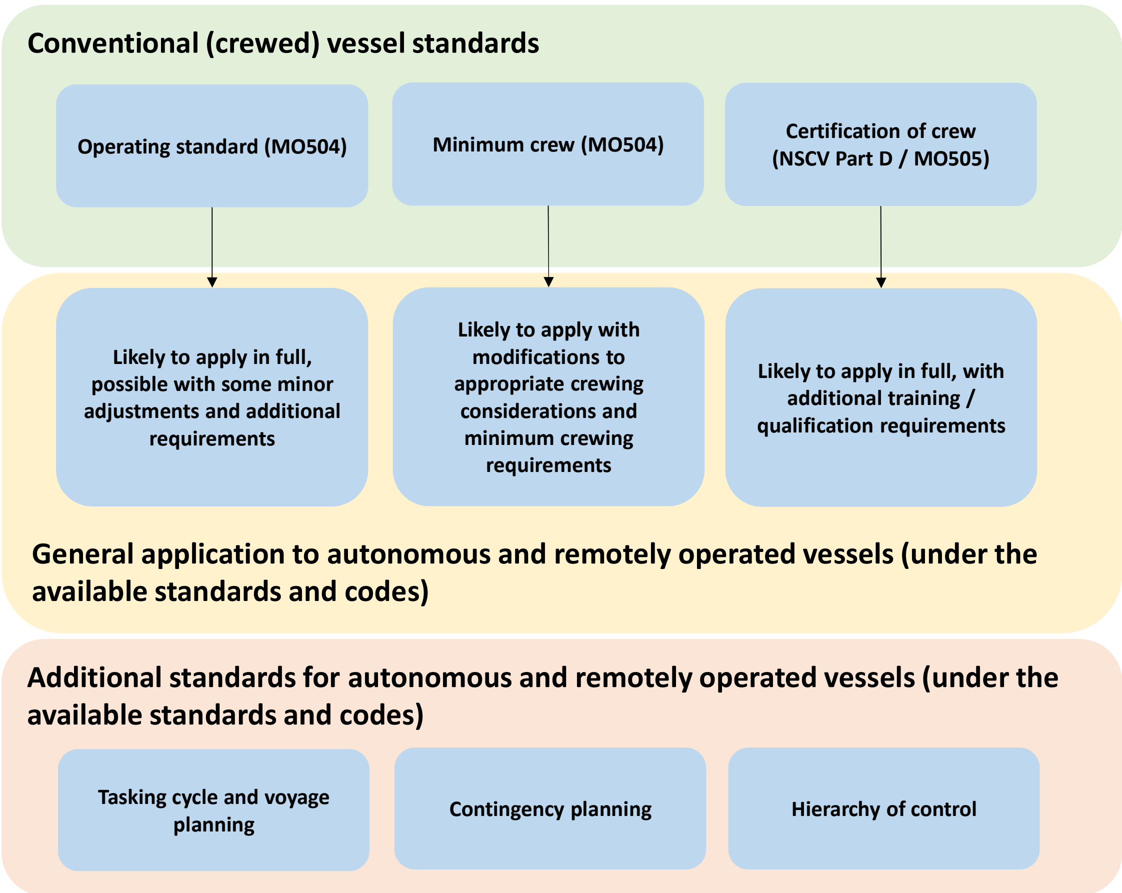
### 6.3.2. Operating standards

The operating standards, including minimum crewing requirements, for all vessels are contained in Marine Order 504.

Based largely on the UK Code for MASS, Figure 11 below illustrates how the conventional vessel standards for operations, minimum crew and crew competencies generally apply to autonomous and remotely operated vessels, and the additional requirements or standards that also apply.

The LR Code and DNV Guidelines touch on some of the operating requirements (such as tasking cycles, voyage planning, contingency planning and hierarchy of control), but do not address crew competency or safety management system requirements in detail.

**Figure 11: Application of conventional vessel operational and crewing standards to autonomous vessels**




*This diagram sets out how the operational requirements of the National Law Act would apply if the approach used in the codes and standards reviewed in this report was applied in the Australian Code of Practice.

Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21

## 6.4 How the available codes interact with the regulatory requirements for domestic commercial vessels

### 6.4.1. Considering the UK Code for MASS in the Australian context

The UK Code for MASS is tailored towards a vessel that complies with international conventions, Although the Code acknowledges that local UK requirements might apply to a vessel (such as the UK MCA Workboat Code), it focuses on ensuring equivalence with the provisions of IMO's current legal instruments (COLREGS, SOLAS, MARPOL, STCW, ISPS, IMDG, ISM, Fire Safety Code and the Load Line Convention).

It also assumes that the survey will be undertaken by either a Classification Society or the MCA, and does not consider competency requirements of the surveyors.

This context for the UK Code – compliance with international conventions – is different to the context for an Australian Code of Practice that will focus mainly on domestic commercial vessels. Although some international conventions do apply to these vessels, many do not. In addition, for some conventions, such as the Load Line Convention, the requirements have been modified for the Australian domestic fleet, as permitted under the convention.

However, if we were to assume that the vessel was required to, or could, comply with the NSCV requirements, in lieu of international conventions or Class Society requirements, the UK Code contains a potential framework for the additional standards or requirements that would apply to domestic commercial vessels that are MASS. In particular, the UK Code performance requirements for:

- situational awareness;
- control;
- base control station operation;
- system integrity certification and test procedures;
- operator standards of training, competence and watch keeping;
- safety management systems; and
- cyber security,

would provide a basis on which to develop performance requirements for MASS that are DCV (or RAV) for these aspects of the vessel and its operation. The guidance contained in the UK Code on these aspects also provides a basis for developing the detailed guidance to be included in an Australian Code of Practice on how the performance requirements are met.

### 6.4.2. Considering the LR Code for MASS in the Australian context

As outlined above, the UK Code for MASS starts from the baseline of the conventional vessel standards. In contrast, the LR Code starts from first principles, and includes tailored performance requirements for all aspects of the vessel.

Although these performance requirements are likely to be met through compliance with conventional vessel standards for many aspects of the vessel, a high degree of knowledge of the LR Class Rules is needed in order to apply the Code. This makes applying the LR Code to domestic commercial vessels difficult, unless it was administered by Lloyd's Register.

However, for some areas of the vessel, the performance requirements of the LR Code are quite detailed and would be highly informative for the development of the modifications and additions to the conventional vessel requirements for domestic commercial vessels covering:

- electrical systems and propulsion and manoeuvring (machinery);
- navigation systems;
- fire safety;
- control;
- auxiliary systems; and
- verification / survey.

The requirements of the LR Code covering these issues are underpinned by the identification of the 'level of integrity' required for each system on the vessel. As outlined in Table 5, the level of integrity is determined by the impact of the failure of the system on safety / the environment and on the operational capability of the vessel. The higher the impact, the greater the redundancies required and the higher the level of verification and testing required.

The Australian code should apply a similar risk / failure mode analysis approach to the requirements for the autonomous (or remote control) systems on the vessel.

In addition, one option to be considered is to provide in the Australian Code of Practice that compliance with the LR Code (including survey by Lloyd's Register) is deemed to satisfy the requirements of the Australian Code of Practice for the design and construction aspects of the vessel (ie all the aspects of the vessel covered in Figure 10 above).

#### 6.4.3. Considering the DNV Guidelines in the Australian context

The DNV Guidelines focus only on those aspects of an autonomous or remotely operated vessel that depart (or may depart) from a conventional (crewed) vessel. Aspects of the vessel that are highly likely to be same as for a conventional vessel are not covered by the DNV Guidelines (such as construction or stability).

The DNV Guidelines are highly detailed and process driven. They provide a process through which DNV can appraise, assess and ultimately certify new technology. In this way, they cater for increasingly autonomous vessels, by providing a framework for the assessment of one, some or all systems on the vessel as autonomous or remotely operated.

The DNV Guidelines also appear focussed on larger, more complex vessels and systems, and may have been developed primarily for the types of vessels that would have already been DNV Class if they were crewed.

The starting point of the DNV Guidelines is to break each vessel function down between those aspects of the function that are system-controlled, and those aspects that are human controlled. Each system is also broken down into the aspects that rely on new technologies, and the aspects that rely on existing (approved) technologies. The representation of autonomous and remotely controlled vessels as a spectrum of different types of control, and as a combination of different control methods, is far more flexible and adaptive than the arbitrary categorisation of MASS in the UK Code. The following figure provides an example of the combination of control methods that could be in place on an autonomous or remotely operated vessel, as described by the DNV Guidelines.

**Figure 12: Human and system control analysis – DNV Guidelines**

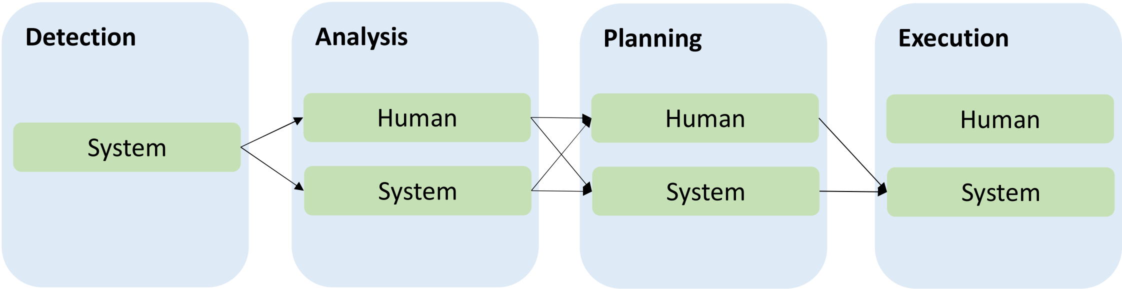



Diagram created by Vanderkooi Consulting for TAS Code of Practice project Aug 21, based on diagrams in the DNV Guidelines

The requirements for the control system, and for all novel technology used on the vessel, in the DNV Guidelines are based on a risk / failure analysis approach. Similar to the 'level of integrity' approach of the LR Code, the DNV Guidelines focus on categorising potential failures and emergencies. Where the failure is 'anticipated', there must be redundancies in place which allow the vessel to continue with its operations. Where the failure is 'potential', there must be redundancies in place which allow the vessel to move into a 'safe state'.

The Australian code should apply a similar risk / failure mode analysis approach to the requirements for the autonomous (or remote control) systems on the vessel.

The DNV Guidelines provide significant detail on the requirements for the control system, tailored towards the different types of control. This detail will be highly informative in developing the requirements of the Australian code.

In addition, the DNV Guidelines contain extensive documentation requirements as part of the vessel approval process. Development of a chapter or annex on documentation for the Australian Code of Practice could be valuable, to assist in the establishment of a common understanding among surveyors and industry of the expectations in this regard. However, the chapter or annex would require input and oversight from AMSA in order to be useful in practice.

Finally, the performance requirements contained in the DNV Guidelines for:

- navigation functions and situational awareness;
- engineering functions (machinery);
- communication functions; and
- contingency planning,

should be considered in the development of the modifications and additions to the conventional vessel requirements for domestic commercial vessels.

Finally, similar to the LR Code, an option for consideration is to provide that compliance with the DNV Guidelines (including verification of compliance / survey by DNV) is deemed to satisfy the requirements of the Australian Code of Practice for the design and construction aspects of the vessel (ie all the aspects of the vessel covered in Figure 10 above).

#### 6.4.4. Could any of the available codes be tailored for use in Australia?

None of the available codes and standards considered in this report provide a template that could be tailored for use in Australia with minor modifications.

However, by considering the requirements of each of the codes – which are very similar in many respects – the modifications and additions to the standards that already apply to commercial vessels operating in Australia can be developed.

In other words, each of the three available codes will significantly influence the content of the Australian code.

# 7. Findings: principles to guide the development of the Australian Code of Practice

The purpose of this first step in the development of an Australian Code of Practice is to analyse the available standards and codes for autonomous and remotely operated vessels and:

- understand the structure and requirements of each of the codes;
- identify the differences and similarities between the codes; and
- consider the codes in the Australian regulatory context.

This Chapter sets out the findings of this analysis in terms of how they should inform the development of an Australian Code of Practice for Autonomous and Remotely Operated Vessels.

## 7.1 The Code should align with the Australian regulatory context

An Australian Code of Practice should align with the Australian regulatory framework that already exists for conventional vessels.

This means that, as a starting point:

- vessels in survey should comply with the NSCV Part C; and
- vessels not in survey, including restricted C vessels, should comply with the NSCV Part G or restricted C vessel standards, as applicable.

As outlined in Chapter 6, in general the requirements of the NSCV are applicable to autonomous vessels with some differences:

- aspects of NSCV Subsection C1 (Accommodation, arrangement and personal safety) and NSCV Subsection C7A (Safety equipment) will not be applicable to vessels which never carry crew or passengers; and
- the requirements of NSCV Subsections C5 (Engineering), C7B (Communication equipment), C7C (Navigation equipment) and C7D (Anchoring systems) may require some modifications to account for the fact that no crew members are on board. However, for these standards, the performance requirements (the required outcomes) may remain appropriate, but the means of achieving those outcomes will be different for an autonomous or remotely operated vessel.

For some NSCV sections, such as NSCV Subsection C4 (Fire safety) and Subsection C6 (Stability), which are designed to both protect the vessel and persons onboard the vessel, more consideration may be required to determine the appropriate requirements for vessels that are not designed to carry any persons.

This principle also means that the three available codes and standards considered in this report do not provide a template that could be tailored for use in Australia with only minor modifications.

However, the modifications and additions to the standards that already apply to commercial vessels operating in Australia should be informed by the content of the three available codes and standards considered in this report.

Based on the content of the three available codes and standards, in addition to the NSCV requirements, additional standards or requirements will apply to autonomous vessels in the areas of:

- situational awareness;
- control;
- software integrity and testing; and
- safe states.

Similarly, the operational requirements of the National Law would apply to autonomous and remotely operated vessels, with some differences:

- the safety management system requirements need to be tailored to autonomous and remote vessel operations;
- the minimum crew and crew competency requirements will be modified; and
- there will be additional requirements for contingency planning and control hierarchies.

## 7.2 A risk-based analysis approach should apply to novel systems

In line with the available codes, a risk-based analysis approach, which focuses on the impact of potential failures, should apply to novel systems on the vessel, including the systems for control.

Both the UK Code for MASS and the DNV Guidelines reference the failure mode and effect analysis (FMEA). However, all the codes allow any appropriate risk-based analysis methodology to be used. The DNV Guidelines, for example, also refer to fault tree analysis (FTA), event tree analysis (ETA), as well as crisis intervention and operations analysis (CRIOP) and operating and support hazard analysis (O&SHA) for systems involving remote operations from a control centre.

Details on a FMEA are contained in the High Speed Craft (HSC) Code, Annex 4. According to the HSC Code, the FMEA approach was developed to allow novel aspects of vessel design or construction to be analysed and certified where the requirements could not be specified in detail because the same level of experience and knowledge as applies to conventional approaches is not available.

The FMEA approach involves an in-depth assessment of the failure characteristics of the vessel and its systems. Each system is assumed to fail by one probable cause at a time. The effects of the assumed failure are analysed and classified according to their severity. Such effects may include secondary failures (or multiple failures) at other level(s). Any failure mode which may cause a catastrophic effect to the craft shall be guarded against by system or equipment redundancy, unless the probability of such failure is extremely improbable.

The first step in the FMEA involves functional failure analysis of the vessel's important systems within the normal design environmental conditions when the vessel is:

- in normal seagoing conditions at full speed;
- at maximum permitted operating speed in congested waters; and
- manoeuvring alongside.

Each system to be analysed is assumed to fail in the following failure modes:

- complete loss of function;

- rapid change to maximum or minimum output;
- uncontrolled or varying output;
- premature operation;
- failure to operate at a prescribed time; and
- failure to cease operation at a prescribed time.

Results of the system functional failure analysis shall be documented and confirmed by a practical test programme drawn up from the analysis.

If a system can fail without any hazardous or catastrophic effect, there is no need to conduct a detailed FMEA into the system architecture.

For systems whose individual failure can cause hazardous or catastrophic effects and where a redundant system is not provided, a detailed FMEA is then undertaken, unless the system is provided with a redundant system which:

- can be put into operation or can take over the failed system within the time-limit dictated by the most onerous operational mode without hazarding the craft; and
- is completely independent from the system and does not share any common system element the failure of which would cause failure of both the system and the redundant system.

For systems requiring a detailed FMEA, the following steps apply:

- define the system to be analysed;
- illustrate the interrelationships of functional elements of the system by means of block diagrams;
- identify all potential failure modes and their causes;
- evaluate the effects on the system of each failure mode;
- identify failure detection methods;
- identify corrective measures for failure modes;
- assess the probability of failures causing hazardous or catastrophic effects, where applicable;
- document the analysis;
- develop a test programme. This should test all systems or system elements whose failure would lead to major or severe effects or other corrective action.;
- prepare FMEA report.

The Australia code could require risk-based analysis, using an accepted methodology such as an FMEA, to be undertaken for all systems on an autonomous or remotely operated vessel, where the deemed to satisfy solutions of the NSCV are not met, or are not appropriate or adequate for autonomous vessels.

## 7.3 The risks posed by remotely controlled and autonomous vessels should be minimised so far as reasonably practicable

The baseline requirement of each of the available codes and standards analysed in this report is that an autonomous or remotely operated vessel should be ‘as safe’ a conventional vessel. Whether this is appropriate for the Australian code will be considered as part of the consultation process.

For example, there may be a subset of autonomous or remotely operated vessels where this equivalency is not necessary because the risks they pose are so minimal. This could include small, slow and light craft, which are unlikely to damage property or the environment, or to place persons at risk.

In addition, it may be difficult to assess the risks of an autonomous or remotely operated vessel, as compared to a conventional crewed vessel, as the risks posed are different. It may be that the code requires the risks of autonomous and remotely operated vessels to be managed, so the vessels are, so far as reasonably practicable, safe.

This issue needs to be explored further as part of the consultation process for the development of the Australian Code of Practice.

# 8. Conclusion

In order to inform the development of an Australian Code of Practice, this report analyses the *UK Code of Practice for Maritime Autonomous Surface Ships*, the *LR Code for Unmanned Marine Systems*, DNV GL's *Autonomous and Remotely-operated Ships Class Guideline* by:

- understanding the structure and requirements of each of the codes;
- identifying the differences and similarities between the codes; and
- considering the codes in the Australian regulatory context.

This report finds that:

- an Australian Code of Practice for autonomous and remotely operated vessels should align with the regulatory framework that already exists for conventional domestic vessels;
- the three available codes focus largely on vessels which comply with international conventions or Class Rules; and
- this is different to the context for an Australian Code of Practice, which will be tailored towards commercial vessels operating only in Australian waters.

For this reason, none of the available codes and standards considered in this report provide a template that could be tailored for use in Australia with only minor modifications.

However, each of the three available codes will significantly influence the content of the Australian code. This report uses the analysis of the three available codes and standards to identify the standards or requirements that should apply to autonomous vessels, beyond the requirements of conventional vessel standards. This will include tailored requirements for:

- situational awareness;
- control systems;
- software integrity and testing; and
- safe states.

This report also finds that the operational requirements that apply to conventional vessels in Australia should apply to autonomous and remotely operated vessels, with some differences:

- the safety management system requirements need to be tailored to autonomous and remote vessel operations;
- the minimum crew and crew competency requirements will need to be modified; and
- there will be additional requirements for contingency planning and control hierarchies, which should be informed by the content of the three available codes and standards.

In line with the available codes and standards, a risk analysis approach, which focuses on the impact of potential failures, should apply to the development and testing of novel systems on the vessel, including the systems for situational awareness and control and all systems which do not meet the requirements of the conventional vessel standards.

Finally, this report notes that the baseline requirement of each of the available codes and standards is for an autonomous or remotely operated vessel to be 'as safe as' a conventional vessel. Given that the scope of the Australian code will include very small, low risk autonomous marine equipment, whether or not this baseline approach is appropriate for all vessels subject to the Australian code will need to be considered as part of the consultation process on the development of the Australian code.