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Using the Watchkeeping regulation to verify safe operation of Uncrewed Surface Vessels

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Abstract

This whitepaper describes how a review of the watchkeeping regulations can provide a set of crew functions which a remote operator of an uncrewed vessel must perform in order to sail the vessel safely. Such a set is an important (and necessary) input in verification and certification of the safety of the operation. In fact, we propose that this set can be used as basis for developing acceptance criteria for a vessel under remote control. The review has focus on lookout and navigation with sub activities. We consider these crew functions to be the most challenging to perform remotely or autonomously. We propose and discuss how lookout and navigation can be performed from a remote control centre, and we show how our proposals can be supported further by an assurance case in a safety verification process.

Abbreviations

AL	Autonomy Level
CONOPS	Concept of Operation
FOV	Field of vision
NMA	Norwegian Maritime Authority
ROC	Remote Operations Centre
SMS	Safety Management System
STCW	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
UMS	Unmanned machinery spaces
USV	Uncrewed Surface Vessel
VTS	Vessel Traffic Service

Introduction and Background

According to the Norwegian Maritime Authority (NMA) circular RSV-12-2020 [1] a gap analysis towards existing rules and regulations is required for a vessel with AL 3 [2] or higher. Particularly, RSV-12-2020 requires a gap analysis towards the watchkeeping [3] and manning [4] regulations. In case one or more gaps are identified, RSV-12-2020 requires that alternative solutions are implemented to close the gap(s). The alternative solution(s) shall provide a safety level equal to or better than the level provided if the gap did not exist.

In our work with such gap analyses in several projects the authors have seen that projects involving vessels with AL 3 or higher may have few gaps towards the manning and watchkeeping regulations. We have also seen that particularly the watchkeeping regulation provides a good identification of the function(s) inherent in the regulation's requirements. Hence, if there is a gap, the regulation's description of what the crew is required to do onboard, assists us in identifying the requirements to the alternative solution. This is important (and necessary) information when verifying whether or not an alternative solution provides a safety level equal to or better than the level provided if the gap did not exist.

In the work referred above we have also seen that gaps are relatively independent of the size of the vessel. Hence, our work with USVs and comparatively small vessels are also relevant for larger vessels. Further, we find that the vessel operating company's SMS plays an important part in addressing and closing the gaps. This whitepaper describes these findings and how they can be used in applications to the NMA for approval of operations involving a remotely operated vessel in accordance with its relevant CONOPS.

Note that "remotely operated vessel" does not necessarily mean the vessel is "manually" and directly operated remotely, but rather some high-level or safety-critical tasks are given to the operator to decide actions for. In fact, manually operating a vessel remotely is in general not a trivial task. Remote operation of a boat or ship requires advanced control and situational awareness systems that make it possible to operate the vessel through high-level commands and supervision. The higher the level of commands and supervision needed/implemented, the higher the level of autonomy required by the vessel's control system. At the highest autonomy level that requires supervision, i.e., AL 4, the remote operator or officer in charge of (remote) navigational watch will have the important duty and responsibility of dealing with any difficulties of the navigation systems in achieving full appraisal of any particular situation.

The analysis presented in this whitepaper has taken regulations as a starting point. This in contrast to starting with technology or ship functions and analysing from there what the design requirements should be [5]. We have found this approach helpful, and it provided a useful starting point for the analysis. The regulations describe in plain text what the crew is required to do and should thus serve as a baseline or benchmark for technical solutions or procedures developed to perform or replace (part of) the crew's tasks. The same cannot with necessity be said about a description of technology or ship functions.

Crew functions described in the watchkeeping regulation

The watchkeeping regulation provides regulations and standards which apply to Norwegian passenger ships and cargo ships of 50 tons and upwards.

For an uncrewed vessel a recurring gap towards the watchkeeping regulation is that the navigational watch shall never leave the bridge. An example of a paragraph which will raise this gap is:

> *"23. The officer in charge of the navigational watch shall:*
> - *23.1. keep the watch on the bridge;*
> - *23.2. in no circumstances leave the bridge until properly relieved;"*

To mitigate this gap our approach has been to identify which functions the crew doing the navigational watch is required to provide. The watchkeeping regulation says:

"Navigational watch functions comprise navigation, manoeuvring, communication, steering and lookout. These functions shall be performed as prescribed by paragraphs 2.1, 2.2 and 2.3 of this section."

Of these functions we regard lookout and navigation to be the more challenging ones when performed remotely or autonomously. This whitepaper therefore focuses on those two functions. In the next section we therefore continue discussing:

- What the crew doing lookout and navigation is required to do.
- How these tasks or functions can be performed remotely.

In the subsequent section we present an assurance case to support the claim that the crew functions can be performed from a remote operations centre.

Note that this whitepaper has a focus on the navigational watch. The watchkeeping regulation also has requirements for machinery watch and the radio watch. Those requirements are not discussed in this whitepaper. However, addressing those requirements and potential gaps towards them can be done in the same way as with the navigational watch. Note also that this whitepaper does not discuss the following:

- passenger safety and requirements related to that,
- availability, capacity, safety and security of the communication link between an autoremote vessel and the remote operations centre. This communication link is a necessity for remotely operating a vessel, and for our discussions we assume that the communication link is available and adequate.

Lookout

For the lookout we have tried to identify descriptive requirements provided by the watchkeeping regulation. This is because they provide concrete or tangible design requirements to the solution we put in place in order to close a gap. If some of the requirements appear to be not so concrete, we have looked elsewhere in the watchkeeping regulation for supporting information. And we have been able to find that. Below is a list of the requirements for lookout from [3], with an analysis of how each one of them can be met by remote operation or supervision (AL 4).

13. A proper look-out shall be maintained at all times in compliance with rule 5 of the International Regulations for Preventing Collisions at Sea, 1972 and shall serve the purpose of:

Analysis and solution: "look-out shall be maintained at all times". This is doable remotely as long as the communication link between the vessel and the ROC is up and running. For some operations, such as for example short river crossings, this function may also be possible from shore.

13.1. maintaining a continuous state of vigilance by sight and hearing as well as by all other available means, with regard to any significant change in the operating environment;

Analysis and solution:

a) Using sight and hearing can be done remotely using cameras and microphones on the vessel. In fact, cameras may also have a field of vision (FOV) which is larger than the FOV of a human lookout on the bridge. Likewise, a microphone may detect sound frequencies which the

human ear is unable to hear. Hence, cameras and microphones may potentially perform better than a crew onboard.

b) "all other available means" is not a very concrete phrase, but we can divide this in two:
    i. Information from available equipment like radar and AIS can be relayed from the vessel to a remote operator. In the case of AIS, this data can also be provided by third parties and does not need to be retrieved from the vessel.
    ii. The human senses a navigational watch officer has available are: sight and hearing (already mentioned above), feeling (motion, wind, pressure, temperature etc.), smell and taste. We assume that taste is not relevant, and taste is therefore not included in the further discussion. The remaining senses are discussed below:
        1. Motion sensors should cover feelings of pressure, heeling, yaw, accelerations etc. which an officer of the navigational watch may feel.
        2. Temperature sensors should cover the feeling of temperature change.
        3. Water and/or moisture sensors should cover the feeling of water in the air or on the skin of the navigational watch officer.
        4. Smoke detectors and possibly other relevant detectors should identify fire or gas leaks.

c) "any significant change in the operating environment" is again a not so concrete description. Let us therefore wait and see if we can find more concrete details on this in the requirements listed below.

13.2. fully appraising the situation and the risk of collision, stranding and other dangers to navigation; and

Analysis and solution: "fully appraising the situation" is, in the case of a remotely operated vessel, done by the remote operator using the information made available through the communication link between the vessel and the ROC. Applications available to the remote operator will also assist in appraising the situation, for example based on detections by the vessel. Potential collisions and risk of collision information will be readily available and can be associated with specific warnings and notifications.

13.3. detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.

Analysis and solution: this is done by the remote operator using sight (cameras), possibly hearing (microphones), and available equipment like a radar, object detectors, sound detectors, and search-light.

14. The look-out must be able to give full attention to the keeping of a proper look-out and no other duties shall be undertaken or assigned which could interfere with that task.

Analysis and solution: this is a task description. And this task is done by the remote operator in accordance with the operational procedures stated in the operating company's SMS. See also paragraph 15 below.

15. The duties of the look-out and helmsperson are separate and the helmsperson shall not be considered to be the look-out while steering, except in small ships where an unobstructed all-round view is provided at the steering position and there is no impairment of night vision or other impediment to the keeping of a proper look-out. The officer in charge of the navigational watch may be the sole look-out in daylight provided that on each such occasion:

Analysis and solution: this is a task description, and the task also involves a risk assessment. This task is done in accordance with the operational procedures stated in the operating company's SMS. See also further discussion below.

15.1. the situation has been carefully assessed and it has been established without doubt that it is safe to do so;

Analysis and solution: this is a task description, and the task also involves a risk assessment. This task is done by the remote operator in accordance with the operational procedures stated in the operating company's SMS.

15.2. full account has been taken of all relevant factors, including, but not limited to:

– state of weather,

– visibility,

– traffic density,

– proximity of dangers to navigation, and

– the attention necessary when navigating in or near traffic separation schemes; and

Analysis and solution: here we find very good clues to which changes in the operational environment the lookout may be expecting (see point 13.1 c) above): weather, visibility, traffic density, proximity of dangers to navigation and traffic separation schemes. This requirement is a task description, and the task also involves a risk assessment. The remote operator should be able to identify changes in all these factors with the means available to him or her. It should be noted however, that it is still a question how well obstacles such as swimmers and kayaks which are not easy to pick up by any sensor will be detected.

15.3. assistance is immediately available to be summoned to the bridge when any change in the situation so requires.

Analysis and solution: this is a requirement to the manning of the ROC. This should be written into the SMS.

16. In determining that the composition of the navigational watch is adequate to ensure that a proper look-out can continuously be maintained, the master shall take into account all relevant factors, including those described in this section of the Code, as well as the following factors:

Analysis and solution: this is a task description, and the task also involves a risk assessment. This task is done by the remote operator in accordance with the SMS. Also, in the sub points below, we find again very good clues to which changes in the operational environment the lookout may be expecting (see point 13.1 c) above).

16.1. visibility, state of weather and sea;

16.2. traffic density, and other activities occurring in the area in which the vessel is navigating;

16.3. the attention necessary when navigating in or near traffic separation schemes or other routeing measures;

16.4. the additional workload caused by the nature of the ship's functions, immediate operating requirements and anticipated manoeuvres;

Analysis and solution: concerning paragraphs 16.1 to 16.4, this is evaluated by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC. Some of this information may also be available from third-party sources, thus reducing the dependency on communication of data from the vessel.

16.5. the fitness for duty of any crew members on call who are assigned as members of the watch;

16.6. knowledge of and confidence in the professional competence of the ship's officers and crew;

16.7. the experience of each officer of the navigational watch, and the familiarity of that officer with the ship's equipment, procedures, and manoeuvring capability;

Analysis and solution: concerning paragraphs 16.5 to 16.7, these are task descriptions, and the tasks also involve a risk assessment. These tasks are done by the remote operator in accordance with the operational procedures stated in the operating company's SMS. It should also be noted that sensors and cameras do not loose concentration or get distracted from use of a mobile phone or such activities like a human could. Good object recognition software could therefore potentially perform better than a human.

16.8. activities taking place on board the ship at any particular time, including radio communication activities, and the availability of assistance to be summoned immediately to the bridge when necessary;

Analysis and solution: this is evaluated by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC. This is also a task description, and the task also involves a risk assessment. This task is done by the remote operator in accordance with the operational procedures stated in the operating company's SMS.

16.9. the operational status of bridge instrumentation and controls, including alarm systems;

16.10. rudder and propeller control and ship manoeuvring characteristics;

16.11. the size of the ship and the field of vision available from the conning position;

16.12. the configuration of the bridge, to the extent such configuration might inhibit a member of the watch from detecting by sight or hearing any external development; and

Analysis and solution: concerning paragraphs 16.9 to 16.12, this is evaluated by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC.

16.13. any other relevant standard, procedure or guidance relating to watchkeeping arrangements and fitness for duty which has been adopted by the Organization.

Analysis and solution: this is a task description, and the task also involves a risk assessment. This task is done by the remote operator in accordance with the operational procedures stated in the operating company's SMS.

Navigation

An extract of paragraphs from the watchkeeping regulation which are relevant for navigation is listed below. This list is not exhaustive but serves to illustrate the point of this whitepaper. The paragraphs are discussed in the same way as for the lookout.

5. Prior to each voyage the master of every ship shall ensure that the intended route from the port of departure to the first port of call is planned using adequate and appropriate charts and other nautical publications necessary for the intended voyage, containing accurate, complete and up-to-date information regarding those navigational limitations and hazards which are of a permanent or predictable nature and which are relevant to the safe navigation of the ship.

Analysis and solution: this is a task description. This task is done by the remote operator in accordance with the operational procedures stated in the operating company's SMS.

20. Prior to taking over the watch, relieving officers shall satisfy themselves as to the ship's estimated or true position and confirm its intended track, course and speed, and UMS controls as appropriate and shall note any dangers to navigation expected to be encountered during their watch.

21. Relieving officers shall personally satisfy themselves regarding the: [...] 21.5.3. the presence and movement of ships in sight or known to be in the vicinity,

24. During the watch the course steered, position and speed shall be checked at sufficiently frequent intervals, using any available navigational aids necessary, to ensure that the ship follows the planned course.

Analysis and solution concerning paragraphs 20, 21.5.3 and 24: these are task descriptions, and the tasks also involve a risk assessment. These tasks are done by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC.

27. Officers of the navigational watch shall make the most effective use of all navigational equipment at their disposal.

Analysis and solution: this is a task description. This task is done by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC and in accordance with the operational procedures stated in the operating company's SMS.

28. When using radar, the officer in charge of the navigational watch shall bear in mind the necessity to comply at all times with the provisions on the use of radar contained in the International Regulations for Preventing Collisions at Sea, in force.

33. Operational tests of shipboard navigational equipment shall be carried out at sea as frequently as practicable and as circumstances permit, in particular before hazardous conditions affecting navigation are expected. Whenever appropriate, these tests shall be recorded. Such tests shall also be carried out prior to port arrival and departure.

Analysis and solution: concerning paragraphs 28 and 33, these are task descriptions, and the tasks also involve a risk assessment. These tasks are done by the remote operator in accordance with the operational procedures stated in the operating company's SMS.

40. The officer in charge of the navigational watch shall notify the master immediately:

40.1. if restricted visibility is encountered or expected;

40.2. if the traffic conditions or the movements of other ships are causing concern;

40.3. if difficulty is experienced in maintaining course;

40.4. on failure to sight land, a navigation mark or to obtain soundings by the expected time;-

40.5. if, unexpectedly, land or a navigation mark is sighted or a change in soundings occurs;

40.6. on breakdown of the engines, propulsion machinery remote control, steering gear or any essential navigational equipment, alarm or indicator;

40.7. if the radio equipment malfunctions;

40.8. in heavy weather, if in any doubt about the possibility of weather damage;

40.9. if the ship meets any hazard to navigation, such as ice or a derelict; and

40.10. in any other emergency or if in any doubt.

Analysis and solution: concerning paragraphs 40 to 40.10, these are task descriptions, and the tasks also involve a risk assessment. These tasks are done by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC and in accordance with the operational procedures stated in the operating company's SMS.

48. The officer in charge of the navigational watch shall positively identify all relevant navigation marks.

Analysis and solution: this is a task description. This task is done by the remote operator by the use of the information provided to him or her via the communication link between the vessel and the ROC.

Towards an assurance case

In this section we illustrate how an assurance case can be used to support the claims made in this whitepaper. The use of an assurance case has been proposed for safety verification of autonomous urban ferries in [6]. An ISO description for an assurance case is:

> *"An assurance case includes a top-level claim for a property of a system or product (or set of claims), systematic argumentation regarding this claim, and the evidence and explicit assumptions that underlie this argumentation." [7]*

In the previous section we have claimed that the lookout and navigation crew functions can be performed by a remote operator. More specifically, we claim three things:

1. That required and sufficient data and information can be captured from the vessel, its surroundings and elsewhere, and presented to the operator at the ROC.
2. The operator is able to analyse and fully appraise the navigational situation, and the situation the vessel is in, from the data and information provided.
3. The operator can navigate the vessel safely from the ROC provided that he or she follows the requirements of the operating company's SMS and that a sufficient SMS can be made for the CONOPS of the vessel.

How can these claims be proved? RSV 12-2020 states:

> *"When the final design and solutions have been clarified, an overall risk analysis with associated HAZID must be submitted. […] In general, risk assessments must include the following:*
>
> 1) *fulfilment of defined acceptance criteria for the project; […]"*

Defined accept criteria thus form an important part of the approval basis. Since no prescriptive regulations exist, defined acceptance criteria needs to be developed. When performing required lookout and navigation crew functions from an ROC, we propose that the relevant crew functions described in the watchkeeping regulations are used as basis for developing acceptance criteria. More specifically, acceptance criteria can be constructed in the following manner:

1. A description of the task. We propose to collect this description from the requirements to the lookout and navigation crew functions as described in the Watchkeeping regulation.
2. A description of how well the task shall be done. The requirement in RSV 12-2020 is that this shall be as good as, or better than, if it was performed onboard. What this means is difficult to say. But we should assume that the captain is doing his or her job correctly onboard. If, for instance, in a training period, the captain switches between operating the vessel from onboard and operating the vessel from the ROC, the captain should be able to benchmark his or her performance. This approach, when done systematically, may then serve as a measure of how well the task shall be done.

With the above as basis, we below present a possible approach for developing arguments which can support the claims. Building a full assurance case including proofs will, however, require further work which will not be covered by this whitepaper.

1. Required and sufficient data and information can be captured from the vessel, its surroundings and elsewhere, and presented to the operator at the ROC: We propose to support this claim by listing examples of equipment which is in use today and which should be able to capture the required information. Such a list is presented in table 2 in Appendix 1.

2. The operator is able to analyse and fully appraise the navigational situation, and the situation the vessel is in, from the data and information provided: Here we base our claim on proven experience from the following similar or related operations:
    a. More than 100 Maritime Robotics USVs have been sold worldwide. All of whom are remotely operated or autoremote.
    b. Ship simulators are widely used today to train ship navigators.
    c. Air drone operations have been in use for several years, particularly in the military.
    d. Air control towers monitor and partly manage highly complex air operations.
    e. VTS'es monitor high density vessel traffic areas today.

    Uncrewed and/or autonomous vessels do also have a greater range of sensors installed than traditional vessels are required to have. These sensors and associated software provide better situational awareness, especially in more challenging conditions.

3. The operator can navigate the vessel safely from the ROC provided that he or she follows the requirements of the operating company's SMS and that a sufficient SMS can be made for the CONOPS of the vessel:
    a. For the lookout function the requirements mainly concern determining that the composition of the navigational watch is adequate to ensure that a proper lookout can continuously be maintained. Onboard a vessel this is an ordinary part of the master's responsibility. Given the assessments in point 1 and 2 above, the operator should be able to determine this also when operating the vessel from the ROC.
    b. For the navigation function the requirements are task descriptions where some also involve risk assessments. Given the assessments in point 1 and 2 above, the operator should be able to perform these tasks from the ROC.

RSV 12-2020 requirements to an ROC

RSV 12-2020 also has a set of requirements to an ROC. To further support the assurance case, these requirements are presented in table 1 below, together with descriptions of how they can be met for the lookout and navigation function.

RSV 12-2020 requirements to an ROC	**Description and solution**
Description of the functions to be covered by the control centre.	In the case of this whitepaper: lookout and navigation
Description of the division of responsibilities between the ship and the control centre.	In the case of this whitepaper: ROC controls the lookout and navigation functions
The equipment and setup of the control centre must be accepted by the NMA.	Guidance and description for equipment and setup can be found in IMO MSC252(83)[8] and other relevant standards
The competence of the control centre operators is subject to approval by the NMA and other relevant supervisory authorities.	This should be developed with STCW as basis. DNV RP0323 "Certification scheme for remote control centre operators" is also relevant here.
The NMA may request additional documentation in the individual project.	[-]

Table 1 The requirements RSV 12-2020 has to an ROC

Conclusion

When developing uncrewed vessels, important discussions have centred on how it may be possible to verify whether or not a safe operation can be conducted if the navigational watch is removed from the bridge and operate the vessel from a remote location. Our analysis shows that the watchkeeping regulation provides a good framework for assessing this question. The analysis also shows that, with the right technical equipment and the right SMS, a vessel can be operated safely from a remote location (AL 4) and that the gaps towards the watchkeeping regulations are few.

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References

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[5] See for instance DNVGL-CG-0264, Autonomous and remotely operated ships, Edition September 2018, Section 2, Chapter 6, https://rules.dnv.com/docs/pdf/DNV/cg/2018-09/dnvgl-cg-0264.pdf

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Appendix

Appendix 1. Description of equipment which can support the lookout function

Table 1 below shows an example of equipment which this review has identified as able to assist the remote operator when performing the lookout function. A similar table can be made for the navigation function.

Crew function	**Assisted by**	**Type**	**Functionality**	**Availability and comments**
Lookout	Equipment	Cameras	360 degrees visible light sensor	Several systems available. Quality may vary. Can be intelligent (IP69 or better is needed)
			Blind sone camera	A large number of cameras are available. Depending on where it is needed it will face quite rough environment (IP69 or better is needed)
			IR cameras for low visibility situation	Limited number of systems available. Relatively expensive (IP69 or better is needed)
		Microphones and sound detectors (External detection)	Hearable sound	Traditional microphone technology will work (IP69 or better is needed)
			Low and high frequency sound	More advanced microphones are available (IP69 or better is needed)
			Changes in frequency or volume	Will require intelligent microphones or signal processing
		External object detection systems	Radar	Will be onboard

			AIS	Will be on board
			Other object detection sensors (for instance lidar and picture recognition)	Different technologies may be used
			Search-light with camera (Visible + IR)	A complete system can be operated from ROC
		Motion sensors	Roll, yaw, and pitch	This information can normally be acquired by a 3D accelerometer
			Wind sensor (direction and strength)	Local meteorological information which is important in determining direction, speed and visibility
		Meteorological information	Temperature sensor	Local meteorological information which is important Weather charts from land based meteorological services
			Air pressure	
			Precipitation	
			Meteorological data (prediction)	

Table 2 Example template for a summary of means and procedures assisting the remote operator in performing the lookout and navigation function.