Identification of information requirements in ROC operations room

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Title:
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Summary:
This report is a part of the second work package in the research project called Land-based Operation of Autonomous Ships (LOAS). The project is financed by the Research Council of Norway and the partners are Kongsberg Maritime AS, IFE and NTNU. The purpose of the LOAS project is to develop and test interaction solutions for a Remote Operation Center (ROC) that ensures safe and effective monitoring of one or more ships.

This report contributes to identifying the information needed for effective and safe monitoring and response from operators in an onshore ROC (Remote Operation Centre). The main purpose of this report is to provide a solid background for designing and evaluating feasible interaction solutions for operators in a ROC.

One challenge in remote operation of autonomous ships or multi-ship operation is to keep the operator "in-the-loop" and avoid "information overload". Based on our focus, we asked four questions: 1. Which operational model is suitable for remote multi-ship operation? 2. What information requires response from operators? 3. What information is needed for operating the Continuously Unmanned Ships (CUS)? and 4. What information is needed for top-down strategic planning? The approach for addressing these research questions has been by exploring operational models, theoretical concepts and relevant literature.

A detailed description of information requirements has been made in the light of Situational Awareness (SA). The overall finding is that the information provided should be tailored to three situations: 1) Remote multi-ship operation, 2) Remote operation and 3) Remote control. Remote multi-ship operation will require a global situational awareness through a constantly displayed overview of the status of all the CUS´s. Remote operation requires overall CUS performance information to comprehend the overall situation related to one CUS. More detailed information should be easily available. Remote control will require a high level of SA, including all relevant information and interaction devices needed to control the ship in the current and future environment explaining which support systems that are "healthy" and active.

The next step in the LOAS project will be to design and iteratively evaluate interaction solutions for a ROC that ensures safe and effective monitoring of one or more ships.

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Keywords

Maritime, Autonomous ships, MASS, Continuously Unmanned Ship (CUS), Shore Control Centre (SCC), Remote Operations Centre (ROC), human-centred design, situational awareness, remote multi-ship operation.

Terms

Automation	The processes, often computerized, that implement a specific and predefined method to execute certain operations without a human controlling it
Autonomy	The system has control functions that can use different options to solve selected classes of problems (NFAS, 2017)
Autonomous ship	Ship with some form of autonomy (NFAS, 2017). The ship uses automation to operate without human intervention, related to one or more ship processes, for the full duration or in limited periods of the ship's operations or voyage (IMO, 2020)
Berth	The space assigned to or taken up by a vessel when anchored or when lying alongside a wharf, jetty, or other structure.
Port	Any port, terminal, offshore terminal, ship and repair yard or roadstead which is normally used for the loading, unloading, repair and anchoring of ships, or any other place at which a ship can call.

Abbrevations

AIS	Automatic Identification System
ARPA	Advanced anti-collision radars
CA	Constrained Autonomous
CAM-HMI	Central Alert Management – Human Machine Interface.
COG	Course over ground

COLREG	Convention on the International Regulations for preventing Collisions at Sea
CUS	Continuous unmanned ship
CPA	Closest point of approach
CWP	Coordinator working position
ECDIS	Electronic chart display and information system
EOSP	End of sea passage (where the ship decelerates from transit speed)
ETA	Estimated time of arrival
ETB	Estimated time of berthing
ETD	Estimated time of departure
EPIRBS	Emergency Position-Indicating Radio Beacon
FOV	Field of vision
GNSS	Global Navigation Satellite System
INS	Integrated navigation system
ISPS	International Ship and Port Facilities Security Code
LOA	Levels Of Autonomy
LOAS	Landbasert overvåkning av Autonome Skip (Onshore Surveillance of Autonomous Ships)
MASS	Maritime autonomous surface ships
MRC	Minimum risk condition
MRCC	Maritime Rescue Coordination Centre
OR	Operations room
PTZ	Pan Tilt Zoom (camera with pan, tilt and zoom functionality)
ROC	Remote Operations Centre
rpm	Revolutions per minute
SA	Situational Awareness
SCC	Shore Control Centre
SOG	Speed over ground
STW	Speed through water
TCPA	Time to closest point of approach
UID	User Input Device (Example: keyboard, tiller, joystick, helm, pushbutton, etc.)
VTS	Vessel Traffic Service

1 Introduction

The purpose of this chapter is to first provide an introduction to the LOAS (Landbasert overvåkning av Autonome Skip) project. Then, the scope of the report is outlined, followed by the approach, challenges and opportunities regarding operation of autonomous ships. Lastly, research questions and the report´s contributions are presented.

1.1 Introduction to the LOAS project

This report is a part of the LOAS research project. The LOAS project is an IPN project (Innovasjonsprosjekt i næringslivet), financed by the Research Council of Norway. The project is a joint cooperation between Kongsberg Maritime AS, IFE[1] , and NTNU[2] .

The project expects that in the future, operators will monitor one or more ships from a land-based operation centre. This involves multi-ship operation, which means that two or more ships are operated from a single control room; the ships are either operated one-to-one by a single operator or one operator is assigned more than one ship (cf. Eitrheim et al., 2019). This is a major change from the traditional operation of ships. According to International Maritime Organization a traditional ship has a Bridge Team, which is a crew that plans and completes a berth to berth passage from the ship's bridge, and the bridge shall never be left unattended at sea (ICS, 2016). This new concept will lead to new challenges related to interaction between technology, people and organization. Among key elements for safe and efficient operation are the human capabilities and limitations, ensuring Situational Awareness (SA) and acceptable workload for the operators, along with trust in automation.

From this, the objective of the LOAS project is therefore to conduct a systematic and holistic approach to technology development for safe and effective monitoring and operation of autonomous ships from a land-based Remote Operation Centre (ROC).

1.2 The scope of the report and work package

The use case defined for autonomous ships in the LOAS project is unmanned autonomous cargo ships, referred to as Continuously Unmanned Ship (CUS); i.e. there is no passenger onboard and normally no crew on the ships. This is hereby referred to as Continuously Unmanned Ship (CUS), according to the NFAS (2017) definition. The CUS´s are equipped for autonomous berth-to-berth operation. After approval of the assignment the operators normally only monitor and supervise the transit (see definition of supervisor in chapter 3.1). Among the different ships´ operations, this study focuses on the navigation during crossing operations, berth-to-berth (e.g. no berthing operations, cargo handling or administration).

Several factors must be taken into consideration concerning multi-ship operation; such as the operation complexity, which will affect the operator´s workload and how many ships each operator can supervise in multi-ship operation (cf. Eitrheim et al., 2019; Hurlen et al., 2020). Variability among

[1] IFE - Institute for Energy Technology

[2] NTNU - Norwegian University of Science and Technology

the ship characteristics, capabilities and trafficking in different areas that require knowledge of different local conditions (local competence) is of importance (Eitrheim et al., 2019; Rindahl & Lunde-Hanssen, 2019). In this project, only homogenous multi-ship operation is included (i.e. all systems, routes and ships are similar).

SCOPE

- Information needed for safe and efficient monitoring and response from the operators
- Continuously Unmanned Ships (CUS); cargo ships
- CUS equipped for autonomous berth-to-berth operation
- Navigation during crossing operations, berth-to-berth
- Multi-ship operation

Figure 1. Short description of the scope of work

The LOAS project includes several work packages. This report is a part of work package H2, which involves identifying the information needed for effective and safe monitoring and response from the operators. Figure 2 presents an overview of the LOAS project´s work packages related to the design process, and their interdependency.

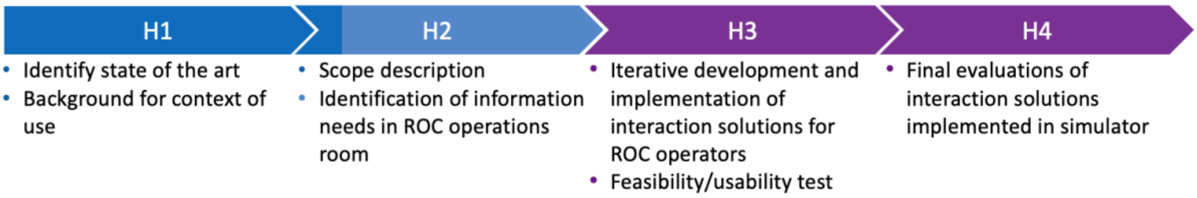

Figure 2. Overview of the LOAS project´s work packages related to the design process

This report uses inputs from the report from H1 work package, by Kaarstad & Braseth (2020). The H1 work package focused on identifying state of the art regarding autonomous operation.

1.3 The LOAS project approach

The approach of the LOAS project as a whole is influenced by the structured and user-centred process used within other industrial domains as described by ISO 11064-1 (2000) and ISO 9241-210 (2010). This process is illustrated in Figure 3.

Figure 3. User-centred and iterative process for design and evaluation, and description of which phase the different LOAS work packages deals with

The result of this report will be used as an input to work package H3; an iterative and user-centred process for designing interaction solutions. This will then be evaluated in work package H3 and H4.

1.4 Autonomous ships: challenges and opportunities

Currently, there are no guidelines for designing interaction solutions or operational models (cf. “job design and work organization” in ISO 11064-1, 2000; “concept of operation” in DNV GL-CG-0264, 2018) for autonomous ship operation. Hence, some industry projects have approached the problem by simply replicating the ship's bridge onshore. The LOAS project position is that this is not sufficient; a new and more holistic approach is necessary to explore the potential of remote operation.

An autonomous ship might require support from an operator, either because of regulations, mistrust in automation or automation capabilities. One challenge in this is to keep the operator “in-the-loop” to ensure safe operation. Another challenge is who should be legally responsible? (See discussions on jurisdiction in Kaarstad & Braseth, 2020). Yet another challenge is that the system/autonomy and sensor technology must be robust and demonstrate its trustworthiness to the operator.

Along with improved automation and sensor technology, more information becomes available. This can cause the unfortunate situation of “information overload” on the human. From this, an appropriate level of information concerning the situation, automation actions and alarms must be provided. This is even more crucial in a multi-operational environment, with the possibility of multiplying the information load.

1.5 Research questions and the report´s contributions

This report focusses on identifying information needed for remotely operating autonomous ships. This identification is needed as a basis for initiating the design of interaction solutions, which will be covered by the next LOAS work package H3. Interaction design, as defined by Norman (2013), focuses on how people interact with technology:

> *The goal is to enhance people's understanding of what can be done, what is happening, and what has just occurred. Interaction design draws upon principles of psychology, design, art, and emotion to ensure a positive, enjoyable experience. (Norman, 2013, p5)*

Based on this, we therefore ask the following questions:

1. Which operational model is suitable for remote multi-ship operation?
2. What information is data driven (see chapter 3.2), requiring response from the operators?
3. What information is needed for operating autonomous ships from a remote centre?
4. What information is needed for top-down strategic planning (see chapter 3.2)?

These questions will have an impact on the solutions for interaction design, workstation design, layout of the operation room and required facilities and functions within the operation suite. We will approach these research questions by exploring operational models, theoretical concepts, relevant literature and interviews.

Research question one is addressed mainly in chapter 4, question two in chapter 5 and 6, number three and four in chapter 6. The next two chapters will first cover several definitions and theoretical concepts needed to discuss relevant operational models and information requirements.

2 Definitions relevant for remote operation of ships

This chapter focuses on definitions relevant for autonomous ships, as these are needed to discuss the operational models presented in the next chapter.

2.1 Definitions for land-based operation centre

Different terms are used in this report to differentiate between the operations room (OR), in which the operators are collocated, and the Remote Operations Centre (ROC), which also includes other functions such as mission and administrative systems/services and associated infrastructure. In this report, the term ROC also includes other needed support functions inside or close to the OR, such as ship engineers and control room coordinators, which has not yet been defined where to locate.

In most cases, land-based centres are referred to as SCC (Shore Control Centre) or RCC (Remote Control Centre). The use of ROC instead of SCC is to synchronize with the terms used by Kongsberg Maritime, as well as emphasising the remote function and downgrade the control function. The OR correspond with the ISO 11064-1 (2000) term “control room”, however, the change of term to “operations room” is to emphasise that the main task is to *supervise* ship operations instead of controlling the ships.

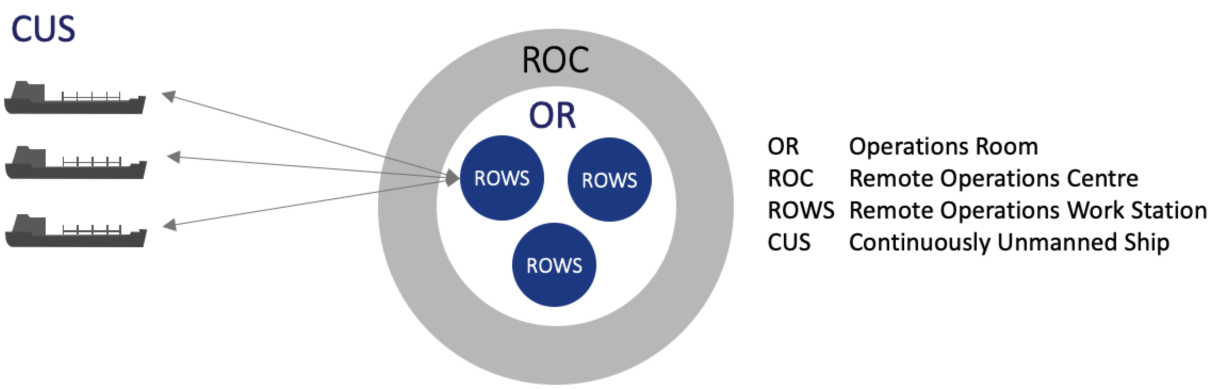

Figure 4. Illustration and terms used for entities that are the focus of the study

2.2 The NFAS autonomy levels

There are several terms and descriptions of Levels Of Autonomy (LOA). In this document, the NFAS (2017) definitions for operational autonomy levels are used. Table 1 reflects the definitions used by NFAS, although the term SCC is changed to ROC to be in line with the term used in this document.

Table 1 Levels of autonomy for operational functions (NFAS, 2017, p.11)

LOA		Description of LOA
LOA 1	Decision support	System decision support functions: e.g. advanced anti-collision radars (ARPA), electronic chart system and autopilot or track pilot. The crew is in direct command of the ship operations and continuously supervises all operations.
LOA 2	Automatic	The ship has more advanced automation systems that can complete certain demanding operations without human interaction, e.g. dynamic positioning or automatic berthing. The operation follows a pre-programmed sequence and will request human intervention if any unexpected events occur or when the operation completes. The ROC or the bridge crew is always available to intervene and initiate remote or direct control when needed.
LOA 3	Constrained autonomous	The ship can operate fully automatic in most situations and has a predefined selection of options for solving commonly encountered problems, e.g. collision avoidance. It has defined limits to the options it can use to solve problems, e.g. maximum deviation from planned track or arrival time. It will call on human operators to intervene if the problems cannot be solved within these constraints. The ROC or bridge personnel continuously supervises the operations and will take immediate control when requested to by the system. Otherwise, the system will be expected to operate safely by itself.
LOA 4	Fully autonomous	The system will execute all functions and handles all situations by itself, without the possibility for a human to intervene.

For this project, the automatic and constrained autonomous ships, i.e. LOA 2 and 3, are relevant in the context of human supervision from a ROC. Further reading concerning automation levels and regulatory issues are discussed in (Kaarstad & Braseth, 2020).

2.3 Ship modes and operator interventions

The International Maritime Organization (IMO, 2020) defines an autonomous ship using automation to operate without human intervention. This is related to one or more ship processes, for the full duration or in limited periods of the ship's operations or voyage. NFAS (2017) has a similar definition as the IMO definition. However, the NFAS definition includes the following consideration:

> "*the ship can perform a set of defined operations with no or reduced attention from a bridge crew. This does not necessarily mean that no human is present*." (ibid, p.7)

Performing the navigation tasks for CUS´s remotely is called remote navigational watch (DNV GL-CG-0264). For the LOAS project, we suggest that the operator has a *supervisory* role, which includes monitoring and intervention. According to Decker & Woods (2002), it is important to specify how humans should decide when and whether to intervene or not when defining operator tasks in a specific LOA context.

Porathe et.al. (2014) describes three different interventions to the autonomous system:

1. *Indirect control*: The operator updates the voyage plan during the voyage due to e.g. weather conditions or to avoid a declared NoGo zone. The autonomous system is still in control.

2. *Direct control*: The operator orders the autonomous system to a specific manoeuvring of the vessel. The autonomous system is still in control.
3. *Situation handling*: The operator controls e.g. rudder and thrusters directly. The autonomous system is bypassed. (remote control)

This report´s two categories of operation

In this report, the human interventions are only divided into two categories, indicating who, the CUS or the operator, is controlling the ship. This separation of interventions does not need a description of which changed parameter is included in different types of operations.

1. *Remote operation (supervision)*: The operator is not directly executing control actions; the operator intervenes by changing different operational parameters in the system or selecting and accepting automation´s option(s). The automation handles how to obtain the new goals set by the operators, still controlling most of the ship functions, such as steering, propulsion system, etc in accordance with the current regulations, environmental conditions and ship operational limits. Examples of operator interventions are changes to speed, track, waypoints or settings related to the predefined sequences of operation (LOA 2) or the predefined selection of options for the CUS to solve commonly encountered problems (LOA 3).
2. *Remote control*: The operator takes complete control of the ship. When the automated functions are in remote control, the system provides decision support, but cannot act independently or without human inputs (cf. "situation handling" in Porathe & Man, 2013). Remote control can be used in situations where the automation system is not fully capable of handling the situation by itself or when the system has only limited autonomy and requires human assistance in most operations. This is similar to on-site manual control (with decision support), yet in this case the ship is controlled remotely. In LOA 3, which is the highest LOA still requiring human supervision, remote control might be needed in unexpected situations that has not been considered in the design of automation capabilities (exceptions).

This report´s three modes of automation (CUS modes)

MUNIN (Rødseth et al., 2013) divides the ship modes into three main modes and two sub-modes, related to different types of human supervisory tasks. In this document, the autonomous actions are simplified by only defining three modes, related to the operator interventions:

1. *Autonomous execution*: The automation controls most of the ship functions and adjusts according to operator interventions. This also includes deviating from the voyage plan within predefined selection of options (for LOA 3).
2. *Minimum Risk Condition, MRC*: The automation autonomously brings the vessel to a minimum risk condition (MRC). MRC is a state that the ship should enter when normal operation is not possible, such as when extreme weather conditions are predicted or occurring, loss of propulsion system or link to shore is broken (DNV GL-CG-0264, 2018; Porathe & Man, 2013; Sjøfartsdirektoratet, 2020). On the deep seas, this might be a complete stop or bow to the wind. Close to shore, it might mean anchoring, or actively keeping a fixed position (Porathe & Man, 2013). More solutions for MRC are described in DNV GL-CG-0264 (2018, p.95). In this mode, the operator either only monitor the automation´s actions, if the automation cannot handle the situation, or has no/little information if the connection is lost/reduced.
3. *Remotely controlled*: The operator has taken complete control of the ship.

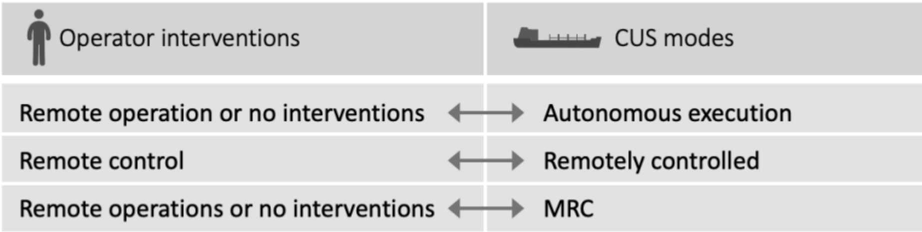

Figure 5 The relationship between operator interventions and CUS modes.

3 Information needs: Theoretical concepts

This chapter is based on relevant theoretical concepts, first discussing the concept of Supervision, followed by Situational Awareness (SA), and then exploring the link between supervision and SA.

3.1 Supervision

Sheridan´s (2002) definition of an operator´s function as a supervisor includes the following five functions:

1. Planning
2. Teach
3. Turn on automation & monitor
4. Intervention
5. Evaluate performance, learning from results

The first function is *planning*, which involves having a mental model of the systems being operated or the operational domain. According to Endsley (2013), mental models provide the basis for interpreting the perceived information. The second supervisory function is to *teach*, which is about instructing the system with what it needs to know to perform assigned functions. The third function is to *turn on the automation and monito*r. Monitoring means being attentive to relevant information, being aware of the general situation and look out for abnormalities or failures; i.e. maintain situation awareness. Actions that do not interfere with automation parameters are a part of the monitoring, such as operating cameras to change the view. *Interventio*n, as in decision and action implementation, is the fourth supervisory function. Intervention is performed when the operator makes any parameter or program change to the automation, e.g. if deviations are detected and diagnosed. The fifth function is to *evaluate performance and learn from the results*, which feeds back into planning the next phase of supervision (ibid, 2002).

Implication for design:

The interaction solution must be organized, and support the operator in performing the tasks of all the five functions related to supervising the CUS during navigation.

3.2 Situational Awareness (SA)

According to Endsley (2013), SA is a key concept to achieving user-centred design. She defines SA as:

> *"the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future"* (ibid, p.97).

This definition is divided into three levels of SA:

1. Level 1: Perception of the elements in the environment
2. Level 2: Comprehension of the current situation
3. Level 3: Projection of the future status

Level one SA involves perceiving the status, attributes and dynamics of relevant information in the environment (Endsley, 2013). In a ship operation context, this means perceiving elements such as other ships, ocean and weather conditions, system status and warnings. Level two SA includes an understanding of the significance of the elements´ impact on one´s goals and is generally about the state of what is currently happening. Level three SA is the ability to project future actions of the elements; what is predicted to happen based on current state.

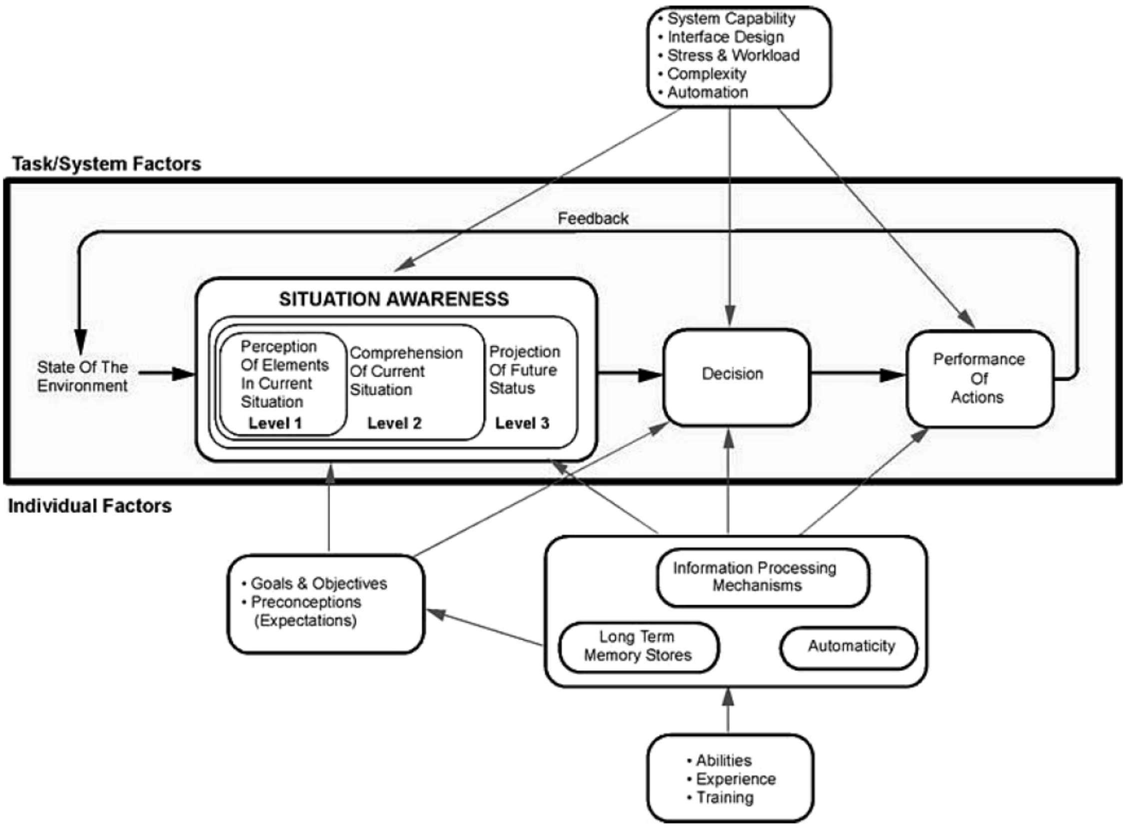

Figure 6. Model of situation awareness in dynamic decision making (Endsley, 2013, p.97)

For operating autonomous ships, it is a challenge to achieve a complete SA across all three SA elements. It will require a number of data sources (Level one), comprehended into a meaningful “whole” (Level two) projected into trends or tendency (Level three).

A top-down/goal-oriented approach for information presentation is relevant for multi-ship operation; i.e. the operator monitors that the navigation operation is progressing as planned and looks for and is informed by the system, first if any projected future actions deviates from the planned, secondly when there are changes or deviations, and thirdly investigate or diagnose the reason for changes or deviations, if needed. “Based on their goals and current understanding and projections (Level 2 and 3 SA), they may look for data to either confirm or deny their assessments or to fill in gaps (i.e., search for relevant Level 1 data)” (Endsley, 2015).

In addition, the operator should be supported for bottom-up data driven events. One example of this type of data is alarms. Switching between top-down goal driven and bottom-up data driven processing of information is an important mechanism supporting SA. As an example, when the goal is to navigate the ship to a certain port, the operator will search for information that is relevant to this goal. If the planned route is in jeopardy due to another ship on collision course (data driven event), the goal must be changed from “navigate the ship to a certain port” to “avoid a collision”.

Implication for design:

In a normal situation, the CUS should support the three SA levels for each ship. Both top-down/goal-oriented information processing, and bottom-up data driven information perception should be supported.

3.3 The link between supervision and SA

The execution of supervisory functions depends on SA and the response from systems during supervision will feed back to deciding whether supplementary or more detailed information is needed for understanding the situation. Planning, teaching and learning is a part of the supervisory functions, though these functions have not been the focus of this study. The focus has been on monitoring and interventions. Figure 7 illustrates the relation between supervision and SA:

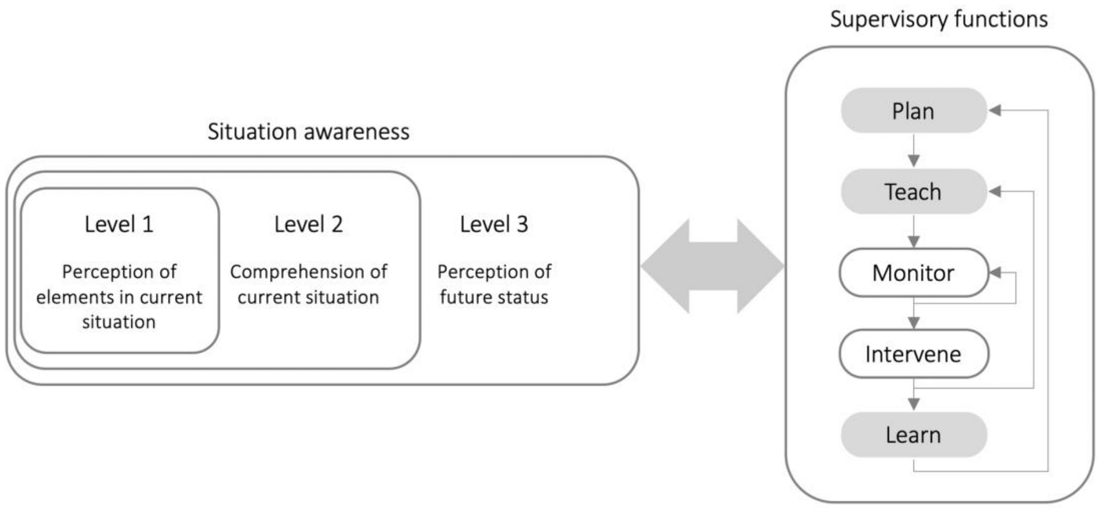

Figure 7. The link between supervisory functions and situational awareness. The illustration of SA´s is a simplification of Endsley´s (2013) model, and the model of supervisory functions is a redesign of Sheridan´s model (2002).

In light of the three levels of SA, we have defined three levels of monitoring tasks, see Table 2:

Table 2 The relationship between monitoring and SA levels

Monitoring levels	SA levels	Description of monitoring levels
M1	1-3	Diagnose or investigate; i.e. diagnose abnormalities, deviations or get SA on details
M2	1-3	Assess current situation or system state
M3	1-3	High level monitoring: Monitor that operational goals will be maintained according to plan, per ship and overall goals across allocated ships

Implication for design:

Figure 8 illustrates a possible relation between the CUS´s LOA 2 and LOA 3 capabilities and the operator´s supervisory functions, the monitoring and intervention, in normal situations, deviating situations and exceptions. This illustration does not account for the different voyage phases (see chapter 4.4). Concerning a CUS with LOA 3 capabilities, no operator interventions should be needed if the CUS finds alternative solutions within the defined limits of options that can solve the situation. This can be used as input to the design of interaction solutions when considering organisation, prioritisation and visualisation of information.

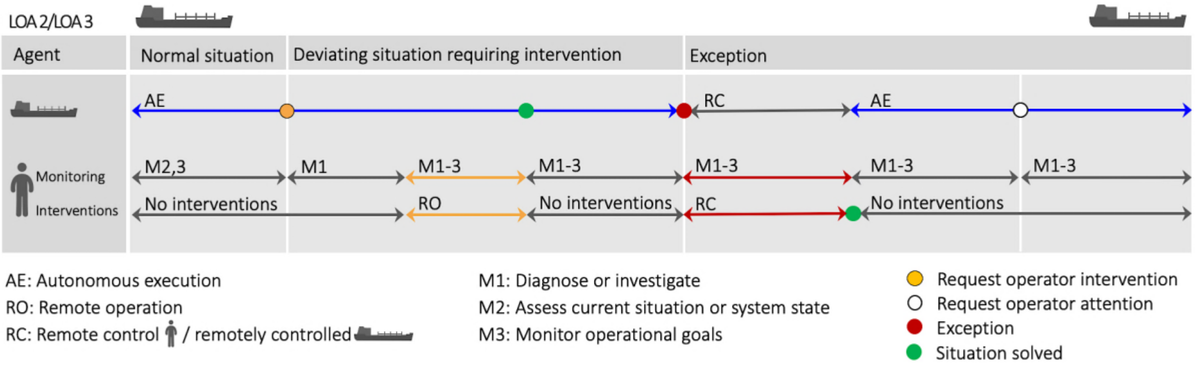

Figure 8. Supervisory functions, monitoring and interventions, related to operational situations and LOA 2/LOA 3.

4 Operational model

This chapter first presents a background related to human operations of more than one ship. Then, operator and automation roles are presented, followed by possible operational models.

4.1 Background

There are many organisational aspects that ought to be solved before implementing remote multi-ship operation. This includes defining an operational model for the operations room (OR); how to work and allocate tasks in multi-ship operations. There are currently no guidelines or specific descriptions of operational models for remote multi-ship operation.

The operational model will give input to what information per ship is required to be visible related to the supervisory task, the required level of SA, how to organise the information and the size and numbers of screens per ROWS (remote operations workstation). Furthermore, the operational model will provide a basis for how and when to switch operational modes in the system and how to reallocate tasks in case of incidents causing high workload.

The human factors research related to operational concepts involving remote monitoring and operation of autonomous ships is quite sparse. Even more sparse is the research on one operator remotely supervising more than one autonomous ship from a ROC concept.

The operational models are depended on the capabilities of the autonomous ship and the human operator, as well as task allocation and responsibilities of human operator, automation and various support functions. Discussions and articles about human factor challenges in remote control and supervision of autonomous ships mainly describes the challenges when the operator is in command of one ship. In a ROC operations room, the operators will be in command of more than one ship. Detailed monitoring of each autonomous ship simultaneously can overload the operator's cognitive capacities. Thus, this chapter discusses possible operational models for handling such multi-ship operation.

The MUNIN project´s hypothesis is that "*One operator can monitor six ships with adequate control, situation awareness and workload even if two events occur at the same time*" (McKinnon et al., 2015, p.13). There is, however, no description of how to organise and handle the ships related to the amount of human attention needed or reallocation of tasks in high workload periods. The project tested an organisation for a SCC (ROC), where the operators were functioning as receptionists and a captain was the final decision maker. They discovered that the captain was "out-of-the loop" in decision making (Man et al., 2015). This is an example of the importance of considering the operational model, including roles, responsibilities and task allocation, when introducing new technologies.

> *Where automation is introduced, new human roles emerge.* (Decker & Woods, 2002, p.6)

4.2 Main/secondary operator & CUS roles and functions

The operators' role, tasks and responsibilities will depend on the autonomy level and CUS mode. Suggested roles and functions for operators and CUS are described in this section.

Operator role and function

Based on the descriptions of the operator's expected interventions in various situations (see 2.3), a description of the operator's main role and function can be described as follows:

- Supervise the system through monitoring and intervention if/when needed.
- Maintain a proper level of SA related to the voyage phase, in case something unexpected occurs, such as obstacles in the planned route, ships with critical proximity or on collision course (Ottesen, 2014).
- Perform condition analysis: Help the automation system in recognising and classifying objects that are detected by the automation, if needed.

The last bullet considering main operator role and functions is described by DNV GL-CG-0264 (2018). This DNV GL document states that if the automation system has limited object recognition capabilities it will be depended on an operator to recognise and classify objects. The secondary operator role and function is presented as:

- Safety barrier and “last resort”: Intervene if needed, and execute remote operation when required in critical situations, to bring the ship back to safety.

CUS role and functions

- Main executor of actions
- “Look out” function: Detect objects and changes in the operational environment (condition detection), classify objects and analyse the situation for applying correct actions (condition analysis) (DNV DL-CG-0264, 2018)
- Provide information to the operator about the object (DNV DL-CG-0264, 2018)
- Action planning: Based on the object classification, calculate an updated passage plan in accordance with COLREG (DNV DL-CG-0264, 2018)
- Action control: Execute the updated plan (DNV DL-CG-0264, 2018)
- Support the human in understanding the automated actions, the situation, and prediction of the near future situation.
- Involve the operator when needed

4.3 Operational models for LOA 2 and LOA 3 capabilities

Each ship voyages have distinctive phases with unique challenges. Depending on the capabilities of the automation, these differences can either mean that more tasks must be executed by the operator, or that more focused attention and interventions are needed for some phases. In the LOAS project, we are studying a CUS, which is capable of autonomous berth-to-berth operation; i.e. either LOA 2 or 3. This implies that more focused attention and interventions are required for a ship with LOA 2 than LOA 3.

Rødseth et al. (2018) state that berthing and port approach are phases in which one would probably use remote control combined with automatic track and berthing control. It might not be necessary, nor appropriate concerning workload, to execute remote control during normal situations in multi-ship operation if the ships have good object recognition capabilities, overall good manoeuvring capabilities and sufficient solutions for handling MRC´s. This provides a starting point for further discussion of possible operational models.

Issues that are relevant to consider per voyage phase when considering operational models are:

- Type of automation mode
- Task allocation between operator and CUS, in different automation modes
- Type of supervisory function: The need for monitoring (continuously/occasionally) and operator intervention

Sequential operation

Factors requiring full human attention and high degree of interventions or remote control in certain phases of the voyage might imply that sequential operation of multiple ship is the solution. The human capabilities concerning e.g. workload and shift of focus between tasks are other issues that might speak for this concept. Sequential operation means that the operator is supervising one ship at a time and can start supervising a new ship when the first has finished the voyage. There will be some risk for conflicting events across ships in case of deviations from the voyage plans. Planning for the next voyage(s) might be a possible task while supervising one ship. Prerequisites for this model is that ships' voyage plans allocated to one operator cannot overlap in time, and the planning should include some time between finishing one voyage until starting the next, enabling the operator to plan for supervising a new ship (as a part of supervisory control).

Condition-based multi operation

Assuming that the required degree of monitoring the CUS and possible need for attention and interventions varies depending on the different phases of the ship operation, an alternative approach to multi-ship operation is possible. Some critical phases, e.g. congested areas, such as when departing/arriving the port and in narrow water[3], might require considerable attention from the operator; the operator must be in-the-loop in order to be able to quickly intervene when needed. Other phases, for example the transit, might need no or minimal attention from the operator in normal situations.

The condition-based model also requires logistical considerations. The allocation of ships to operators must ensure that no vessels are in critical phase at the same time. In this condition-based operation, the operator is in command of several ships simultaneously, however, only one ship in critical phase in normal situations. In case of changes to voyage plan after the ship has left the berth, there is a risk for conflicting events. Reallocation of ships between operators or support might be needed, both concerning changes to voyage plan and situations that require more operator attention and intervention. Whether this solution is realistic or not, is also depending on regulations, CUS robustness and reliability, as well as human capabilities.

Multi-operation

With CUS´s equipped for autonomous berth-to-berth operation, possessing an extensive degree of robustness and reliability, as well as regulations approving minimum supervision from operators, true MULTI operation can be a reality. With a high degree of automation, the operator interventions might

[3] Narrow waters mean "*waters with restricted freedom of course setting and where pilotage conventionally is the foremost navigational method*" (DNV GL RU-SHIP, 2019, p.120).

rarely be needed, and the operator can supervise more than one ship simultaneously. The number of simultaneously supervised ships are not discussed here. However, as long as the operator is in command of each ship allocated to her/him and is therefore also responsible for the ships´ behaviour, the operator must monitor all ships allocated to the operator which are in active state (berth-to-berth operation has started). The operator might not be able to maintain full situational awareness (in-the-loop) of all ships simultaneously, and therefore M3 monitoring, i.e. high-level monitoring, is suggested for normal situations, occasionally, and when the automation calls upon attention from the operator. Thus, the reliability and robustness of the CUS (ship, automation and other ship systems), as well as other systems providing information to the CUS, is crucial. This operational model might only be relevant for automation with LOA 3 capabilities.

In case of unexpected events and high workload, reallocation of ships and/or support might be needed. If systems are designed properly, accounting for situations that might occur, there will be less need for coordination of voyage plans. Nevertheless, the human operator´s role might represent both a safety barrier when automation fails, and also to make changes from the CUS´s operational options. However: Will the operator be able to understand the situation and respond timely and correctly in the situation when the automation fails? Humans tend to “do something” in all situations, even if the situation is not fully understood. Another challenge is: How to ensure the operator tasks are meaningful, while supporting a suitable workload? Hence, both workload and job satisfaction must be considered.

Phase-divided operation

As discussed by Kaarstad & Braseth (2020), it might be an idea to allocate all tasks related to each of the different ship phases to different operators; “one operator is responsible for berthing and unberthing, another for approach and departure, a third operator has responsibility for narrow water, and a fourth for open sea”. The same considerations as already discussed above applies to this operational concept, here referred to as PHASE-DIVIDED operation, and can be executed sequentially, condition-based or as in multi operation. Phase-divided operation might cause too high workload for some operators and too little for others, assuming that some phases require more attention from operators. This model can however be challenging related to handover because it requires several handovers per voyage. For each handover, all relevant information must be communicated from one operator to another or the operators must perform self-briefing.

Summary of the operational models

Figure 9 illustrates the difference between the suggested operational models and Figure 10 illustrates possible automation mode (AE and RC) relative to the supervisory functions, including monitoring level and the frequency for monitoring for the operational models - in the context of the different voyage phases. As illustrated, the three different models will provide various opportunities for how much of the voyage that the operator can monitor in detail, continuously or occasionally.

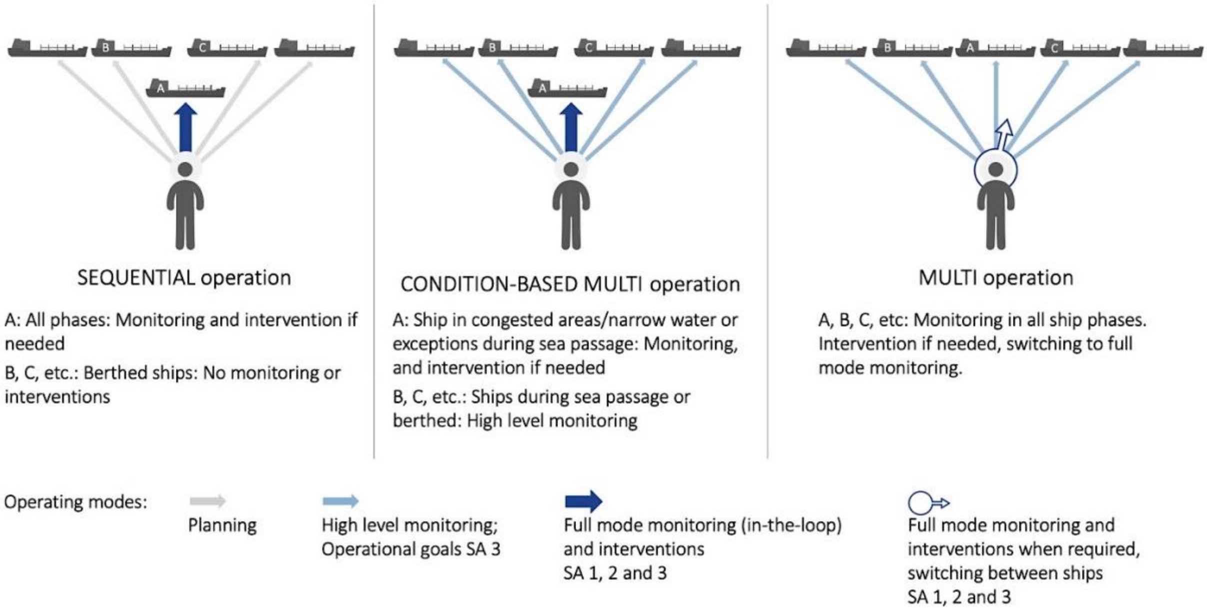

Figure 9 Three different proposals for operational models. Phase-divided operation can be executed as sequential, condition based or multi operation.

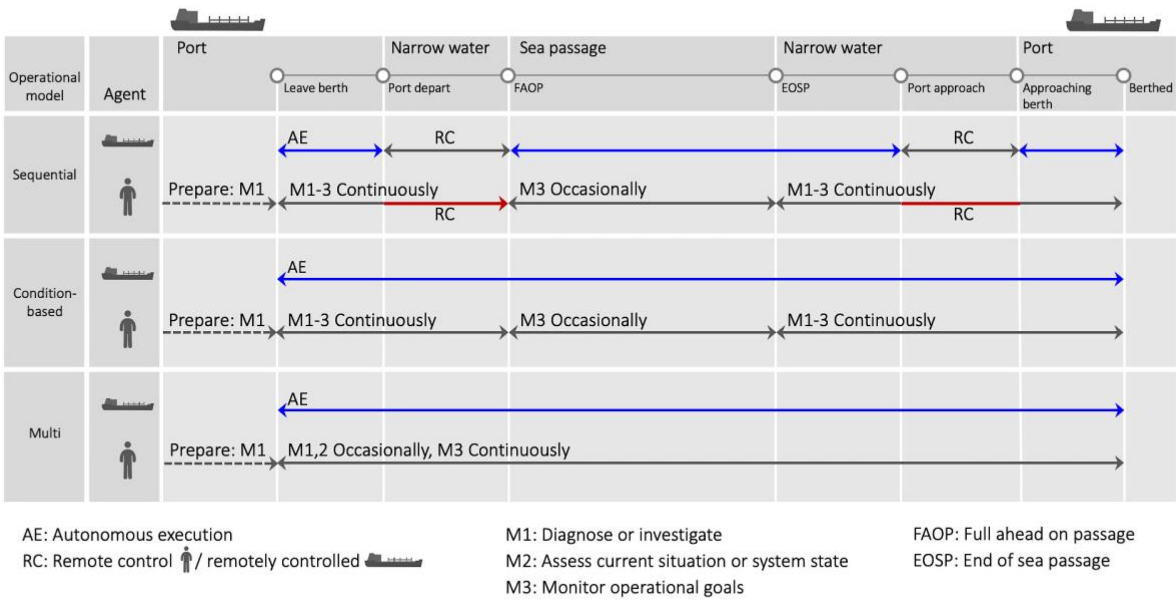

Figure 10. Three proposals for operational models in context of voyage phases: automation mode and monitoring level per phase. Phase-divided operation can be executed as sequential, condition based or multi operation.

The voyage phases mentioned in Figure 10 correspond to the areas described by Sjøfartsdirektoratet (Norwegian Maritime Authority, 2020, figure 1, chapter 7.3) related to areas requiring a different set of MRC´s, and thus might need different attention from the operator depending on automation capabilities and other factors described in the introduction to chapter 4.

Other considerations concerning operational models

For all of the proposed operational models, there will be more or less risk for conflicting events, in case of delays for some reason. Thus, a coordinator might be needed in the OR, to address conflicting events and reallocate tasks between operators. Other possible tasks allocated to a coordinator is to plan and coordinate OR tasks, monitor the overall plans and workload in the operation room, judge the operators' current state and fitness for duty. When operators are stressed, they do not always manage to verbally communicate the situation. A coordinator placed in a central position in a control room can often read the operators´ bodily movements, and by this, understand their current state and workload (cf. Lunde-Hanssen & Rosenqvist 2019, Lunde-Hanssen et al. 2015).

Technical support is also a role that should be considered in the operational model. Various research has found that technical support is needed close to the operations room (Hurlen et al., 2020; McKinnon et al., 2015). In the MUNIN project, the ship engineer was called upon when help was needed. The operator requested the engineer´s help via the coordinator. The organisational solution depended on operators providing the engineer and captain sufficient information to get these actors into the loop (Man et al., 2015). Another solution is that the engineer monitors technical ship statuses and alarms on both high and detailed level, while the operator monitors this information on a higher level if the alarms require a timely response (cf. alarm definition in ANSI/ISA, 2016). This model might ensure that the engineer is already in the loop when technical failures occur or as the situation develops, before an error occurs.

Regardless of which operating model proves to be most appropriate, both for business case and performance, an underlying goal should be to plan for an even workload distribution over time for all operators. A plan for high activity periods must be considered, and how to reallocate responsibility for ships in case of unexpected events causing high workload.

4.4 Implication for design – operational models

The operational model will have implications for the design of interaction solutions. Each model will require an individual consideration related to what information per ship should be visible continuously or occasionally. Furthermore, each model will be a leading factor for how to organise and prioritise the information and affect the size and numbers of screens per ROWS (remote operations workstation).

For sequential operation, only information concerning one ship operation is needed on the screens, for all information required per monitoring level. This operational model will also include the need for bringing up information regarding upcoming ship voyages. Condition-based multi operation require an extended information area, since high-level monitoring (M3) of some ships should be performed occasionally while monitoring one ship in more detail (M1, 2 and 3). Multi operation involves monitoring several ships simultaneously and even more information area might be needed. High-level monitoring (M3) of all ships continuously and information area for more detailed information (M1 and 2) of one or several ships might be needed, with easy access to the information. Figure 11 offers a general illustration of the implications for design related to operational models.

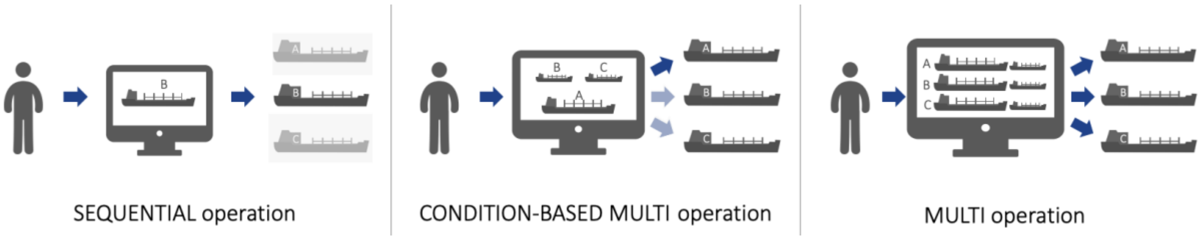

Figure 11. Implications for design related to operational model. Phase-divided operation can be executed as sequential, condition based or multi operation

When designing interaction solutions for the operators, it would be useful to also consider whether a coordinator can be of better support if some information displayed on the operators´ screens are legible from the coordinator working position (CWP).

This discussion regarding operational models provides a step towards answering research question 1: Which operational model is suitable for remote multi-ship operation? Condition-based multi operation or multi operation are suggested, depending on regulations and CUS capabilities.

5 Operator tasks in remote operation of autonomous ships

The allocation of tasks between automation (the CUS) and ROC operator will affect the information needed by the operator. The content of this chapter discusses the task allocation as found in relevant literature. Please note that we focus on CUS´s within LOA 2 or 3 (see chapter 4), which means that they are equipped for autonomous berth-to-berth operation and handles more or less all the operational tasks. After approval of the assignment, operators normally only monitor and supervise the CUS.

5.1 Task related to remote operation of one CUS

Ottesen (2014) suggests that autonomous ships will be able to determine their best route, and either make suggestions (LOA 2), or inform the operators about changes in the voyage plan (LOA 3). According to DNV GL (DNV GL-CG-0264, 2018), the planning of the voyage may be performed manually by personnel in the ROC with the aid of support systems. The planning may also be done automatically by a system. Another solution related to creating a voyage plan, is to allocate navigation planning tasks to personnel dedicated to planning (DNV GL-CG-0264, 2018). In this report, the planning before the voyage has started is not within our focus. We, however, assume that the operator has enough information about the plan to understand the situation prior to supervising a ship.

The MUNIN project (Rødseth et al., 2013, pp.27-29) has documented several functions and tasks related to remote operation of autonomous ships, which has been analysed based on literature review, and allocated to either the unmanned autonomous ship or to SCC (ROC). These functions are also used in the NFAS document "Definitions for Autonomous Ships" (2017) (except the group System functions and some observation tasks).

The functions and tasks defined by MUNIN (Rødseth et al.,2013, pp.27-29) and some of the NFAS´s (2017) adjustments to the MUNIN descriptions, will be used as inspiration in our work. The terms used by MUNIN has been changed to match the terms used in this document, and some tasks have been changed to match the scope description and discussions in this document. More details are added for the purpose of analysing the information needed by the operator about the voyage, ship behaviour and CUS´s actions. Expected operator interventions are described in table 11 below (cf. Ramon et al., 2019).

In the following tables, the "Agent" column indicates which roles are the main responsible for executing the task in normal situations: CUS, RO = ROC operator. ROC = other role in ROC, CO=coordinator and n/a= not relevant for unmanned ships.

0. System functions			
	Sub-group	Agent	Description
0.1	Ship data link	CUS	Monitor and control ship through a ships-shore communication link, main or backup.
0.2	Automation mode	CUS	Change automation mode according to environmental conditions and human interactions (start/stop autonomous execution, change mode): Autonomous execution, MRC or remotely controlled
0.3	Nautical communication	CUS	Communicate with other ships and shore, e.g., mariners, tugs, reporting areas or VTS (Vessel Traffic Service). Including updates to MetOcean. NAVTEX, SafetyNet, AIS text, GMDSS etc. (Rødseth et al., 2013; DNV GL-CG-0264, 2018)

1. Voyage management			
	Sub-group	Agent	Description
1.1	Plan	CUS or ROC	Create and maintain a voyage plan based on instructions from shore and known sailing constraints (e.g. related to ship characteristics, traffic regulations and restrictions), including planning for port calls and other events. (Rødseth et al., 2013; Walther et al., 2014)
1.2	Nautical information	CUS	Keep track of information related to voyage, nautical publications, weather forecasts, tide tables, port instructions, legislative documents etc.
1.3	Location /time (Navigate)	CUS	Determine and plot the ship´s position, course, track and speed, follow route, and monitor where it is moving in relationship to its voyage plan (route, ETD/ETA, etc) and "track made good" (past positions) against the voyage plan (Rødseth et al., 2013; DNV GL RU-SHIP, 2019).
1.4	Economize	CUS	Monitor and assess the operational and economical parameters of a voyage, including fuel consumption, late arrivals etc. Determine corrective measures.
1.5	Consumables	CUS	Monitor fuel, lube oil, other consumables.

2. Sailing			
	Sub-group	Agent	Description
2.1	Manoeuvres	CUS	Control the ship during passage, and compensate for external conditions, including weather, sea state, traffic regulations, and other objects. May also include dynamic positioning.
2.2	Interactions	CUS	Manage direct interactions with other ships, pilot boats, tugs, berths, locks etc.
2.3	Anti-collision	CUS	Detect and avoid other objects in the vicinity that may be a danger to the ship. Use COLREGS where applicable (Rødseth et al., 2013). Determine CPA and TCPA for potential navigational dangers/objects and other ships (DNV GL-CG-0262, 2018)
2.4	Anti-grounding	CUS	Avoid groundings by keeping to safe channels with sufficient air and sea draft and sufficient distance to land (Rødseth et al., 2013). Monitor COG and SOG (DNV GL-CG-0262, 2018)
2.5	Ship characteristics	CUS	Maintain data on turning rate, max speed, weight, height, etc. (Rødseth et al., 2013; Walther et al., 2014)

3. Observations: Keep general lookout. Monitor the traffic by sight and hearing as well as by available means. (DNV GL-CG-0262, 2018)			
	Sub-group	Agent	Description
3.1	Weather and sea condition	CUS	Assessment of weather- and sea-related environmental factors that can impact the ability to execute voyage plan and to manoeuvre, including, e.g., icing and ice. (Rødseth et al., 2013; Walther et al., 2014)
3.2	Visibility	CUS	Assessment of factors that impact the possibilities to detect other ships, objects, waves, land, aids to navigation etc. Also linked to anti-collision functions.
3.3	Objects	CUS	Detect and observe objects that are important for own and other ships and services, such as traffic, underwater rocks, shipwrecks, navigation lights (e.g. vessels not under command) beacons (lighthouses, stakes, lightship, buoys), other moving objects such as ships and icebergs, life saving devices, signal flare, man overboard etc. (Rødseth et al., 2013; Chopra, 2020; DNV GL-CG-0262, 2018)
3.4	Ship motion	CUS	Monitor necessary dynamic information related to ship motion, such as roll, heave, vibrations, hogging, slamming etc. (Porathe & Man, 2014; Porathe et al., 2014)
3.5	Sound	CUS	Monitor outdoor microphone and analyse for unwanted sound, e.g. leakage, slamming, sound signals e.g. from other vessels (DNV GL-CG-0264).
3.6	Other sensors	CUS	Monitor sensors and check consistency of sensor systems.

4. Safety/emergencies			
	Sub-group	Agent	Description
4.1	Safety communication	CUS	Communication related to emergencies on own ship; communicate with MRCC and ships, EPIRBS, portable radios.
4.2	Onboard communication	n/a	Public Announcement (PA), General Alarm (GA), UHF radios.
4.3	Emergency management	n/a	Distress team, response groups, firefighting, smoke divers, first aid etc. Includes man overboard (MOB).
4.4	Emergency preparedness	n/a	Drills, training, maintain hospital, fire prevention, fire patrols, life saving devices, escape routes, lifeboats etc.
4.5	Technical safety	CUS	Fire detection, fire doors and dampers, watertight doors, extinguishing systems.
4.6	AOS	n/a	Assist other ships or persons in distress.
4.7	Anchors	CUS	Use of anchors for safety.

5. Security			
	Sub-group	Agent	Description
5.1	ISPS	CUS	Monitor access to ship and interactions with entities that can endanger ship's ISPS status.
5.2	Onboard security	CUS	Access control for crew and passengers, network firewalls and data protection etc.
5.3	Antipiracy	CUS	Monitor and control attempts to board or otherwise interfere with ship operations.
5.4	CCTV	RO	Operation of onboard CCTV, also for inspection, diagnostics etc.

6. Life support and welfare			
	Sub-group	Agent	Description
6.1	Passengers	n/a	Monitor and manage passengers on-board and services for these.
6.2	Life support	n/a	Maintain good working and living conditions for the crew and passengers. Ventilation, heating, AC, black/grey water, drinking water, supplies etc.

7. Cargo/stability/strength			
	Sub-group	Agent	Description
7.1	Stability	CUS	Detect dangers and maintain ship stability and trim. Operate stabilizers, use ballast systems.
7.2	Integrity	CUS	Observe and maintain water and weather integrity of ship, including ship strength and damage integrity. Monitor and operate hatches and doors.
7.4	Bunker management	CUS	Monitor and manage bunkers and bunker tanks.
7.5	Cargo condition	CUS	Observe and control cargo condition for safe transport during passage.
7.6	Pollution prevention	CUS	Observe and control cargo and ship supplies to avoid and manage discharges and possible pollution, including ballast water handling. Handle dangerous or noxious substances safely.

8. Technical: Sense and analyse and control equipment			
	Sub-group	Agent	Description
8.1	Environment	CUS	Monitor and optimize ships environmental impacts from energy systems and hull in terms of emissions to sea or air including, when applicable sound emissions.
8.2	Propulsion	CUS	Maintain propulsive functions and efficiency based on available power from engines. Monitor rudder angle, propeller revolutions and pitch, thrust, etc (DNV GL-CG-0262, 2018)
8.3	Main energy	CUS	Produce required energy on shafts to propeller and generators.
8.4	Electric	CUS	Convert and distribute electrical power from generators and other systems.
8.5	Other systems	CUS	Control and manage boilers, incinerators and other technical systems not covered elsewhere.
8.6	Hull equipment	CUS	Access, lifting, ladders etc.
8.7	Lights	CUS	Turn on/off running lights, lanterns and signal lights (e.g. not under command" signal) (cf. Porathe & Man, 2013); DNV GL-CG-0262, 2018

10. Administrative			
	Sub-group	Agent	Description
10.1	Administrative communication	ROC	Communicate with ship owner, charterer, cargo owner, ports and agents, weather outing companies or others that may send instructions to ship or require status updates. Including port logs, noon at sea and other reports.
10.2	Manning	CO	Consider the number of, tasks for and working ability of ship crew (STCW).
10.3	Logs	CUS	Keeping mandatory logs on actions taken on board.
10.4	Mandatory reporting	CUS/ ROC	Send mandatory reports to ship reporting systems, port state authorities, ports or other entities.
10.5	Documents	ROC	Keep non-nautical ship documents updated: Certificates, ISM documents, manuals …

11. Operator interactions			
	Sub-group	Agent	Description
11.1	Start/stop	RO	Approve and/or maintain awareness of the voyage plan (depending on CUS´s LOA) and accept the allocated responsibility of being in command of the ship. Activate the CUS´s mission to start and stop; i.e. activate autonomous execution.
11.2	Alarms, alerts, warnings	RO	Act on alerts and warnings from the automated system, either accept/reject system suggestion(s) or take control if the automated system has no solution to the problem
11.3	Changes, deviations	RO	Act on changes in plans (e.g. delays): either accept/reject system suggestion or intervene by changing waypoints, route, start of voyage, etc
11.4	Collision	RO	Act on system failure in detecting or handling a collision candidate
11.5	Nautical communication	RO	Communicate with target ship or VTS if necessary. If the data provided by the system about the target ship is not enough, or if the operator is unsure of the target ship's intention, she/he can contact the ship, or contact the Vessel Traffic Service

Implication for design

The tasks in table 1-10 in this chapter provide a basis for discussing research question 2 and 4: 2) What information is needed for operating autonomous ships from a remote centre? 4) What information is needed for top-down strategic planning? Table 11, describing operator interventions, will provide a basis to research question 3: What information is data driven, requiring response from the operators? These questions are further explored in chapter 6 and 7.

Please note that decision support as described for LOA 1 (see chapter 2.2) and support for condition detection and analysis (see CUS role and function in chapter 4) is probably needed also in remote control operations; i.e. provide the operator with information on operational risks and alternative solutions when the ship is set to remote control. Whether nautical communication should be a part of the operator tasks during remote control, or still be handled by the CUS needs further discussions.

5.2 Tasks related to remote multi-ship operation

We have not found any tasks specifically related to remote multi-ship operation during the literature review. The tasks mentioned here are for this reason, suggested as possible tasks and should be further explored.

Automation tasks concerning multi-ship operation:

- Prioritise alerts and alarms across ships´ state, according to urgency (e.g. priority 1 is situations the CUS cannot handle independently) and direct the operator attention to the relevant critical or urgent problem.
- Conflicting ship handling (route, time, ship voyage phase): detect conflicts across ship voyage plans

Implication for design

In multi-operation, it is important that the operator intuitively understand which situation to address first, both concerning one ship and across ships. A first priority situation (most critical or urgent) occurring for one ship must be handled before a second priority situation for the same ship or a different ship. Displaying a group of information that provides an overview of all critical or urgent situations, prioritised according to criticality and urgency, might help the operator in comprehending what to do first.

If a first priority situations occur on a ship, reallocation of tasks/ships to an extra operator resource might be needed. In this case, an overview of situations across all tasks handled in the OR provided to a coordinator will help the coordinator in relieving the operator´s workload. We suggest to particularly focus on avoiding challenges related to conflicting ship handling. Both current conflicts, and projection of possible future conflicts should be managed.

6 Requirements to interaction solutions per CUS

The operator needs information to monitor the general situation and abnormalities or failures (Sheridan, 2002). This includes both the information related to various traditional monitoring tasks (as described e.g. by DNV GL RU-SHIP, 2019, see Appendix 2) as well as information about automated actions during navigation. The operators supervising the CUS should have sufficient information about relevant conditions, to conduct independent analysis of the situation and appropriate actions in addition to understanding the motivation for the CUS´ actions (DNV GL-CG-0264, 2018). The information and interaction solution provided should not only take normal operational conditions into consideration, but also emergency conditions and demanding operational situations (cf. ibid).

According to Sheridan (2002), proper allocation of attention depends on what is most urgent and important. Providing effective and cognitively efficient visualisation of information will simplify the process of staying in-the-loop with several ships simultaneously (Ottesen, 2014). A hierarchy and prioritisation of the information presentation, depending on the operational condition and information requirements will be needed.

To be able to supervise or take direct control of a ship, the operator needs to understand the automated actions. However, providing the operator with information on all automated tasks can result in information overload. All three SA levels should be supported; however, it might be important that the information visualisation only draws operator attention when there are deviations from plans and when the CUS is not capable of handling a situation. The CUS can in most cases make its own decisions, and when it cannot do that (or is not authorised to do that) it should, according to Van der Klugt (2018) give a clear assessment of the situation together with precise questions on what it wants to be resolved.

When remotely monitoring ships, the operators need more time to absorb the required information to be in the loop before acting, and for this reason, “tendency” information is suggested as a way of providing the operator with early information before an alarm situation occurs (Man et al., 2015). To support the operators SA concerning prediction of the future, the system should provide trends and information about developments at an early stage (Ottesen, 2014). This is in line with projection of the future, as described by Endsley (2013)

Implications for design:

The information provided should support the operator in achieving a high level of SA. All three levels of SA should be considered depending on the operational requirements to:

4. Have an overview of the goals per ship (the necessary data)
5. Assess current situation or system state (comprehension of the situation)
6. Diagnose or investigate current situation (a projection into the near future)

The information content for CUS in the following sections are discussed in light of these three levels of SA.

6.1 Overall ship information

Because of the risk of missing the bigger picture, especially when supervising several ships, an overall information level of ship information might be needed. The overall information needed per ship should be considered along with overall information needed for the multi-ship operation. Monitoring is made easier by providing graphical overview pictures of combined history and predictions, such as trends.

Ottesen (2014) suggest that overall ship performance indicators can be presented at an overall information level, while more detailed information about the underlying factors can be provided at a lower information level. Suggestions to overall performance indicators means aggregated status on all conditions that can affect the planned voyage, such as ship health and mission management. Thus, systems should be designed with sophisticated diagnostic functions (e.g. condition/health monitoring) to detect evolving failure conditions and hidden failures (cf. DNV GL-CG-0264).

- Mission management: Maintaining voyage plan port-port, sailing, observations and deviations to plan when necessary
- Ship health: E.g. engine health, ship stability, satellite communication signal status and environmental conditions.

Implication for design

A group of overall or aggregated CUS performance concerning mission management and ship health, including projection of future status should be designed to support the operator in comprehending the overall situation related to one CUS. Voyage phases, current phase and indication of required monitoring level per phase might be useful for the overview information, e.g. as context information with little attraction of attention.

6.2 System functions

To be able to respond properly and timely when supervising or remotely controlling a ship, the operator needs to know of and understand the ship mode and activated support systems (i.e. what is the automated actions). Information on whether the ship data link is functioning or has a reduced or loss of capacity is also important. According to Kongsberg Maritime (2018), the possibility to change ship mode (interventions) should be easily accessible when occasionally needed.

In normal situations, the CUS will handle the nautical communication. The CUS should inform the operator if the data provided is lacking information about a ship in vicinity for the operator to evaluate if he/she needs to communicate with the ship or VTS (Vessel Traffic Service).

Implications for design

The operator will need feedback from the system when the autonomous function is activated (in-the-loop), and whether it is set to autonomous execution or MRC. In normal conditions when all systems are functioning as they should after activating the autonomous function, the operator will only need to be informed if system, including data link, fails, is degraded or is no longer active.

6.3 Voyage management

It is assumed that the CUS at some point will be able to determine the best route and either make suggestions or inform the operators about changes in the voyage plan or occurrences of challenges (Ottesen, 2014). The CUS should also provide real-time updates of voyage plan to VTS. Having these characteristics, the CUS will be able to reduce the operator’s workload, which may be necessary in a multi-ship operational context.

The CUS should autonomously navigate along a set trajectory according to the voyage plan. In case of a possible collision situation, it should request for operator interventions (LOA 2) or, as stated by Pietrzykowski & Hajduk (2019), it should navigate along a safe determined trajectory (LOA3).

The operator needs information about both the planned and deviations to the voyage plan, and the possibility to investigate the reason for the deviation. Changes in the voyage plan is required in order to intervene in a timely manner if the automation should fail or is incapable of handling a situation (command latency, cf. DNV GL-CG-0264, 2018). Some information needed are actual position, predicted future positions, ETA per waypoints and ETB (estimated time of berthing) if waypoints or route are changed.

The MUNIN project suggested what they call a "safe haven"; a box that moves over the map following the planned voyage, illustrating that the ship is "on time and on track". The size of the "safe haven" box varies with the context (e.g. narrow water and deep sea). An additional feature of this box, investigated in other projects, is to use this as a "look-ahead-alert" by testing box intersections ahead of time (Porathe & Man, 2013).

Implications for design

The operator will need all information related to the voyage for planning, diagnosis and investigation in case of deviations. However, not all information has to be explicitly visible at all times. During sea passage, mainly high-level monitoring will be necessary. This implies that during sea passage information related to prediction of future status concerning the voyage plan should be visible continuously, while other information should be easily available on demand.

When the ship is located between berth and narrow water, information on current changes or deviations to the voyage plan should be the main information source to monitor, while looking to predictions and easy access to more detailed data if needed.

6.4 Navigational limits and safe operational zones

We assume that automation is responsible for monitoring details concerning ship performance, ship health and mission management (see chapter 6.1). Thus, some details will not be the priority of the operator to monitor, such as propeller revolutions in rpm number, exact pitch, etc. Visualising navigational limits and/or safe operational zones for the current situation can reduce the cognitive load on the operator. Navigational limits include information about route restrictions (Walther et al., 2014), ship characteristics, weather and sea conditions. Safe operational zones mean safe distance to i.e. other ships, objects, etc.

Operational constraints concerning ship capabilities can also be valuable information. According to Sheridan (2002), the operator must also understand the resource constraints, such as available fuel and time. Distance to a potential complete stop compared to the ship´s capability of stopping, manoeuvring characteristics, such as turning radius and max speed will be valuable information for the operator, especially concerning collision avoidance.

The CUS should navigate according to safe operating conditions, which involves taking into account the limits of ship´s manoeuvring capabilities in the current environment, including hydrometeorological parameters (weather), sea state, other ships, navigational obstructions, etc. This indicates that the operator does not need detailed information about this continuously, unless the situation requires details. According to Chopra (2020), the most important element impacting the calculation of optimal ship´s route is proper interpretation of navigational limits occurring in the navigational environment. Visualisation of navigational limits will therefore be important information for the operator during remote operation and control.

Information about the ship´s position is one of the most important when navigating (Appendix 1: Findings from interview). Different systems provide information about position, such as the radar, chart system, anemometer (i.e. wind speed and direction; cf. DNV GL RU-SHIP, 2019) and depth measuring system (i.e. water depth under the keel; cf. ibid).

> *"The radar provides information about both the ship position and the position of other boats, including boats without AIS (Automatic Identification System), and is therefore especially important in foggy conditions".* (Appendix 1: Findings from interview).

Implications for design

Perceiving detailed distances from ship to objects, distances to areas the ship should stay clear of and turning radius can be cognitively demanding. The reason is that these measures and calculations must be remembered and recalled from memory. A less demanding approach is to visualise areas for safe operational zones, both for the current situation, and projected safe routes. This can be done using a combination of all datasets that provide guidance for a safe area within the limits of the automations operational area and ship capabilities. The operator can then "scan" the screen and see if the ship is positioned within the safe zone or is closing in on the limits (comprehension of the situation). Calculations of the ship speed, heading, weather condition (wind, gust, temperature) and sea state (waves, currents, etc), along with the same data of other objects, can provide predictions (future state) to whether the ship might cross the safety zone and possibly end up on collision course or allisions (running of one ship upon another ship that is stationary).

Weather forecast, predicted sea state and visibility, along with the possibility to further investigate this information in more detail might be needed to analyse the situation if the ship is deviating from the optimal position within the safe zone.

Visualising the ships manouvring capabilities, such as the turning radius, and stopping capabilities can provide the operator with valuable information related to evaluating possible options in collision avoidance manoeuvring.

6.5 Uncertainties

Trust in the automated system is dependent on reliable information. The automated system should inform the operator about the reliability of the information provided. According to Ottesen (2014), the automated system must actively inform about uncertainties and the challenges the system has. Lack of information, such as when a detected ship goes missing, information becomes unavailable, or objects not identified, should be presented to support the operator in taking correct actions (ibid). The intention of oncoming vessels or objects without AIS and electronic charts where their route is entered, might not be known to the CUS even though they are detected. Therefore, the operator needs information about these detected objects to identify the vessel and monitor its movements before considering what to do. Data loss and sensor errors are other issues that should be communicated to the operator.

In general, as long as all information is available and confirmed, it should not be necessary with any continuous indication of the reliability of the information provided. Only when the information is unreliable, diverging from normal state, the operator should be informed. If the missing or unreliable information might lead to a near-miss or ship on collision course, an early warning will be needed. If the situation is developing to a critical situation, an alarm should ensure operator attention in time to deal with the situation. In such a situation, the automation should possibly also bring the vessel to a MRC and inform the operator about the change of CUS mode.

Some categories of forecasts typically have a span of reasonable certainty which can vary in time. Providing information about the span in which the information is reasonably certain can help the operator in understanding when focused attention is required. As an example, the certainty of projected weather information can vary in time depending on the projected weather stability. If the projected weather forecast indicates normal weather conditions within a certain timespan, the operator can attend to other tasks than focusing on weather effects on ship performance. Projected hazards related to weather, projected changes in visibility and estimated time for the weather to improve are possible candidates for being integrated with the weather forecast.

Implications for design

In general, only inform the operator of unreliable or missing information. However, provide projections of conditions into the near future and early warnings and alarms if the situation has the potential to escalate into a critical state.

6.6 Hazards

Examples of typical hazards include, for example, other ships, small unlit boats, floating logs, buoys, ice, hazardous waves and whales (DNV GL-CG-0264).

In order to supervise that navigation is performed in a safe way following COLREG, it will not be sufficient for the operator only to be informed of detected surrounding hazards. The information provided should be sufficient to analyse the complete navigational situation. This includes considering the hazards in relation to other factors that may affect the further navigation planning: Location, traffic in the surroundings, the risk of grounding, the weather conditions and sea states, and the own ships' operational mode and capabilities (DNV GL-CG-0264, 2018, p.58). To support a high level of SA about hazards, the operator needs information from radars, ECDIS, AIS, ARPA, instruments showing the ship´s condition and substitute information for human senses of hearing, sight and ship movement. See more about representing human senses in chapter 6.9.

Pietrzykowski & Hajduk (2019) raise the question on how the operator should be informed of a possible collision situation, whether the information should be a warning, alarm or instructions to take over the control. This probably depends on the CUS capabilities (LOA 2 or LOA 3) and the amount of time the operator is given to acquire SA before an act is required.

A CUS should be able to autonomously bring the vessel to a minimum risk condition (MRC) without the need for interventions from the operator (see chapter 2.3). However, the operator should be provided information about the situation. If the CUS cannot handle the situation, it should ask for operator interventions.

For operations at night, the operator should be provided night vision facilities to help detecting hazards. CCTV´s might not provide a sufficient picture to detect possible hazards at night. Thus, a picture combining information from e.g. radars, ECDIS, AIS, etc should include sufficient information, including night vision facilities, for the operator to perform condition analysis.

For the operator to fully understand a hazardous situation, both detail information, current status and projected status will be needed. Remote operators should be informed about hazards and developing conditions in time to analyse the situation, plan appropriate actions and intervene before a situation becomes critical. The visualisation of safe zones including warnings if the safe zone margin is closing up, should provide some barriers from facing hazardous situations related to navigation (see chapter 6.4). The support systems, such as ARPA (advanced anti-collision radars) and NDSS CA-GA (collision- and grounding avoidance), and the automation mode MRC should also provide a barrier.

Data fusion can be the solution for fully comprehending situations that might evolve to a critical state. This involves integrating data from many sources into one coherent presentation to assist in the overall understanding of a situation and help the operator grasp a large amount of information. (Duggan et al., 2004). The data fusion can be merging data from e.g. radars, sensors, AIS, INS, ECDICS and PTZ. As stated by Duggan et al. (2004) data fusion can reduce workload and enhance SA, unless too much fusion is used, which can reduce system transparency and SA. A virtual presentation through data fusion should ensure that relevant human perceptions are reflected (DNV GL-CG-0264, 2018). A holistic real-time navigational display based on data from sensors can provide vital information concerning monitoring and intervening in navigational tasks and remote control, including manoeuvring the ship to avoid hazards.

A possible solution could also be to provide simulated 3D images of out of window view, including information of navigational limits, safe zone and all relevant objects in the surrounding for the operator to get a more realistic understanding of the situation.

Implications for design

Information from the support systems related to projected hazards and critical conditions should be integrated into one meaningful presentation of the information. The ship should be visualised in the environmental context to support the understanding of what the data and cues perceived mean in relation to relevant goals.

6.7 Ship movements and stability

There are several factors that influence the stability of the ship, making it roll, heel, pitch or vibrate. The effects of wind and current on the vessel (DNV GL-CG-0246), as well as loading conditions are some factors. The mass distribution and loading condition can also influence the stability of the ship. The loading of the ship, and thus trim, draft, centre of gravity and metacentric height, may vary during the voyage in line with fuel consumption and tank filling levels (Walther et.al., 2014). These are factors that the CUS should handle in normal situations.

Concerning the representation of motion information, MUNIN has suggested a vessel gyroscope (ship motions gauge) as a visual feedback on roll, heave and vibrations (Porathe & Man, 2014; Porathe et al., 2014). This is based on an existing solution for aircraft.

Implications for design

Information about ship movements will probably not be needed continuously as long as aggregated status on ship health is available. This information should be easily available, e.g. on demand or related to the voyage phases in which this information is needed. The first level of information to be provided could be visualisation of the ship movements and stability deviations from normal and/or safe condition, affected by the environment (weather, sea, etc) and loading. An additional solution could be to provide simulated 3D images of out of window view. Details about loading condition might be needed for planning and diagnosis.

6.8 Remote control

The operator should be able to take control of the ship to avoid critical situations, collisions, and allisions that are outside the capability of the automatic system. In remote control, Dybvik et al. (2020) have found that the ship-board sensory information is important for the operator. Also, parameters such as rudder angle, rate of turn (ROT), etc. will be needed (Porathe & Man, 2013).

Navigation is conventionally based on a high degree of human observations, analysis and decisions. The main information being continually monitored is the information received by looking out the window (Appendix 1: Findings from interview). According to DNV GL-CG-0264 (2018), the ROC systems shall support a 360^{o} horizontal field of vision (FOV) to the horizon around the vessel. Whether the representation of the environment through FOV should be replaced by CCTV camera with live streaming of the environment or if data fusion without CCTV is sufficient, is not concluded by DNV GL (ibid).

Concerning remote control and detecting hazards at night, see chapter 6.6.

Implication for design

Remote control will require a high level of SA, including all relevant information and interaction devices needed to control the ship in the current and future environment explaining which support systems that are “healthy” and active.

6.9 How to represent sensory information

Remote operation separates the operator from the actual ship and might limit the operator’s understanding of a situation due to a lack of visual, auditory and kinetic information about the ship´s environment and state. In conventional shipping, the bridge crew uses several different senses to understand the situation, e.g.:

- Kinetic information: Feeling the sense of balance, waves, ship rolling and pitching, ship vibrations, ship performance when cargo is loaded; how the ship reacts to external and internal factors.
- Smell: e.g. from machine room, leakages or fire
- Sound: engine, waves slamming, wind howling, striking or colliding with objects, etc
- Visual: Weather, waves, currents, feel for speed (local conditions), feel of distances, day/night, binocular views

Man & Porathe (2014) states that tacit and gut feeling, the “ship sense” or bodily sense of the ship, is considered critical for ship handlers in ship manoeuvring. They have made an illustration of the ship handler´s decisions in manoeuvring, based on information from visual perceptions and bridge instruments (ibid, see Figure 12).

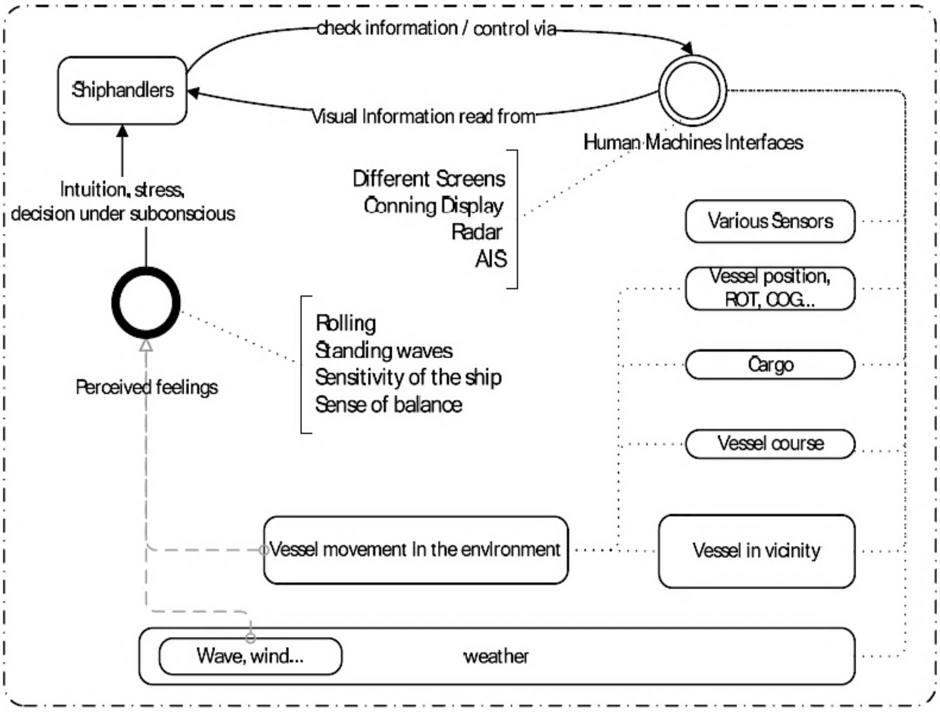

Figure 12. The ship handlers' decisions in ship manoeuvring is based on visual information from bridge instruments while perceiving feedback coming from the environment and the movement of the vessel (Man et al., 2014, Figure 1, p.6)

More than perceived feelings, as mentioned in Figure 12, is important to understand the ship´s movement and ship´s state when deciding proper actions to execute when operating a ship. Figure 13 is a suggested illustration for including more of the sensory information needed for deciding proper actions to execute when operating a ship.

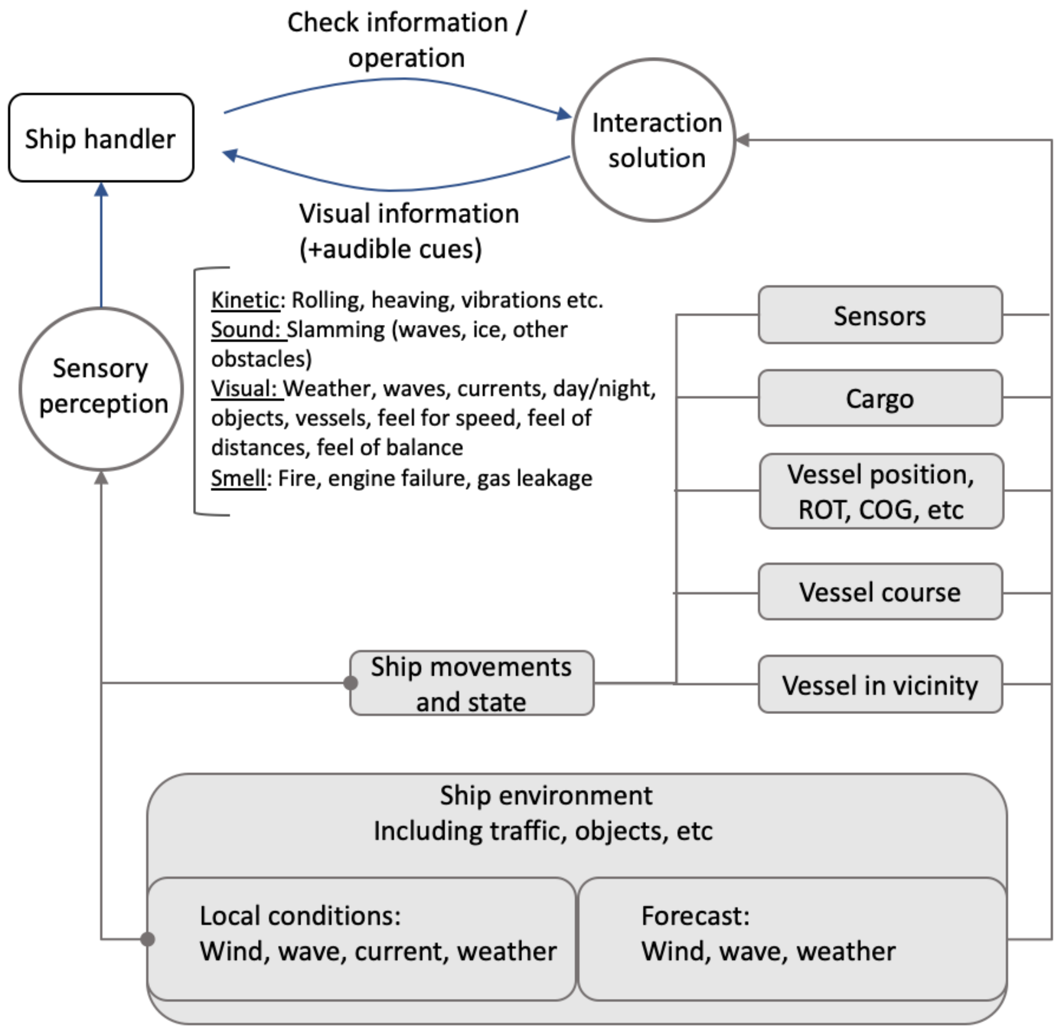

Figure 13. Deciding proper actions to execute when operating a ship, based on information from the interaction solutions (screens, thrusters, etc) and sensory perceptions (suggested changes to illustration by Man et al., 2014, Figure 1, p.6)

If the operators´ main task is to monitor the CUS and intervene if required, and only remotely control the CUS on rare occasions, to which degree will such bodily sense of the ship be essential for the operator? If the automation handles the control of ship behaviour according to environmental conditions, the operators might not need the ship-sense through a bodily sense. Then the question is: how to ensure that the operator perceives the ships movement and environmental conditions in a sufficient manner to supervise and remotely control the CUS?

Sensors, radars, ECDIS, AIS, instruments showing own vessel's condition and CCTV is assumed to compensate for the loss of human sensory perception (cf. DNV GL-CG-0264, 2018).

> *The complete situational awareness is obtained by merging the information provided by these aids with information the navigator obtains from own senses, such as sight, hearing and vessel movements. When navigation is performed from a remote location, the sensor data should be presented to the remote navigator in such a way that the objective to obtain an equivalent situational understanding is achieved.* (ibid, p.58)

Sensors can detect several types of information: e.g. gas leakage, local weather, temperature, waves and currents, ship motions, etc. This sensor data should be detected, classified and analysed by the CUS as a part of voyage planning and decisions. Sensor data should be available to the operator when required, including a presentation of the data in context: the effects on the ship performance, safety and voyage plan.

The out of window view from the bridge can be replaced by a digital representation in a panoramic view, through the use of cameras (CCTV), optionally with information overlay or using data fusion. On one side, the field of vision will no longer be limited by the bridge design/wheelhouse and operator anthropometric profile. Furthermore, the use of data fusion, including night vision features, will improve the operator´s possibility to perceive important information during low visibility conditions, such as fog, extreme rain and nighttime. On the other side, the question is: Will the representation of information in a ROC be adequate for replacing the operator's perception and analyses of wave patterns, sudden weather changes, the sound of the wind or engine and the ship vibrations? The quality of visual presentation might depend on the requirements during remote operation, and "*may range from a reading to continuous streaming of high definition images with zoom possibilities covering a wide sector*" (DNV GL-CG-0264, 2018, p.86). Another issue is that a large amount of data may be challenging for the communication link to be transferred from the CUS to the ROC. High definition CCTV may be challenging and consequently other systems suitable to get good situational awareness may be required (ibid).

Images, such as from CCTV, are often two-dimensional (2D). This means that estimates of depth and distances, which are achieved through a three-dimensional (3D) perception of the world. DNV GL-CG-0264 (2018) states that the lack of 3D perception of the world should be compensated through other means if 3D images cannot be achieved, such as by additional distance sensors and merging a graphical presentation of distance and depth into the image presentation.

Ottesen (2014, p.5) argues for using 3D in remote operation of ships: "*one can gain SA in a more natural and traditional way by developing an enhanced understanding of the 3D space surrounding the ship*". On the other hand, 3D presentation of "the world" should be considered carefully for daily operational tasks. It has been reported that some people experience visual fatigue with symptoms like eye strain, headache or nausea (Solimini, 2013).

Implication for design

Substitutes for the human senses are required for remote operation and control. They should be provided by sensor technology, CCTVs and radars. The presentation of the information should ensure that the total SA for the remote operator will be equivalent to, or better than, the information provided in a traditional local operation context.

6.10 Alarms

A proper alarm system and alarm philosophy is critical in operational contexts. A bad alarm management system and design can overload the operator´s cognitive capacity. This might be even more important in multi-ship operations if one operator is to supervise several ships simultaneously, with the possibility of concurrent alarm situations. A study of multi-unit operation, by Eitrheim et al. (2019) have found that the task execution at one unit may be interrupted by an incoming alarm at another unit. There is a potential risk that the operator forgets to continue the scheduled task at a later point of time (ibid). Providing support for operators in maintaining awareness in such a context can introduce design challenges.

The primary function of an alarm system is to direct the operator's attention towards conditions requiring timely assessment or action (EEMUA 191, 2007). The definition of an alarm, according to ANSI/ISA (2016) is that an alarm is "*Audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring a timely response"*.

The MUNIN project (Man et al., 2015) has found that the alarm management system is the most important information for an operator remotely supervising a ship. The alarms should trigger actions from the operators in case of automation failure onboard as well as keeping the operators in the loop to understand required decisions and actions.

Alarms related to technical issues are not handled by roles on the bridge in a traditional ship; they are handled by an engineer (Appendix 1: Findings from interview). The alarms cannot be confirmed and require no response from the bridge. Whether technical alarms and detailed information on technical faults should be presented to the operator or not depends on the operational model, and the operational model should also reflect the operators' limitations in cognitive workload : Should the operator monitor all ship statuses or only statuses related to navigation; i.e. should an engineer monitor technical statuses? However, they need information about the situation, and possible escalations, if this causes ship performance to be reduced.

The threshold of alarm systems onboard traditional ships might not be suitable for remote operation. Man et al. (2015) suggest that a three-colour based alarm system, as was tested in the MUNIN project, should be replaced by properties related to "tendencies" of events to support the operators SA.

Implications for design

Because of possible response and command latency related to remote operation, operators need information about tendencies of escalations and deviations from normal state to be able to monitor the situation closely and intervene in a timely manner if the automation should fail or is incapable of handling a situation. If the situation is close to its limits, of e.g. separation from other traffic, alarms should direct the operator's attention towards the situation in sufficient time for the operator to intervene.

7 Requirements to interaction solutions in multi-ship operation

Information and cognitive overload due to the plurality of ships and ship sensors is a challenge in multi-ship operation. Concept testing of multi-unit operation have found that there might be a risk of overloading the human operators´ cognitive capacity to handle all information, and work in such an operational environment (Porathe et.al., 2014).

7.1 Multi-ship operation overview

NUREG 0700 (U.S. NRC, 2002) and ISO 11064-5 (ISO, 2008) recommends providing for global situational awareness through an overview of the status of all the operator´s goals at all times. An overview display supports operation room personnel by bringing their attention to significant changes in conditions and presenting those that are important (ibid). SA can suffer when operators are focusing on particular information, such as e.g., one ship, leading to ignore other information (attentional tunnelling). An overview of the total goals for the operations (multi-ship operation) is therefore necessary.

An example of overview information is the timeline described in the MUNIN project, providing both a temporal overview and a detailed temporal view (Porathe & Man, 2014). This timeline presents quite many detailed information entities and might not provide a quick "at the glance" overview of the voyage situation. For the purpose of providing a quick overview of all voyages allocated to the operator, less information or more cognitively efficient visualisation might be needed.

Some aggregated overall status information per ship, as described in 6.1 could be possible candidates for a total overview of the multi-ship operation. Suggestions for information included in a multi-ship operation overview are:

- Overview of status per ship (aggregated information on ship health and mission management)
- Voyage phases and current phase, including indication of required monitoring level
- Timeline (ETD/ETA, ports, current time/current position of ship, prediction of possible conflicts, deviations from voyage plan)
- Information on conflicting events across voyage plans (Deviations related to one ship might interfere with the current or near future operation of the other ships allocated to the operator).

Implications for design

An overview of status on the total goals for the multi-ship operation can provide an overall understanding of the operators´ tasks and responsibilities. If this information is visible at all times, it might help the operator in spotting conditions requiring the operators´ attention.

7.2 Which ship?

When supervising multiple ships simultaneously, it is important that the interaction solution and presentation of information ensure that the operator does not accidentally monitor or intervene "the wrong ship" (cf. Ottesen, 2014).

Implications for design

Visualisation techniques to separate the different ships is necessary. Considerations concerning audible alarms to distinguish which ship has an alarm situation is also necessary, e.g. by direction (if the information layout allows) or by unique sounds.

7.3 Handover

An operator starting his shift should be provided information about the current situation of her/his tasks. This could either be conducted by having a handover at the ROWS, and/or providing information for self-briefing on workstations adjacent to the control room (cf. Lunde-Hanssen et al., 2015; Duestad & Hilstad, 2017).

The system should include a handover functionality for changing between autonomous execution and remotely controlled CUS to avoid the operators unintentionally intervening with the wrong ship. Also, a handover functionality for reallocation of the responsibility of a CUS between operators might be needed to enhance awareness of which operator is in command of a ship. Reallocation of responsibility between operators is mentioned as a hazard in DNV GL-CG-0264 (2018).

Implications for design

The interaction solution should support technical handover of responsibility (operator-operator, operator-CUS) and handover or self-brief for planning a shift and when tasks/ships are reallocated to another operator. Challenges related to handover are particularly relevant for phase-divided operation (see chapter 4.3).

8 Detailed information requirements related to SA levels

There are numerous information entities that are needed for the navigating task berth-to-berth, especially when the ship, in rare occasions, must be remotely controlled. This is unless the operator is only intended to bring the ship back to safe state and execute anchoring (close to shore) or ensuring that the ship keeps a fixed position (sea passage), and thereafter other functions will enter into force, e.g. by a crew entering the ship to handle the ship manually. Not all information entities are accounted for in this document. There are some entities mentioned in the tables in chapter 8.1 and 8.2 that are not discussed earlier in this document. These are specified with literature reference. The linking between information requirements and SA levels have been inspired by Endsley (2013).

8.1 Per ship

Table 3. The table is focused on "data", typically needed for SA level 1

"Data", typically needed for SA level 1	
Ship characteristics (Walther et al., 2014) Call sign Ship type Manoeuvring characteristics: turning radius, max speed Weight Height (Walther et al., 2014) Length over all, breadth, depth (Walther et al., 2014)	**Current weather state** Icing and ice Wind: Speed, direction, gust Visibility: Fog, rain, snow Lightning
Ship state and health Heading Position Speed (SOG and STW) Course over ground (COG) Distance to land Roll, heave, vibrations, hogging, slamming Turn rate Thrust setting Propulsion system (propeller rpm and pitch) Fuel quantity and consumption Ballast /loading conditions Ship stability: center of gravity and metacentric height (Walther et al., 2014) Sensor status information, if reduced capability (Rødseth et al., 2013) Water depth under the keel, DNV GL p.171 Anchored (MUNIN, Porathe & Man, 2014) Running light and signal light settings	**Current sea state** Waves: Wave height (significant), length, speed, direction (Porathe & Man, 2013) Current speed and direction (Walther et al., 2014) Swells height (significant), direction and period (Walther et al., 2014) Tide situation (DNV GL-CG-0264, 2018) Water temperature (Walther et al., 2014) Water depth

"Data", typically needed for SA level 1	
Voyage management Sailing constraints, traffic regulations, restrictions (water depth, area, height) (restrictions: Walther et al., 2014) Port instructions PTD, PTA, ETD, ETA/ETB Available tracks and routes (Walther et al., 2014) Waypoints (number, name position) (Porathe & Man, 2013) Nautical publications Legislative documents Voyage phases, current phase and required monitoring level per phase	**System functions** Ship data link (OK, reduced or loss of capacity) Automation mode (Autonomous execution, MRC or remotely controlled) Support systems on/off
Traffic and objects Vessels or other obstacles (moving or stagnant) in the vicinity: Position, speed, distance, ship call sign Underwater rocks, shipwrecks, navigation lights (e.g. vessels not under command) beacons (lighthouses, stakes, lightship, buoys), other moving objects such as ships and icebergs, life saving devices, signal flare, man overboard et Sound signals from other vessels Safety communication: MRCC and ships, EPIRBS, portable radio (if not handled by CUS) Out of window view	**Clearances** (IMO, 2011) Clearance of ship to entry/exit berth/port Clearance for bunker or other port operations.

Table 4. The table is focused on "comprehension of data", typically needed for SA level 2

"Comprehension of data", typically needed for SA level 2	
Ship state and health The effects of wind and current on the vessel (DNV GL-CG-0246). The effects of load and load placement on the vessel Drifting (when the ship should have been anchored) (MUNIN, Porathe & Man, 2014) Changes to technical safety Reduced capacity of propulsion system and engine Fuel sufficiency Corrections in heading, thrust and speed Deviations between current and desired: - heading, according to voyage plan - position - center of gravity	**Weather state** Confidence level in weather information Hazard level Potential for icing, low visibility and extreme weather conditions. Weather impact on ship performance, fuel, voyage plan, ETD/ETD, ship control (safety)
Voyage management Deviations between current and desired PTD/ETD and PTA/ETA Waypoint changes Nautical charts Passed line orientation and distance (Porathe & Man, 2013)	**Sea state** Confidence level in sea related information Hazard level Potential for ice, low visibility and extreme sea conditions. Potential for grounding (tide, water depth) Sea state impact on ship performance, fuel, voyage plan, ETD/ETD, ship control (safety)

“Comprehension of data”, typically needed for SA level 2	
Traffic and objects Current separation from other traffic (Walther et al., 2014) Vessels or other moving objects on collision course; estimated time for collision, CPA and TCPA. Trajectory of other ships and moving objects relative to ones´ own ship. Estimated time for collision with land or other objects, CPA and TCPA	**Equipment malfunctions** Impact of equipment malfunctions on ship safety and safety of ship operations

Table 5. The table is focused on “projection into the near future”, typically needed for SA level 3

“Projection into the near future”, typically needed for SA level 3	
Ship state and health Estimated fuel reserve, relative to remaining distance, weather and sea conditions Projected trajectory (according to heading, positions, speed, weather and sea state)	**Weather state** Weather forecast, trends: Projected hazard Projected changes in visibility Estimated time for weather to improve Projected safe routes Projected impact of changes to maneuvering, related to weather, on safety of voyage and changes to voyage plan
Traffic Projected trajectory of other vessels or moving objects (according to heading, positions, speed, weather and sea state) Projected separation between own ship and other vessels or moving objects	**Sea state** Sea state forecast, trends: Projected hazard Projected changes in visibility Estimated time for sea to improve Projected safe routes Projected impact of changes to maneuvering, related to sea state, on safety of voyage and changes to voyage plan

8.2 In multi-operation

Table 6. The table is divided into focus on: "Data", typically needed for SA level 1; "Comprehension of data", typically needed for SA level 2; and "Projection into the near future", typically needed for SA level 3

"Data", typically needed for SA level 1	"Comprehension of data", typically needed for SA level 2
Ship Distinct visual indication of each ship allocated to an operator Visualisation/information on ship handed over and accepted when reallocating ships between operators (giver and receiver) ETD, ETA Current position Time (current) Ports (from – to) Voyage phases, current phase and indication of required monitoring level per phase	**Ship** Aggregated information on ship health Deviations from voyage plan
"Projection into the near future", typically needed for SA level 3	
Ship Prediction of possible conflicts	**All ships allocated to the operator** Information on conflicting events across voyage plans. Deviations related to one ship might interfere with the current or near future operation of the other ships allocated to the operator

9 Summary

This report constitutes one of the first deliveries within the LOAS NFR-project, considering the opportunities afforded and expected by new technology to co-locate operator expertise in one control room onshore and assign more than one autonomous ship to each operator; i.e. multi-ship operation. The LOAS project includes several work packages, of which this report is a part of work package H2. The H2 work package involves identifying the information needed for effective and safe monitoring and response from the operators.

The concept of multi-ship operation from onshore raises new challenges to ensure safe and efficient operation. From this report, the LOAS project has initiated the process of conducting a systematic, user-centred and holistic approach to technology development for safe and efficient monitoring and operation of autonomous ships from a ROC. The main purpose of this report is to provide a more solid background for designing feasible interaction solutions for safe handling of autonomous ships from shore. This report should be applied in conjunction with Kaarstad & Braseth (2020).

This study focuses on homogenous multi-ship operation (i.e. all systems, routes and ships are similar) and the navigation of autonomous ships during crossing operations. The use case defined for autonomous ships in the LOAS project is unmanned autonomous cargo ships (CUS). The CUS´s are equipped for autonomous berth-to-berth operation and after approval of the assignment the operators normally only monitor and supervise the transit.

Currently, there are no guidelines for designing interaction solutions for autonomous ship operation or multi-ship operation. Neither are there any guidelines for operational models; how to work and allocate tasks in multi-ship operations. One challenge in this new concept is to keep the operator "in-the-loop" to ensure safe operation. More information becomes available when automation and sensor technology is improved. This can cause "information overload" on the human. Thus, an appropriate level of information, automation actions and alarms must be provided. This is even more crucial in a multi-operational environment, with the potential of multiplying the information load.

The overall approach of the LOAS project is based on a structured and user-centred process (ISO 11064-1, 2000 and ISO 9241-210, 2010), of which this report addresses the "clarifying and analysis phase"; defining the scope and ROC operation room goals, as well as providing input concerning tasks, role(s) and operational models to the iterative design process.

This report has focused on the information required for effective and safe remote multi-ship operation of continuously unmanned ships (CUS) during navigation. In light of our focus, we asked four questions: 1. Which operational model is suitable for remote multi-ship operation? 2. What information requires response from operators? 3. What information is needed for operating the CUS? and 4. What information is needed for top-down strategic planning? The approach for addressing these research questions as been by exploring operational models, theoretical concepts and relevant literature. Furthermore, we have conducted an interview of a captain of a passenger ferry equipped with autonomous berth-to-berth operation.

Before addressing the research questions, we discussed several definitions regarding autonomous ships: The definitions were needed to be able to discuss the operational models, such as autonomous levels, CUS modes and operator interventions. This report has focused on ships with LOA 2 and 3, which require a human supervisor. The human interventions were defined as "remote operation" and "remote control", of which the first involves monitoring and no direct control actions, and the second means that the operator takes control of the ship. The ship modes were defined as "autonomous execution", "MRC" and "remotely controlled", respectively.

Thereafter, we explored the concept of supervision, followed by Situational Awareness (SA), and the link between supervision and SA. Definition of SA levels, supervisory control and the relation between SA and monitoring levels in LOA 2 and LOA 3 has been used as the approach to assess information needs when supervising from a ROC. Furthermore, we suggested four operational models, describing how to conduct multi-ship operation and the operator´s and CUS´s role and function. These models were discussed in relation to the monitoring levels. Each of these models will require unique considerations related to what information should be visible continuously or occasionally.

Summary of main findings

Sufficient SA is not only linked to providing the required information. The visualisation and prioritisation of information is a crucial part of the SA, especially in a multi-ship operation, to ensure proper cognitive demands and workload. A basis for assessing how to organise the information and the number of screens needed per ROWS are sketched through the discussions on operational models, SA and monitoring levels.

To understand the information requirements, we collected a set of tasks to be performed by either the CUS or the operator, based on literature review. From this, including findings from literature, requirements to interaction solutions and information were analysed in the light of SA. A detailed description of information requirements has been made (see chapter 8).

Multi-ship operation will require a global situational awareness through a constantly displayed overview of the status of all the operator´s goals. This includes aggregated status information on CUS´s, a timeline visualising the voyage and information related to conflicting events across voyage plans.

During remote operation, the information needed per CUS is depending on the situation. A group of overall CUS performance concerning mission management and ship health, including projection of future status might be needed to comprehend the overall situation related to one CUS. During voyage phases requiring both continuous and occasional monitoring, we suggest visualising areas for safe operational zones and navigational limits for the current situation, and projected safe routes. More detailed information should be easily available. The operator might need to act on changes in voyage plans, system failure and alarms, and the CUS must inform the operator about these events.

Remote control will require a high level of SA, including all relevant information and interaction devices needed to control the ship in the current and future environment explaining which support systems that are "healthy" and active.

This document provides an input to the further process of developing and testing interaction solutions that ensures a safe and efficient operation of the autonomous ships of the future from a land-based control centre.

There are many relevant questions that needs to be explored with regard to multi-ship operation, which will also affect the interaction solutions. Some of these are:

- What is the appropriate operational model for multi-ship operation from onshore?
- What support functions are needed in the control room or nearby?
- How to reallocate tasks/ships when workload is too high?
- How many ships are possible/appropriate for one operator to handle (normal situation/high workload situation)?
- What tasks are/are not suitable for an operator located onshore?
- What is the appropriate allocation of tasks between automation and operator (for an operator to handle N ships)?
- How should the interaction solution be designed for an operator to be able to handle N ships?
- Will the representation of human sensory information in a ROC be adequate for replacing the operator's perception and analyses of e.g. wave patterns, sudden weather changes, the sound of the wind or engine and the ship vibrations?
- What competence, skills and training are necessary for an operator to be able to supervise one or more autonomous ships?

Some of these questions will be relevant for the LOAS work package H3 and H4 to explore. The next work in the LOAS project (H3) will be to design and iteratively evaluate interaction solutions for a ROC that ensures safe and effective monitoring of one or more ships.

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Appendix 1: Findings from interview

During the initial phase of the LOAS project, the project team interviewed a captain of a passenger ferry with short-sea crossings. The ferry is equipped with autonomous berth-to-berth operation. During our visit, the automatic berthing function was not used due to lack of training and passengers onboard.

The autonomous berth-to-berth operation includes predefined routes and barriers that must be confirmed by the operator before violating them. When approaching the shore, the operator must confirm that the automatic berthing function shall be used. The operator can immediately take control of the ship by e.g. grab the thruster with some force.

Information

The most important information for this captain is to know the position of the ferry. Different systems help him by providing the information, such as the radar, chart system, anemometer (i.e. wind speed and direction; cf. DNV GL RU-SHIP, 2019), depth measuring system (i.e. water depth under the keel; cf. ibid). "*The radar provides information about both the ship position and the position of other boats, including boats without AIS (Automatic Identification System), and is therefore especially important in foggy conditions.*"

The captain included the windows as an important source of information, providing a 210^{o} visual field. When observing the captain´s actions during manual unberthing operations, mainly the windows are used as information. The weather conditions that day was good. When approaching shore, a new role appears on the bridge, using binoculars to get a closer view of a possible situation close to the berth. They had been told that a small boat had been observed close to the berthing area.

The main focus of the captain is to have control over the ship´s position. Other roles take care of the technical tasks. The captain can trim, control ballast, etc.

The alarm system in the engine room is duplicated with a slave system on the bridge. The technical alarms cannot be acknowledged from the bridge system. Actions related to technical alarms are handled by engineers in the engine room. The captain needs the information about the events causing the alarms, however he has no actions related to these alarms.

Trust in automation

At the point of the interview, the captain had more trust in people than fully automated ships. His argument is that the operation is complex, and information such as weather, wind and currents are more easily discovered with "the naked eye". He has also experienced situations where the automation has fallen short and human intervention was needed. The automation must be able to take this into account such as wind causing swells in the sea to ensure that it does not become unsustainable for passengers and those working on board. The captain is also uncertain whether the automation will handle a situation with 2 m wave heights and 10 m/s wind (significant wind). He also believes that as long as the automation works, people will gain more confidence in the system.

When questioned, the captain confirms that the ferry could be operated remotely from shore as long as all needed information is provided ("*as long as you see everything you need to see*").

Competence

You have to drive the ferry once in a while to maintain competence (onboard experience). If you have driven the ferry for many years, "*it is in your fingers*". Less experienced operators will need to drive the ferry more often. He believes that the future operators who come straight from school and have never learned to drive themselves will struggle a bit. *“You have to have quantity training and driving yourself every 10 rides is not quantity training”.*

Appendix 2: Operator tasks in traditional ships

The tasks when monitoring from a traditional ship bridge according to DNV GL RU-SHIP (2019):

Monitoring tasks

Determine and plot the ship's position, course, track and speed made good	Adjusting the voyage plan
Effect internal and external communication	Monitor and analyse the traffic situation
Monitor time, heading, speed, rudder angle, propeller revolutions and propeller pitch (when applicable)	Decide on collision avoidance manoeuvres
Monitor position, COG, SOG and “track made good” (past positions) against the voyage plan	Cooperation with personnel at the navigating and manoeuvring workstation

The tasks when navigating and manoeuvring from a traditional ship bridge are described by DNV GL RU-SHIP (2019):

Navigating and manoeuvring tasks

Monitor the traffic by sight and hearing as well as by available means	Monitor position, COG, SOG and track made good (past positions) against the voyage plan
Analyse the traffic situation	Adjusting the voyage plan
Manage AIS information and messages	Acknowledge all navigational alarms
Decide on collision avoidance manoeuvres	Monitor all alarm conditions on the bridge
Change course	Cooperation with personnel at the monitoring workstation
Change speed	Monitor the performance and status of the equipment and sensors of the grounding avoidance system
Change operational steering mode	Monitor speed over ground in both longitudinal and transversal directions
Effect internal and external communication	Operate whistle and manoeuvring light
Operate auxiliary manoeuvring devices	
Monitor time, heading, speed, propeller revolutions, thrust indicator, if the ship is equipped with thrusters, pitch indicator, if the ship is equipped with pitch propeller, rudder angle and rate of turn	

At a traditional bridge there is a separate role being responsible for conning tasks. These tasks might also be relevant for the automation system and/or ROC operators.

Conning tasks related to navigation and manoeuvring:

Navigation and manoeuvring, conning tasks

Observe all relevant external and internal information for determination and maintenance of safe course and speed of the ship in narrow waters and harbour areas and during canal passages.	Give sound signals
Monitor surrounding traffic and conduct pilotage and direct the ship’s heading and speed in close cooperation with the attending bridge team	Effect external communication (radio)
	Monitor heading, rudder angle, rate-of-turn, propeller revolutions, propeller pitch (if controllable), status of thrusters (if provided) and speed
	Operate whistle and manoeuvring light

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Identification of information requirements in ROC operations room

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