Operating autonomous ships remotely from land-based operation centers: The current state-of-the-art

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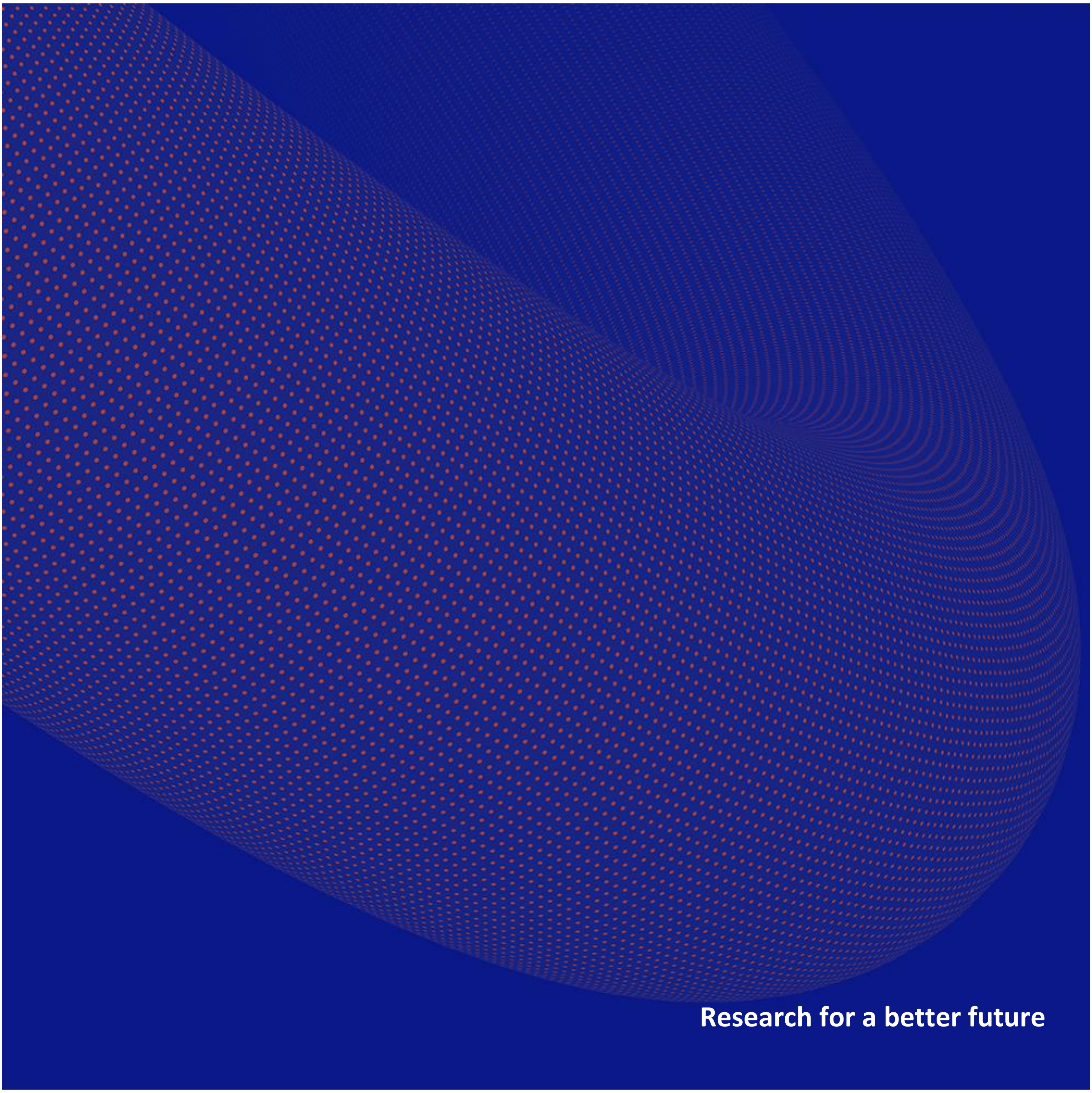

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Title:
Operating autonomous ships remotely from land-based operation centers:

The current state-of-the-art

Summary: In the maritime domain, there are several research and development projects regarding remotely operated autonomous ships. One initiative is the current innovation project: Land-based Operation of Autonomous Ships (LOAS), financed by the Research Council of Norway. This project started up the last quarter of 2019 and will be completed in 2023. The project is performed by Kongsberg Maritime, IFE and NTNU. The objectives are to develop and test interaction solutions for a Remote Operation Center (ROC) that ensures safe and effective monitoring of one or more ships that are wholly or partly unmanned.

This report contributes to the first work package, which is to gain an overview of the current state-of-the-art regarding remote operation of autonomous ships. Based on this, the report asks the following questions: 1) How is operation of autonomous ships incorporated into governing documents? 2) What are important theoretical concepts related to the human operator in remote operation centers? 3) What are the recent and ongoing research and development cases in the maritime domain relevant for autonomous ships? and 4) What are experiences with remote operation from other domains? These questions are answered through a broad scoped literature review, visiting more than 100 references.

The main findings are that it is a need to update and adjust current international regulations to include autonomous ship as a mode of operation. Furthermore, concepts such as situation awareness, out-of-the-loop, cognitive workload, fatigue, boredom and trust are important to take into consideration when developing ROCs. The report presents recent and ongoing national and international maritime autonomy initiatives, and summarize main lessons learned with automation and remote operation from other domains. The next step in the LOAS project is to document, in a more detailed way, the information needed for how to operate autonomous ships from a ROC.

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Keywords

Maritime, Autonomous Ships, Shore Control Centre, Remote Operation Centre, State Of the Art Report (SOAR)

Abbreviations

AAWA	Advanced Autonomous Waterborne Applications Initiative
ACC	Adaptive Cruise Control
CLL	International Convention on Load Lines
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
DH/DB	Double Hull/ Double Bottom
DMA	Danish Maritime Authority
EBAO	Effects Based Approach to Operations
EC	European Commission
FAA	Federal Aviation Administration
HAD	Highly Automated Driving
HF	Human Factors
HFE	Human Factors Engineering
IFE	Institutt for Energiteknikk (Institute For Energy Technology)
IGS	Inert Gas System
ISM	The International Management Code for the Safe Operations of Ships and for Pollution Prevention
IMO	The International Maritime Organisation
INMARSAT	International Convention of the Maritime Satellite Organization
KM	Kongsberg Maritime
LOAS	Land based Operation of Autonomous Ships
MSC	Maritime Safety Committee
MARPOL	International Convention for the Prevention of Pollution from Ships
MASS	Maritime Autonomous Surface Ships
MCC	Mission Control Centre
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
NTNU	Norges teknisk-naturvitenskapelige universitet (Norwegian University of Science and Technology)
OOTL	Out-Of-The-Loop
RCN	Research Council of Norway
ROC	Remote Operation Centre
ROV	Remotely Operated Underwater Vehicles
SA	Situation Awareness
SAR	International Convention on Maritime Search and Rescue
SCC	Shore Control Centre
SOAR	State Of the Art Report
SOLAS	The Safety of Life At Sea convention
STCW	The International Convention of Standards of Training, Certification and Watchkeeping for Seafarers
UAV	Unmanned Aerial Vehicles
UNCLOS	United Nations Convention on the Law of the Sea
VTS	Vessel Traffic Service
WL	Workload

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1 Introduction

1.1 Introduction of autonomy in the maritime domain

Over the past few years, the technology related to autonomous and remote-controlled ships has evolved, and several industrial projects are currently piloting the implementation of such technologies. Implementation of more automated systems in the maritime domain has resulted in a shift from local control of machines and systems in the past, to bridge based operations and more automated systems. Recently, there has also been technological development that can enable autonomy. It is therefore expected that future ships can be monitored and operated from a Shore Control Centre (SCC) or Remote Operation Centre (ROC). The expectations from the authorities and the society are that if such technologies are to be implemented, they should not affect the safety of people, assets, the environment and other aspects negatively.

The current debate on automation is not new. More than 400 years ago, knitting machines were built, and the industrial revolution led to the introduction of machines in the factories from 1760 onwards. About 50 years ago, digital computers were introduced, and today we are taking advantage of robots, artificial intelligence, and autonomous vehicles. Sheridan explained remote (or tele-) operation, already in 1992, as operating an object from a distant location, from which there is no direct human sensory contact to the machine (Sheridan, 1992; Sheridan, 1993).

To exploit the potential of automation and remote operation, attention to the human role in working with autonomous systems is fundamental (Lee, 2008). Research has demonstrated that automation alters tasks in ways which pose different demands upon the human operator (Parasuraman, Sheridan, & Wickens, 2000). Automation may support people to achieve tasks that otherwise would not be possible, but only if the design of the automation considers the characteristic of human and automation combined (Vagia, Transeth, & Fjerdingen, 2016).

A move towards partly or fully autonomous operations, will raise several questions. Can operators in the ROC monitor one or more ships at the same time? When should operators in the ROC take manual control? A remote operational concept will lead to new challenges related to the interaction between technology, people and organization. It is therefore a need to explore aspects on how to ensure sufficient situational understanding, trust, control and acceptable workload for ROC operators in different operating situations.

1.2 Purpose and scope of the research and innovation project, LOAS

Based on the above, a research and innovation project was established: Land based Operation of Autonomous Ships (LOAS). The project group consists of Kongsberg Maritime (KM), Institute for Energy technology (IFE) and the Norwegian University of Science and Technology (Norges teknisk-naturvitenskapelige universitet -NTNU). The LOAS project is financed by the Research Council of Norway (RCN). The purpose of the LOAS project is to develop both knowledge and interaction solutions that support monitoring and operation of autonomous ships from land-based or remote operation centers. The project will seek to answer how interaction solutions should be set up to support safe and cost-efficient operation of autonomous ships. There are four main work packages in the LOAS project: 1) Identify "State of the Art" relevant for remote operation of autonomous ships; 2) Map necessary information flow between ships and the ROC[1]; 3) Iterative development of information presentation solutions that support operator monitoring in a ROC; and 4) Final evaluation of the information presentation solutions developed for ROC. The LOAS project adopts a holistic approach

[1] See Lunde-Hanssen, 2020

based on a human-technology-organisation perspective, as well as a research-based and user-centered design- and evaluation methodology. The objective is to support a high degree of functionality of the final interaction solutions across different operational conditions.

1.3 The purpose and scope of this document

This State-of-the-art-report (SOAR) is part of the first work package of LOAS where we seek to document knowledge relevant for design and operation of future ROCs. The report will be used as a basis for the next phases in the project where we will identify, and document information needs for effective and safe monitoring and operation from a ROC and develop and test interaction solutions for ROCs.

In this SOAR, we will approach human challenges and opportunities associated with remote operations from a land-based operation center by reviewing relevant literature. The target readers of this report are primarily members of the project group. However, information in the report is assumed to be useful also for individuals who are involved in research and development projects related to autonomous ships, as well as those involved in standardization and regulations. The report covers both regulatory characteristics and theoretical aspects and experiences from the maritime and other domains. The chapters in the report are written in a way which makes It is possible to read them separately. The report does not provide final answers and solutions but is meant as background for further work specifically for the LOAS project. Also, although the technical security of a land-based solution (sensor reliability, cyber security, etc.) is important, it is outside the main scope of this project, and will thus only be briefly touched upon.

1.4 Approach and research questions

The general objective of LOAS is, through a comprehensive approach, develop and test interaction solutions for a ROC that support operators to monitor one or more vessels that are wholly or partially unmanned. In order to meet this objective, it is important to explore challenges related to the interaction between technology, organizational and human factors. Based on this, the report asks the following top-down oriented questions:

1. How is operation of autonomous ships incorporated into governing documents?
2. What are important theoretical concepts related to the human operator in ROCs?
3. What are the recent and ongoing research and development cases in the maritime domain relevant for autonomous ships?
4. What are experiences with remote operation from other domains?

This SOAR report answers the research questions chronologically by visiting relevant literature such as research publications and reports[2]. Chapter two presents both international and national recommendations regarding autonomous shipping. In chapter three, we present theoretical concepts and empirical findings regarding human and organizational factors that is considered to be important for remotely monitoring partly or fully autonomous ships. Chapter four gives a short overview of ongoing and recent major initiatives in the maritime domain related to humans and automation. Chapter five gives an overview of findings regarding automation and autonomy from other industrial domains. In Chapter seven we summarise the report and give direction for further work in the LOAS project.

[2] It is beyond the scope of this work package to cover a complete review of all relevant literature. We have, based on relevant literature, tried to establish a picture of the situation.

2 Regulations for autonomous ships

In this chapter we will take a look at the maritime regulatory framework, and highlight areas that are relevant for autonomous ships, and thus address the first research question: How is operation of autonomous ships incorporated into governing documents?

2.1 Degrees of autonomy and positioning autonomy levels in the LOAS project

The international maritime organisation (IMO) is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. IMO has identified four levels of autonomy (IMO: Autonomous shipping, 2020): [3]

1. *"Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.*
2. *Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.*
3. *Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location with no seafarers on board.*
4. *Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself."*

In the current project, we are investigating solutions for an operator to safely monitor, and, if necessary, operate one or several autonomous ships from a remote location. Autonomy level one and two assume seafarers on board, and in such situations, the current national regulation might be relevant. However, level three and four will be more relevant for the LOAS project, as remote monitoring and operation of partly or fully autonomous ships is expected in future operations. It should be noted that this represents a different way of ship operation than described in current laws and regulations. In this chapter, we will therefore investigate which regulations will be challenging to apply within the operational concept of level three and four. That is where the ship is monitored, and if necessary, controlled and operated from another location, with no seafarers on board.

2.2 The general maritime regulatory framework

The international maritime regulatory framework consists of several legal instruments. No uniform sea-safety, security or environmental protection rules for international shipping existed before the creation of IMO in 1948 under the auspices of the United Nations (Churchill & Lowe, 1992). The most noticeable legal instruments are listed below (Komianos, 2018, p. 340):

- "The Safety of Life At Sea convention (SOLAS)
- The International Management Code for the Safe Operations of Ships and for Pollution Prevention (ISM code)[4]
- The International Convention of Standards of Training, Certification and Watchkeeping for Seafarers (STCW)

[3] The Norwegian Forum for Autonomous Ships (NFAS) has suggested a definition for Autonomous Merchant Ships that will be referred to and applied in later work packages in LOAS (nfas.autonomous-ships.org)
4 The purpose of the ISM Code is to provide an international standard for the safe management and operation of ships and for pollution prevention.

- Convention on the International Regulations for Preventing Collisions at Sea (COLREG)
- The International Convention for the Prevention of Pollution from Ships (MARPOL)
- The International Convention on Maritime Search and Rescue (SAR)"

Other regulatory and technology factors that contribute to strengthen the safety culture of international shipping include (Komianos, 2018, p. 340):

- "The International Convention of the Maritime Satellite Organization (INMARSAT).
- The International Convention for Safe Containers.
- The Double Hull/ Double Bottom (DH/DB) regulation, which plays an important role in oil spill prevention and the Inert Gas System (IGS) which operates in such a way that it renders the atmosphere of the cargo tanks non-flammable and maintains incombustibility."

Safety of Life at Sea (SOLAS) is the most recognized international convention. This regulation applies to vessels that sail in international seas. The IMO Convention on the International Regulations for Preventing Collisions at Sea (COLREG) applies to all vessels, regardless of domestic or international voyages (DNVGL-CG-0264). Vessels engaged in domestic voyages within the jurisdiction of one coastal state only, are not subject to the international regulations set by IMO.

2.3 Guidelines for MASS trials

According to the Strategic plan 2018-2020 (IMO: Strategic plan, 2017), one of IMOs priorities is to "Integrate new and advancing technologies in the regulatory framework" (IMO: Strategic plan, 2017, p.6). Currently, IMO is assessing how existing instruments apply to ships with varying degrees of automation. The purpose is to investigate the benefits from new technologies concerning safety, security, and the impact on environment, economy and personnel.

Furthermore, in 2017, IMO included autonomous surface ships on the agenda to take a proactive role. At this point, it was decided to perform a scoping exercise to determine to which degree safety, security and environmentally sound operation of maritime autonomous surface ships (MASS), is addressed through the IMO instruments (IMO: Strategic plan, 2017; Ringbom, 2019).

In June 2019, the Maritime Safety Committee (MSC) approved interim guidelines providing guidance to coastal States, flag States and port States, as well as shipowners, operators and other parties in the conduct of MASS trials (IMO: MASS trials (2019). The guideline lists ten key elements to be included in trials to guide authorities and stakeholders in planning and authorizing MASS-related systems and infrastructure (Risk management; Compliance with mandatory instruments; Manning and qualification of personnel; The human element; Infrastructure; Trial awareness; Communication and data exchange; Reporting requirements and information sharing; Scope and objective for each individual trial; Cyber risk management).

When risks are identified in the trials, measures to reduce the risks should be suggested and implemented. The exercise is planned to be completed in 2020 (IMO Autonomous shipping). However, one should be aware that such measures, if not carefully planned, can create additional challenges if solutions to individual problems are implemented early and risk is not addressed from a holistic perspective. In the first phase, twelve IMO conventions under MSC will be reviewed to assess the regulatory challenge that various degrees of autonomous shipping pose for each provision in the selected instrument. In a second phase, potential regulatory solutions to address the challenges identified will be analysed (Ringbom, 2019). Whether this work will eventually result in new requirements, or amendments to the existing ones, is to be decided based on the results of the trials (ibid.).

A safety framework will have to be established by IMO before the benefits of the technologies with respect to reduced or no manning on board can be achieved for international shipping (DNVGL-CG-0264). In the meantime, there is an opening in the regulatory framework allowing national or regional regulatory bodies to support the introduction of novel technologies and autonomous ships within their own territorial waters. Furthermore, the international convention of Standards of Training, Certification and Watchkeeping for Seafarers (STCW) opens for flag administrations to give exceptions from the regulations for ships engaged in particular trials. The trials need to be conducted in accordance with guidelines adopted by IMO. The flag administrations do not have authority to authorize such trials and permanent operations for a ship until IMO has adopted related guidelines (ibid.).

2.4 Adapting regulations for autonomous ships

There have been several efforts to analyse current international regulation to see how it relates to a possible future situation with autonomous ships. Komianos (2018), The Danish Maritime Authority (2017), and Ringbom (2019) are examples of such efforts. The areas that stand out as challenging, are regulations for jurisdictional issues, preventing collisions at sea, assist persons in distress at sea, protection of the maritime environment, and cyber-security issues. In the following we will present how these identified areas may be challenging in the current regulations, and what it may take in order to approve autonomous or remote operated ships in future regulations.

2.5 Norwegian adaptation of the maritime regulatory framework -DNVGL

Norway is one of the countries that is currently exploring new technologies for operation of autonomous ships. DNV-GL has developed a class guideline to provide a framework[5]. The Norwegian maritime authority (NMA) has not delegated its authority for granting sailing permission for unmanned ships to class societies. All unmanned vessels must be evaluated by NMA and obtain its permission to sail from them (Norwegian waters)[6]. The objective of the DNV-GL guideline is to ensure a safety level equivalent to or better than conventional vessel operations for novel concepts and technologies in the area of autonomous and/or remotely controlled vessels (DNVGL-CG-0264). A main principle in DNV-GL´s guideline, is that an equivalent or improved level of safety shall be obtained for: the on-board crew; the public; the assets and the environment.

The DNVGL-CG-0264 guideline was developed to support actors in the industry and the regulatory bodies in documenting and assuring a safe implementation. DNV-GL states that due to the immature nature of the field, it is currently not possible or desirable to provide detailed rules for all areas and combinations of concepts. Therefore, the guideline focuses on ensuring that a risk-based process is followed and supported by functional and detailed technical guidance where possible. The guideline is planned to be further developed, as more experience is gained from ongoing research-, new-builds- and retrofitting projects.

The guideline covers a functional approach and lists a set of design principles in design of autonomous or remotely operated vessels (DNVGL-CG-0264, p.21, further described here: p.17-23; 83-91): maintain a safe state, maintain normal operation, include redundancy and alternative control, include independent barriers, design self-contained capabilities on board, and include self-diagnostics and

[5] Other countries have other class societies which also provide guidelines, such as Burau Veritas (with Guidelines for Autonomous Shipping) and Lloyds Register (with LR code for Unmanned Marie Systems)

[6] Since regulations are under development NMA has used IOMs "MSC.1/Circ.1604 Interim guidelines for mass trials" and "MSC.1/Circ.1455 Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments" as guidance

supervision. The guideline further covers the qualification and approval process (ibid., p.23-50), including the concept qualification, approval of conventional technology and the technology qualification process. The guideline does also provide guidance to the design and arrangements of systems supporting autonomous and remote operation of vessels. The objective is to ensure a level of safety or navigation that is equivalent or better compared to a conventional vessel, where navigation is performed by navigators on board (ibid., p.50-67). The design guidance also covers vessel engineering functions (ibid., p.67-83). With regard to organizing the work within the ROC, the guideline specifies that "*Manning is not within the scope of class. This guideline does not provide any guidance with respect to number of personnel or competence in the remote control centre, even if these aspects should be analyzed and documented as a part of the concept qualification process*" (ibid., p.83). Overall guidance related to the functions in ROC is based on personnel having roles and responsibilities in accordance with the STCW code and that a *single vessel* is being remotely operated from a *single control center*. No specific guidance is provided related to organizing a ROC team. The guideline recommends IMO MSC/Circ.982 as a basis for the design and layout of remote workstations.

2.6 Jurisdictional concerns

Applied unmanned systems can be found in other transport areas such as air-traffic, trains and autonomous cars. However, a distinct challenge applies in the maritime sector, namely the lack of autonomous ships´ coverage and inclusion in relevant safety, security and environmental protection conventions and regulations (Komianos, 2018). The lack of regulation means lack of classification certificates. The result is that the ships cannot be insured and allowed to sail. Ringbom (2019) stress that legal issues, challenges and possible solutions related to autonomous shipping will vary depending on degree of automation, manning levels and whether or not there will be crew on board. Ringbom (ibid.) further notes that accepting autonomy legally will be different for different functions. Completely autonomous operations, for example, for unloading or mooring, are easier to accept than bridging operations that are highly regulated and involve obvious risks to third parties and to maritime safety. A ship may have an autonomous navigation system in place to avoid close contact with other ships, but manual intervention will still be required to handle near-misses or emergency situations at sea (Ringbom, 2019).

The United Nations Convention on the Law of the Sea (UNCLOS), is accepted by 169 states. International shipping regulation stipulates principles of states' jurisdiction over ships as a flag State, a coastal State or a port State as well as states' territorial jurisdiction over the sea. Jurisdiction entails the competence to regulate and enforce (Danish Maritime Authority, 2017). A ship with the Norwegian flag is subject to Norwegian jurisdiction and is considered Norwegian territory. The competence of the flag State follows the ship, irrespective of where the ship is located geographically, whereas the jurisdiction of coastal States and port States follows the geographical location of the state (ibid.).

The exercise of authority (such as maritime surveillance, customs authority, maritime authority and court authority) vis-à-vis autonomous ships gives rise to challenges in connection with unmanned ships. According to current regulation, the master is the shipowner's and the ship's representative vis-à-vis the authorities and can receive guidance about navigational issues and orders on course changes, stopping, detention (including arrest) and access to the ship. Furthermore, the master is the representative vis-à-vis the authorities in relation to the presentation of certificates and other documents on board as well as any other communication purpose (Danish Maritime Authority, 2017).

Here, the Danish Maritime Authority (DMA) assume that a human being with the necessary qualifications in control of the ship could perform similar functions from places other than the ship. Consequently, they propose that the remote operator could be the shipowner's representative vis-à-vis authorities. Some certificates and other documents are required to be kept on board according to IMO regulations (Danish Maritime Authority, 2017). If flag States' regulations open up for certificates and other documents digitally, DMA argues that autonomous ships could be promoted. A common database of certificates would furthermore allow for simplified port State controls (Danish Maritime Authority, 2017). This aspect needs to be further addressed in order to find a well-functional solution.

The absence of specific parameters for autonomous or remote operation in the IMO conventions may be explained by the fact that such operations were not realistic at the time the conventions were drafted. A different question is whether IMO should adopt standards for shore-based control centers and their operation. IMO has traditionally avoided regulating shore-based matters. However, some aspects of remote operation are so closely related to safety of ships at sea that it is difficult to see how uniform standards in this area could be avoided (Danish Maritime Authority, 2017).

2.7 Regulations for safe manning - preventing collisions at sea

The more autonomous the function is, the greater is the departure from traditional navigational practices (Ringbom, 2019). COLREG include 41 rules for navigation decisions, and these assume that ships are controlled by humans who take navigation decisions based on their professional seaman assessment.

Rule 5 in COLREG requires that "every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision". This rule is of particular importance with regard to autonomous ships and has been discussed comprehensively in the literature (e.g., Komianos, 2018; Ringbom, 2019; Felski and Zwolak, 2020; DNVGL-CG-0264; Danish Maritime Authority, 2017). There seem to be some disagreement with regard to how this requirement can be fulfilled for autonomous ships. DMA states that (Danish Maritime Authority, 2017, p. 47):

> *"To the extent that it is technically possible to replace the human sight and hearing by cameras, sensors, radars or other technical means (electronic lookout), the first part of COLREG regulation 5 ("a proper look-out by sight and hearing") could be met electronically without human involvement as long as the electronic solution corresponds, as a minimum, to the human sight and hearing and provides the same safety level. This is supported by the presupposition in regulation 5 that "all available means" (in addition to "sight and hearing") must be used. It cannot be presumed that COLREG regulation 5 is a hindrance to the use of technological means for lookout as long as these means correspond to human sight and hearing, as a minimum. This is supported by the fact that, already today, the use of radar (including radar plotting), VTS (Vessel Traffic Service) and AIS (Automatic Identification System) are considered as using "all available means".*

DMA (2017) argues that when navigation decisions are taken by human beings, they could be made in accordance with COLREG irrespective of where the decisions are made, on the condition that it is possible to get a sufficient decision basis (situational awareness) from the location where the decision competence is exerted. There are experiences both from industry (see chapter 5.5), and research (se chapter 3.3) that provide information on how to achieve this. Ringbom (2019) stresses that the crucial question of whether the crew´s tasks can be assumed by crew members from a remote location, is not settled in any of the existing legal instruments. He furthermore notes that it is:

> *"arguable that a broader automation of the lookout functions could be accommodated within the existing wording of the COLREGs, provided that the technical performance of the equipment allows the person in charge of the ship to have an overview of the circumstances*

which is the same or better than through a human lookout; thus, allowing him/her to take appropriate action in good time" (Ringbom, 2019, p.13).

COLREG was developed to support safe operation and avoid collisions at sea. What is important to remember, is that at the time when COLREG was written (1972 and put into action in 1977), the technological development was not at a stage where we are today. One important aspect in supporting safety at sea at that time, was that the human operator keeps a proper look-out from the bridge. Today, there might be several technological means that can support, supplement, or even replace the human eyes and ears on a bridge to avoid collisions and ensure safety at sea. This is addressed through DMA (2017), which recommend the drafting of new international regulations for preventing collisions at sea for autonomous ships. If it is technically possible to change the bridge watch from the ship's physical bridge to an" electronic bridge" somewhere else with an equivalent safety level and functionality, DMA concludes that it would presumably be compatible with COLREG and the STCW Code. The bridge can then be considered to be "manned" under the STCW Code and, thus, to be in compliance with current regulations.

As COLREG has an international authority on the collision regulation, it seems important that a clarification or interpretation is made at an international level, rather than by individual (flag) states. Furthermore, remote operation triggers a need to address a whole series of associated matters, such as standards for lookout arrangements, requirements on technology, procedures for dealing with communication failures, cyber threats, procedures for dealing with military ships sailing under the radar, and so on. Another aspect related to this, is that the regulations is developed for each individual ship – not for a remote operator maybe monitoring several ships. The regulations should therefore also incorporate human and technical opportunities and challenges related to the possibility of monitoring several ships. All these issues need to be identified and resolved before flag states can confidently accept new concepts of operation as equivalent in terms of safety.

2.8 Regulations for safe manning - obligation to assist persons in distress at sea

SAR was adopted in 1979, and covered search and rescue operations on a world-wide scale. A fundamental maritime principle is that seafarers are obliged to assist persons in distress at sea to the extent that it will not compromise the safety of the ship, its crew or passengers. In relation to autonomous ships, this raises the question whether there is an obligation to maintain a certain manning level or whether there will be certain structural restrictions on the ability to meet the obligation to offer assistance to persons in distress at sea.

In the event that an autonomous ship is close to an incident, it will most probably be challenging to provide the required assistance. DMA assume that the obligation to notify search and rescue services about persons in distress at sea, could be met from a shore centre. This requires that an autonomous ship is equipped with sufficient electronic lookout to register persons in distress. Furthermore, an autonomous ship could serve as a communication hub in case of a marine accident. The wording of UNCLOS, article 98(1), and SOLAS chapter V, regulation 33, is that the obligation applies if the ship is" in a position to be able to provide assistance", and" in so far as such action may reasonably be expected of him" (Danish Maritime Authority, 2017, p.24). This implies that it will be necessary to develop new regulations on the technical arrangements for unmanned autonomous ships. From this, adjustments for search and rescue operations are needed in order to efficiently support assistance to persons in distress at sea.

2.9 Regulations for safe manning - the role and competence of remote operators

For the near future situation, there will probably be some crew members available either on board or remotely, to assume control if needed (Ringbom, 2019). In this situation, remote operators (the ship´s crew) will thus adopt a central role in connection with autonomous ships. DMA assume that remotely located operators will be required to complete normal training for navigating officers. In addition, they should receive education and training on current operational technology. It should also be specified how to train the remote located operators in practical seagoing experience. Remote operators will presumably be specialized as either operators with navigating competence or operators with engineering competence. DMA assume that in the long term, the operator's roles will include elements of both the navigating officer's and the engineer officer's functions (Danish Maritime Authority, 2017).

2.10 Protection of the maritime environment

An important purpose of autonomous ships is a reduced impact on the environment. However, autonomous ships will need to demonstrate that they do not present an increased risk of pollution damage, especially from the ship's own oil tanks and from its cargo, and that prevention and risk minimization in case of damage can be mitigated by technical solutions.

MARPOL contains requirements to protect the sea against ship pollution, and SOLAS contains requirements on the handling of cargo on board ships. To the extent that it is technically possible to monitor goods via cameras/ sensors on board, these obligations could be met by a remote located operator.

2.11 Cyber security and anti-terror protections

The vision of a fully autonomous ship is that the ship's systems interpret the situation by themselves in relation to the surroundings and are capable of handling all situations. (Bertram, 2016). On the path towards unmanned ships, the introduction of autonomous navigation will require reliable sensor information in order to ensure safe and reliable navigation. Autonomous vehicles will use a combination of different technologies that work together to map the vehicle´s position and its proximity to everything around it (e.g., cameras, sensors, GPS, radar, LiDAR, and on-board computers). Due to reliance on such technologies, autonomous vehicles are prone to cyber-attacks if an attacker can discover a weakness in a certain type of vehicle or in a company's electronic system.

There is a general agreement in the IMO Maritime Safety Committee, that provisions for countering cyber threats is a natural part of the ISM Code. In June 2017, it was decided that shipowners must have addressed cyber risk management as part of their safety management system (SMS). In addition to the IMO Guidelines on Maritime Cyber Risk Management, guidelines have been developed on ships' cybersecurity by a number of industries organisations. The most widespread guidelines are "Guidelines on Cyber Security Onboard Ships", which have been drawn up and supported by the industry organisations BIMCO, CLIA, ICS, INTERCARGO, INTERTANKO, OCIMF and IUMI. In addition, an ISO standard for cybersecurity has been outlined (ISO/IEC 27001). DNM recommend cybersecurity to be regulated via industry-established guidelines, which could be continuously adjusted, rather than via prescriptive convention-based regulation.

2.12 Summary

Current international conventions, rules and codes do not include the autonomous ship concept as a definition, or as a possible mode of operation. On the contrary, it may seem like existing regulations challenge rather than facilitate the operational arrangement of autonomous vessels. In this chapter, we have seen that there is a need to update and adjust existing international conventions to meet the challenges of operating autonomous ships. These are issues related to jurisdiction, manning and protection of the maritime environment.

As long as there is currently no regulatory guidance by the IMO on autonomous ships, interpretation of the international requirements will be left to individual (flag) states. States may have rather different interpretations of the key terms, which in itself is a justification for pursuing international harmonization in this area. A review of relevant regulatory frameworks followed by suitable modifications is needed in order to legally and technically assure that the autonomous ship concept is accepted by the maritime industry. The documents reviewed in this chapter seem to agree that many novel elements in operating autonomous ships argue in favour of a new regulatory instrument, at least for unmanned vessels. Furthermore, it seems that technical standards for sensor-based look-out functions, remote operation, and system-based decision-making are needed to be developed from scratch. In addition, generic requirements regarding redundancy, cybersecurity, certification and training are also needed.

3 Theoretical concepts and empirical findings

This chapter addresses the second research question: What are important theoretical concepts related to the human operator in remote operation centers? There are many theoretical perspectives that may be relevant for remote operation of autonomous ships. Today, we do not know which operational concept (s) will be implemented. We do not know whether there will be one or more operators in a ROC, if the task will be monitoring or also management, if the operator will have an overview of one or more ships, etc. Therefore, we do not know which theoretical aspects will be most relevant. However, we believe that the concepts we have mentioned here will be central, and a starting point for further research / development. The research question is addressed by exploring theoretical concepts as well as relevant empirical findings for remote operation of autonomous ships[7]. Some of the concepts are used and developed for other domains.

3.1 The Human Factors Engineering perspective on automation

Human factors engineering (HFE) is the discipline that takes into account human characteristics, capabilities and limitations in the design of interactive systems that involve people, tools and technology, to ensure safety, effectiveness, and ease of use. The discipline is a combination of several fields, such as psychology, sociology, engineering and interaction design. The way in which technology is designed can significantly affect the performance of the people who interact with it. When the user interface is designed in-line with human capabilities, it can make human performance more efficient and human error significantly less likely. When the system is easy to use, is error tolerant and helps people to understand key information about what is happening, high levels of human performance can be achieved. On the other hand, if the technology design is complex, the displays are difficult to understand, and effort is needed to understand the information presented, the likelihood of human error increases significantly (Endsley, 2019).

The research field of HFE was established when it was discovered that a large number of airplane crashes occurred due to human errors resulting from design inconsistencies in the cockpit (Meister, 1995). Since then, HFE has expanded to address human performance challenges across a wide range of industries such as aviation, transportation, military operations, power systems, space, and healthcare. Specific human performance challenges relevant for remote operation of autonomous ships include situation awareness, out-of-the-loop syndrome, workload, fatigue, boredom and trust. Theoretical and empirical aspects associated with these human performance challenges will be presented in the following paragraphs.

3.2 Situation awareness

To date, several Situation Awareness (SA) models have been developed. However, Endsley's three-level model has received the most attention. This model describes SA as "being aware of what is happening around you and understanding what that information means to you now and in the future" (Endsley, 2012, p. 13). Psychological constructs and theories that have impacted the research area of SA, include human working memory and attention. Humans actively try to create a consistent, logical explanation to account for their observations. Other related concepts to SA are mental models and situation models (Endsley, 2000). Mental models represent stored long-term knowledge about the systems that can be called upon when needed during interaction with the relevant system. A situation model is described as a schema describing the current state of the mental model of the system. Based on this, information systems should support operators in efficient top-down (planned), and bottom-

[7] The reader should note that we have focused on relevant theoretical and empirical findings for the LOAS project, as well as experiences that are publicly available.

up (data driven) information processing. Endsley explains that the situation model provides a useful window on the broader mental model (ibid.).

In the three-level model of Endsley, level 1 is related to perception of important information, level 2 is related to comprehension and how people integrate information to determine its relevance, while level 3 is related to projection. This includes people´s ability to predict the future situation based on the information available and their understanding of the situation (Endsley, 1995). All three levels must be supported for achieving a high level of SA. Supporting operator SA has become a major design goal in the development of operator interfaces, automation concepts and training programs. However, the typical challenge is to define what information is needed, and when this information is needed (Endsley, 1995).

3.3 Empirical findings on situation awareness

Some researchers have performed meta-studies of maritime accidents in order to learn from previous events. A meta-analysis of 100 maritime accidents by Wróbel, Montewka, and Kujala (2017) advised that actions aiming at reducing the occurrence of accidents must be implemented at early stages of system's design. Similarly, Sandhåland, Oltedal and Eid (2015) examined accident reports for collisions between attendant vessels and offshore facilities at the Norwegian continental shelf between 2001 and 2011 from a perspective of the bridge crew SA. The findings revealed that in 13 of 23 analysed events, the bridge crew failed to monitor or observe critical available information (level 1 SA). Reasons for this was that it was hard to discriminate or detect data, that data was not available, or that it was misinterpreted. In four of the events, the errors concerned a poor/ lack of mental model, which was assumed result from insufficient training or unsatisfactory interface design (level 2 SA).

Stratmann and Boll (2016) investigated 500 maritime accidents based on Endsley´s eight "Demons of Situation Awareness" (Attention tunneling; Requisite memory trap; Mental stressors; Data overload; Misplaced salience; Complexity creep; Errant mental models; Out-of-the-loop syndrome) (Endsley, 2011) and the three-level model of SA (Endsley, 1995). The researchers found, in accordance with Sandhåland et al. (2015), that level 1 SA was the most prominent source in maritime accidents. Mental stressors, and particularly fatigue, was the demon most often identified in the investigated sample. The researchers advised that by addressing the SA Demons, the maritime system designers can enhance the SA of maritime operators (Stratmann & Boll, 2016).

Skraaning and Jamieson (2017), investigated "automation transparency" in studies performed in the nuclear domain. The automation transparency principle is described as a design principle that support human performance through more observable or transparent automatic systems in the user interface. In a meta-study of several simulator studies, the authors found that explicit feedback from automation improved operator performance with regard to workload, precision in task execution, response time, trust and "probably also situation awareness" (Skraaning & Jamieson, 2017, p. 61).

The MUNIN project performed several research activities that provided relevant finings. Man, Lund, Porathe and MacKinnon (2015) performed a study where mariners took part in scenario-based trials with operators controlling the ship remotely, working with the same type of systems as is currently on the bridge. The findings from this study showed that SA was not satisfactory for land-based operators with the set-up used. An important implication of the finding is that the design of the ROC and the interfaces that the operators will use should be adapted to the actual concept of operation.

Another finding from the MUNIN project related to situation awareness, was that camera technology combined with computer vision in a visible and infrared area provides a safer perception of a situation than human lookout (Porathe, Hoem, Rødseth, Fjørtoft, and Johnsen 2018). Other researchers show similar findings: In case of fully or partly unmanned vessels, the lookout can probably be replaced by a combination of different sensors, including radar and computer vision in various wavelength areas (AAWA, 2016; Levander, 2017)[8]. Experiments with these systems are ongoing in several contexts. In Herman, Galeazzi, Andersen and Blanke (2015), sensor fusion by use of car radar technology and computer vision in the visible area is being tested.

A high level of SA is considered crucial for adequate decision-making and efficient performance, as the likelihood for efficient performance is larger if an individual clearly understands the situation that he or she is in (Skjerve, Strand, Skraaning, Nihlwing, Helgar, Olsen, Kvilesjø, Meyer, Drøivoldsmo, Svengren, 2005). SA is resulting from various sources of information. Cues may be received both through tactical, visual and audible means. Some indications may be explicit (e.g., a system alarm) and some quite subtle (e.g., the slight change in the sound of an engine) (Endsley, 2019). With respect to remote operation, a major challenge will be to provide sufficient information to compensate for the cues once perceived directly. Braseth, Toppe, Randem and Fernandes (2020) looked into experiences in the literature with different ways of presenting haptic feedback. Their empirical review found that visual and haptic cues in certain situations contribute positively to performance and has been found to improve response accuracy and time in driver behaviour (e.g., Pitts, Burnett, Skrypchuk, Wellings, Attridge, Williams, 2012; in Braseth et al., 2020). It is important that analyses of SA take into account the different information operators derive from various sources.

3.4 Out-of-the-loop syndrome

A central short-coming associated with automated systems has been called the "out-of-the-loop" performance problem. Wiener recognized this phenomenon in operators when controlling highly automated systems (Wiener, 1985). The out-of-the-loop (OOL) performance problem arises in highly automated systems, where operators have been allocated a passive monitoring role, with an increased risk for humans of a decreased system understanding. OOL performance problem may arise when automation does not behave as expected, and when understanding the system or taking back manual control may be difficult (Wiener, 1985). Endsley suggests that automation may impact SA through three different mechanisms that has the potential to drive operators out-of-the-loop: 1) changes in vigilance and complacency associated with monitoring; 2) assumption of passive operator roles (i.e., less manual control) instead of an active role in controlling the system, and 3) inadequate system feedback provided to the human operator (Endsley, 1996). In addition, operators may find it challenging to understand how automation is working, and thereby be less able to behave proactively. Endsley relates these challenges to level 2 SA, comprehension, and level 3 SA, projection of system parameters (ibid.). Out-of-the-loop performance can occur when operators are not able to identify the necessary corrective actions, when they respond too late, or when they have forgotten manual skills for error recovery (Kaber & Ensley, 1997).

Bainbridge (1983) pointed out ironies of automation in a research paper published in 1983. Her work has been widely recognized as a statement of the challenges inherent in automation. In this paper, Bainbridge describes unintended consequences of automation that could negatively affect human performance in critical tasks. One irony is that operating errors may occur due to errors introduced by designers. Another irony is that the operator will be left to do the tasks which the designer cannot foresee how to automate. This may leave the operator with several arbitrary tasks, with little concern in how they should be performed. Furthermore, if operators are supposed to take over manual control if the automatic systems fail, they will probably need more training than what operators receive today (Bainbridge, 1983).

[8] This finding is highly relevant for the requirement from DMA referred in 2.7

3.5 Empirical findings on Out-of-the-loop syndrome

The previously referred MUNIN study of Man et al., (2015) found some interesting results with regard to the out-of-the-loop syndrome. They performed a study designed in such a way that the operator in a ROC worked as a receptionist, the supervisor as coordinator, the engineer as a technical consultant and the captain as final decision maker. The study showed that in some situations, the operator delayed reporting of deviations to the supervisor (this was explained to be due to over-confidence to the system or miscommunication/ misunderstanding). The captain was supposed to make the final decision, but as he was conferred last, he was completely out-of-the-loop and became the team's weakest and most vulnerable link (ibid.). From this study, it seems crucial to ensure that different solutions with regard to ROC organization should be further tested in dedicated studies before a solution is selected.

3.6 Cognitive workload

Cognitive overload can result from too much to do, and too little time to do it. Already in 1956, Miller (Miller, 1956) stated that humans at the most could handle 5–9 information chunks at one time. The extent to which operators perceive the operational situation as complex or easy to handle is assumed to be associated with their level of workload. Workload generally refers to the mental and physical strain, associated with an activity (Wiener, 1985). Workload is associated with the operator's arousal level. If the workload level of an operator is inadequate (too high or too low), performance is assumed to be impaired. (Hockey, 1996). It is documented that mental overload is an adverse state leading to slow and poor performance (McKendrick, Feest, Harwood, Falcone, 2019). Mental underload is more difficult to observe than mental overload but may have equally devastating effects on performance, and is linked to boredom and fatigue (Hancock, Williams, Manning, Miyake, 1995).

The ability to measure and identify mental workload can be useful for improving safety, efficiency, and performance. There are generally three main types of methods for measuring mental workload: self-report; behavioral secondary tasks, and physiological measurement. Self-report measures are easy to use and cost-efficient. A frequently used subjective tool is the National Aeronautics and Space Association Task Load Index (NASA TLX) (Hart & Staveland, 1988). This tool has almost become synonymous with the concept of mental workload due to its extensive use (de Winter, 2014). Secondary task performance build upon an assumption that the decrement seen in performance on the secondary task is due, primarily, to the combined task load exceeding an individual's mental workload capacity. The magnitude of this decrement is taken to represent the workload required of the primary task (Gopher, 1993; Wickens, 2008). Neuroergonomics uses non-invasive neurophysiological tools to measure known correlates of mental effort to assess workload during a task. When the brain works harder, increased workload can then be observed through changes in brain activity (McKendrick et al., 2019). Such technology is most often used in controlled, experimental conditions, and not in real situations. The least invasive, and also a highly reliable way of measuring workload is through self-reporting (e.g., NASA TLX). This method is often used in real-life contexts to regulate operator task demands.

3.7 Empirical findings on cognitive workload

In a ROC, the workers can be exposed to too much information in a manner such they would no longer have the capability of understanding the situation. This might be caused by the number of ships and sensory information. With an operation concept where one operator supervises several ships, there is a risk of "carry over effects". This means that aspects from one ship's situation can mistakenly be carried over to other ships and have significant impacts on operator decision-making (Porathe, Prison, and Yemao, 2014). Furthermore, if information from the surroundings is replaced with visual representation, this could be overwhelming in view of the capabilities of the operators (Man et al, 2014). Replacing the bodily feel of the ship with visual indications could also result in information overload for the operators. However, by letting the autonomy operate without human interference, the system handles much of the general workload - but is at the same time actively distorting the operator's mental model. If automation fails, the operator is therefore at risk of being out-of-the-loop (Man et al., 2014; Porathe et al., 2014).

Another identified challenge in current bridge control is information overload caused by a large number of alarms and warnings. The seafarers are often overloaded with information, and not able to read and respond to the alarms within a reasonable timeframe. There is also a danger that they will turn off the warning sounds and thus not detect in time when a real event occurs. Therefore, information systems such as alarm systems should be designed in-line with human cognition, ensuring that only relevant and actual alarms are presented to the operators, and in due time for them to take action (Porathe et al., 2018). Standards for bridge alert management has been put forward by IMO and should be taken into consideration in alarm system design (IMO, 2010).

Nordby, Gernez and Mallam (2019) performed a systematic literature review of maritime design regulations and guidelines and found that there seems to be a lack of effective support of standards for user interfaces. The authors point out that ships are normally delivered with ship bridge systems from multiple system vendors. On a single bridge there can be up to 30 different brands (Oltedal and Lützhöft, 2018). This makes it necessary for the users to adapt to multiple designs, information presentations and means of interactions on a single bridge. This mixture of interaction devices and interface designs may negatively impact the seafarers´ cognitive workload, and the tasks they are required to perform (Lützhöft 2004). Such a lack of a harmonized design can result in a workplace that has reduced efficiency and performance and can lead to an increased possibility of errors and accidents (Nordby et al., 2019).

3.8 Fatigue and boredom

The human cognitive system is designed to be active by day and sleep at night. Despite of support from technical means, decision making is impeded during night, even if we are accustomed to shift work (Wilson and Korn 2017; Porathe et al., 2018). Hopstaken et al (2015) explain the association between fatigue and performance in terms of task engagement. According to the authors, task engagement will decrease when the level of fatigue increases. The classical Yerkes-Dodson law (Teigen, 1994) show that human performance describes an inverted U-shaped curve when plotted against arousal. “Intermediate arousal leads to optimal engagement and performance… low and high arousal, on the contrary, lead to disengagement and impaired task performance” (Hopstaken et al, 2015a, p. 306).

Some authors claim that “fatigue” and “boredom” are two concepts closely related to each other, as many symptoms are similar (Lal and Craig, 2001). Others argue that these concepts are quite different: while fatigue is a result of high demands, boredom is a result of low demands (Ackerman, Calderwood and Conklin, 2012). As cited in Strand, Nystad and McDonald (2019), May & Baldwin (2009, cited in Körber, Cingel, Zimmermann & Bengler (2015)) proposed a model of fatigue where they categorized it into three forms: 1) Active fatigue, 2) Passive fatigue, and 3) Sleep-realted fatigue. Active fatigue is explained as a result of being actively engaged in a task which leads to weakening of mental resources. Passive fatigue is considered as the opposite, namely as task underload, monotony and extensive use of automated systems (Körber et al, 2015). Passive fatigue is thus a result of difficulty to maintain attention due to monotony and boredom of the task. Strand et al. (2019) suggest that this model of fatigue corresponds to the model by Lal & Craig (2001), that both passive (low demands) and active (high demands) forms of fatigue may lead to symptoms such as reduced attentional capacity and performance impairment.

3.9 Empirical findings on fatigue and boredom

The literature points out that a larger degree of accidents happens during night (e.g., Wagstaff, Sigstad and Lie, 2011). Furthermore, the ability to focus and sustain attention on a task is crucial for the achievement of one's goals, and there is a general agreement that humans are not capable of concentrating on a task without being distracted on longer periods of time (Wilson and Korn 2017; Porathe et al., 2018).
Deficiencies in human performance due to fatigue have been noted in several domains (Hopstaken, Linden, Bakker, and Kompier, 2015). Porathe et al. (2018) notes that automation may induce boredom and through this increase the time operators need to take control of the ship. The Three Mile Island incident and the Challenger accident have been associated with fatigue (Matthews, Desmond, Neybauer, Hancock, 2012). Psychological consequences of fatigue can be reduced alertness, attention and concentration, impaired memory and information processing, poor judgment, difficulties in planning and adaptation, decreased task motivation, longer reaction time, poorer psychometric coordination and less often correcting mistakes (e.g., Sadeghniiat-Haghighi & Yazdi 2015; Hopstaken et al, 2015; Boksem & Tops, 2008; Lal & Craig, 2001, as cited in Strand et al., 2019).

3.10 Trust

One factor relevant for the interplay between human operation and automation, is trust. Lee and See define trust as: "the attitude that an agent will help achieve an individual´s goals in a situation characterized by uncertainty and vulnerability" (Lee & See, 2004, p. 54). It has been suggested that trust in humans and trust in automation depend on different attributes. Interpersonal trust is often based on ability, integrity or benevolence of a trustee, while human-automation trust depends on the performance or purpose of the system (Hoff and Bashir, 2015; Lee and Moray, 1992).

A challenge often mentioned related to monitoring of systems is related to in what extent the user´s trust matches the system´s capabilities (Muir, 1994). Operators may over - or under-estimate the probability of human or system failure. Placement of either too much or too little trust in colleagues or in the system may be the result. Muir (1994) termed this as "poorly-calibrated trust". Over-trust and under-trust may have implications for safety and productivity. Over-trust may lead the human operator to always depend upon the automation with a reduced likelihood of detecting and diagnosing errors in the system. Under-trust may lead to disuse of the automation, resulting in excessive operator workload and diminished system performance (Lee & See, 2004).

3.11 Empirical findings on trust

Hoff and Bashir (2015) have exemplified how fatal outcomes can occur if people have too much or too little trust in the systems they control. In the Costa Concordia ship accident in 2012, the captain did not rely on the navigation system. He instead took manual control prior to the accident. This illustrates the case of under-trust (or false distrust). In 2009, a Turkish aircraft crashed because the pilots continued to rely on the aircraft's autopilot, even after an altitude measurement instrument had failed. This illustrates a case of over-trust (or false trust) (ibid.).

Muir and Moray (1996) performed a study where they found that trust towards the system was significantly reduced when it behaved unreliably. However, this distrust did not generalize to other components or to other systems (ibid.). A finding in a nuclear setting, indicates that operators tend to have less trust in situations where the process information is unreliable than when it is missing

(Kaarstad & Nystad, 2019). Another aspect of trust in automation is related to how early in the interaction with the system unreliability occur. Manzey, Bahner and Hueper (2012) found that operators who experience unreliability in early use of the system, seem to distrust the system more than operators who experience system unreliability later. Such findings suggest that early system errors can have a lasting impact on how trust is formed, developed and maintained by the operators. Porathe et al. (2018) claim that the recent decline in shipping accidents is related to the fact that more tasks are being automated. As an example, manual steering could previously cause large course errors and has now been replaced by autopilots or track pilots, which can follow a pre-programmed path with an impressive accuracy (ibid.). Irrespective of the robustness of an autonomous system, it is likely that it will fail in some instances. Thus, facilitating appropriate levels of trust in automation is essential to performance and safety of human-automation teams (Hoff & Bashir, 2015).

On the path towards unmanned ships, the introduction of autonomous navigation will require reliable sensor information in order to ensure safe and reliable navigation and to ensure operator trust. An autonomous system must be capable of functioning even if one sensor fails, and it must be capable of functioning in all weather conditions. Practical testing of sensor types and sensor fusion technologies in all relevant weather conditions is therefore needed (DTU Elektro).

3.12 Summary

The focus in this chapter has been on theoretical concepts and empirical findings that can be relevant for the human-automation interaction in a future ROC. The topics discussed in this chapter is based on theories and empirical research on human factor issues and include situation awareness, out-of-the-loop challenges, cognitive workload, fatigue and boredom, and trust. Such issues are important to take into consideration when designing and developing a remote operation centre for monitoring and operation of autonomous ships, and for planning operator tasks to be performed from the ROC.

4 R&D cases in the maritime domain

In this chapter, the third research question will be addressed: What are the recent and ongoing research and development cases in the maritime domain relevant for autonomous ships?

4.1 The YARA Birkeland

One recent project related to the Autonomous Ship is the "YARA Birkeland" (YB). Findings in the LOAS project will be relevant for the further development of the concept of a land-based operation centre for YARA Birkeland. YARA and KONGSBERG teamed to build the world's first zero-emission container vessel. The project started in 2017, first as a manned vessel. Then towards remote operation by 2019 and is scheduled to go fully autonomous by 2022. It is estimated that Yara Birkeland can be able to replace 40,000 truck journeys a year and will thus contribute to emission reduction and to improve road safety in densely populated areas in Norway, and thus support the achievement of UN sustainability goal.

During the first stage of the project, a bridge with crew facilities will be used in a shore-based container Yara will have a temporary "traditional bridge" fitted with bridge equipment and space for two operators. At the end of the test period for autonomy this will be removed when fully autonomous. The vessel will be able to berth automatically and to go underway without human intervention. When fully autonomous, Yara Birkeland will be programmed to sail within 12 nautical miles of the Norwegian coast, between three ports of the country's southern area which is safely covered by the VTS system at Brevik of the Norwegian Coastal Administrations. It is suggested that three control centres with diverse operational profiles will handle all operational issues in addition to any emergency situations and other safety and security aspects.
Further reading: https://www.kongsberg.com/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/

4.2 The Munin

The Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project, was a project that started in 2012 and ended in 2015. It was funded by the European Commission (EC), with the purpose of investigating the technical, economic, and legal feasibility of unmanned ships. It is therefore reasonable to take advantage of some this work for the LOAS project.

The objective for MUNIN was to develop and verify a concept for an autonomous ship. An autonomous ship was defined as a vessel primarily guided by automated on-board decision systems and controlled by a remote operator in a shore side control station. The most important characteristics of this project include the ability of the ship to be operated by an autonomous shipping system on board (while having the ability to be supervised and controlled by land operators). Further, its ability to minimize the risk of collision and comply with the Convention on the International Regulations for Preventing Collisions at Sea (COLREG), and the fact that its safety and operation sensors can be used to search for objects. *Further reading: http://www.unmanned-ship.org/munin/ (visited 15 May 2020)*

4.3 The ReVolt

ReVolt is an unmanned, zero-emission, shortsea vessel developed by DNV GL. This vessel is 60 meters long and is battery powered and autonomous. A multi-disciplinary, team-based undertaking at DNV GL developed ReVolt through support by Transnova. It is based on an assessment of current requirements along short-sea routes. Researchers at the Norwegian University of Science and Technology (NTNU) in Trondheim, use the experimental model to investigate how advanced control systems and navigation software could control an unmanned vessel. Depending on the results of the investigations, DNV GL predict that such a design could possibly be built and deployed as a 100 TEU feeder vessel on fixed routes in coastal waters. *Further reading: https://www.dnvgl.com/technology-innovation/revolt/index.html (visited 15 May 2020)*

4.4 The AAWA

Former Rolls-Royce, now Kongsberg Maritime, is heading a project called the Advanced Autonomous Waterborne Applications Initiative (AAWA). This project was initiated by Rolls-Royce in 2015, and the purpose is to bring together universities, ship designers, equipment manufacturers, and classification societies to explore factors (economic, social, legal, regulatory, and technological) which need to be addressed in order to make autonomous ships a reality. The purpose is to produce specifications and preliminary designs for the next generation of autonomous ship solutions. Mikael Makinen, president of the marine business in Rolls-Royce, stated in a position paper from June 2016: “Autonomous shipping is the future of the maritime industry. As disruptive as the smartphone, the smart ship will revolutionise the landscape of ship design and operations” (AAWA position paper, 2016, p.4). *Further reading: https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf (visited 15 May 2020)*

4.5 The Autosea

The Autosea project (Sensor fusion and collision avoidance for autonomous surface vehicles) started in 2015 and is a knowledge-building project funded by the Research Council of Norway (RCN). In this project, researchers at NTNU collaborated closely with the DNV GL, KONGSBERG and Maritime Robotics. The partners have contributed by making their surface vehicles, sensors, navigation technology, control systems and general know-how available for the project. The main goal of the Autosea project is to develop methods for guidance and navigation of autonomous ships. A central component of this is collision avoidance. The Autosea project has demonstrated collision avoidance systems in full-scale experiments involving autonomous and semi-autonomous surface vehicles both in Trondheimsfjorden and in the Netherlands. *Further reading: https://www.ntnu.edu/autosea/about (visited 15 May 2020)*

4.6 The Autoship

Autoship started in January 2020 and will last for four years. This self-propelled vessel research project is supported by EU's Horizon 2020 research programme. Several international partners collaborate with Sintef and the Kongsberg Group. The project will focus on developing methods for cost-effective and safe designs for future autonomous transport systems. According to the project webpage, the project goal is to strengthen three initiatives:

1) Development of better methods for early design of autonomous ship transport systems.
2) Establishing international standards to increase innovation in digital and autonomous shipping.
3) Further development of the communication systems for autonomous vessels.

With these objectives, the goal is to contribute to a significantly more sustainable freight transport. *Further reading: https://www.sintef.no/en/latest-news/sintef-makes-important-contributions-to-autonomous-maritime-transport/ (visited 15 May 2020)*

4.7 Cyber enabled ships

Lloyd's Register (2016) initiated a project called Cyber-enabled ships. This project explores the existing procedures and guidance for autonomous ship operations. Through this project, six main risks have been identified:

1. The System
2. The Human-system
3. Network and communications
4. Software
5. Data assurance
6. Cyber security

For each of these risks, the guideline describes the aspects which should be investigated in relation to cyber-enabled systems. *Further reading: https://www.lr.org/en/latest-news/early-adopters-and-innovators-in-connected-assets-on-ships/ (visited 15 May 2020)*

4.8 Centre of Excellence - AMOS

Centre for Autonomous Marine Operations and Systems (AMOS), is a "Centre of Excellence" initiative developed by the Departments of Marine Technology and Engineering Cybernetics at the Norwegian University of Science and Technology (NTNU). This is done in collaboration with international and national partners. AMOS started in 2013 and focused on two main research areas:

1. Autonomous vehicles and robotic systems
2. Safer, smarter and greener ships, structures and operations

The project has a large number of publications and several completed and on-going research activities. *Further reading: https://www.ntnu.edu/amos (visited 15 May 2020)*

4.9 Summary

In this chapter we have seen that there are several larger recent and ongoing national and international initiatives on autonomous ships. This implies a further need for development of national and international regulations, as well as focused research in the area to support such regulations and standardisation and to ensure safe and efficient operation of autonomous ships.

5 Experiences with remote operation from other domains

Several domains have experience with remote operation. Some of these demonstrate benefits, but also challenges that can create new types of errors and contribute to catastrophic events (Bainbridge, 1983; Strauch, 2017). The purpose of this chapter is therefore to address research question four: What are experiences with remote operation from other domains? We will do this by summarize findings, and to make them usable for the maritime domain.

5.1 General opportunities with remote operation

Remote operations imply that more activities can be performed remotely, exposing fewer personnel to hazards. Transportation modes where autonomous systems have been successfully implemented, show that autonomous vehicles can be operated safely, provided that the system is properly designed, relevant hazards are properly anticipated and the lessons from the past are properly learned (Sivak and Schoettle, 2015; Howard, 2014; Benjamin, Dezfuli and Everett, 2016). Furthermore, both increased information, and integrated analyses, may lead to more efficient planning, operation, and detection of degraded equipment before it fails. Also, decisions are more informed, as the right information can be delivered to the right people in the right time, with the ability to collaborate more widely and to faster and better react to upcoming issues and emergency situations (Farrelly and Records, 2007).

5.2 The petroleum industry

The petroleum industry has exploited different solutions of remote operation. Some of the solutions of automation in the petroleum industry include remotely operated platforms (e.g., Ivar Aasen and Valemon); remotely operated underwater vehicles (ROVs); inspection robots; and deep-water pipeline repair robotic systems.

Experiences with regard to opportunities with remote operation are lower costs of operating, including lower labour costs and travel costs; less direct risk for the operational personnel due to the distance to potential hazards; reduced staffing levels offshore; possible to measure and control the process with the use of advanced data analyses resulting in faster and better decisions; and less production interruptions and platform downtime (improved regularity). In addition, new technology also results in improved maintenance and better access to remote specialist competence. It is furthermore reported that it is easier to share information, and to identify and address hazards early (Thieme and Utne, 2017; Chen, Stavinoha, Walker, Zhang, Fuhlbrigge, 2014).

ROV can be challenging to operate, and visual inspections are more difficult to perform through an indirect video view. Furthermore, the ROV is connected to the ship by a cable and has therefore less freedom to move around (Chen et al., 2014). Other challenges for operators monitoring and controlling highly automated systems in the petroleum domain include e.g.: long periods of monotonous monitoring that may bring the operators into a “rest modus”; suddenly interrupted by the need to deal with a critical situation within a short time span; not enough familiarity with how the automatic system operates; and limited opportunity for practicing sensemaking in safety-critical situations, as these situations rarely arise (Hurlen, Skjerve and Bye, 2019). In addition, there has been mentioned that in remote operations, operators may perceive a lower degree of risk which may imply lower safety margins in situations when operators are not themselves in physical danger (Chen et al., 2014).

Challenges relevant for the maritime domain:

- Difficult to remotely operate vehicles
- Difficult to get an overview of the situation through an indirect video view
- Lower perceived risk might imply lower safety margins as operators are not themselves in physical danger
- Long periods of monotonous monitoring may bring operators into a “rest modus”
- Lack of training and familiarity with how the automatic system operate
- Limited training in safety-critical situations

5.3 Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles (UAVs) are used in a variety of operations related to e.g., search and rescue and reconnaissance and surveillance. UAVs operate in an open environment, where they are vulnerable to the elements causing disturbances of various kinds, which may negatively impact system performance (Ordoukhanian, 2016). It is therefore reasonable to assume that some of the problems with UAVs could apply also to unmanned ship operations.

UAVs allow that expertise can be distributed to geographically dispersed specialists. A specialist team can handle unfamiliar situations, while other operators can develop specific skills in take-off and landing the vessel. In a study by Thompson and colleagues (in Endsley 2019), 92% of UAV operators reported “moderate” to “total” boredom. Furthermore, several mishaps with UAVs have occurred during changeovers or handoffs, these having been the direct or indirect cause of the incidents (Tvaryanas, 2003). Also, for UAV operations, the operators lack cues to feel the shifts in altitude and changes in engine vibration, variation in speeds or engine troubles (Drury and Scott, 2008). Similarly, Porathe, Prison and Yemao (2014) noted a lack of “ship sense” in unmanned ship operations, that is, lack of bodily understanding of the ship orientation vis á vis wave and wind conditions and information on engine noise.

In human-UAV interaction, there are two management schemes: management by consent and management by exception (Goodrich and Cummincs, 2015). Management by consent means that human operator approves an automated solution before execution, while in management by exception the operator has a period of time to reject the solution. Ruff, Narayanan and Draper (2001) showed that management by consent provided the best situation awareness ratings, the best performance scores, and the most trust by operators for controlling up to four UAVs (Goodrich and Cummings, 2015). When number of participating UAVs increases, operators tend to not reject system’s action since they are not engaged enough to know what is happening in the system (Mosier and Skitka, 1996)

During normal operation in highly automated situations, human operators often has the role of an observing agent, however, when dealing with a disruption, this is changed to a controller (Goodrich and Cummings, 2015). Mandi (2010) found that this role transition has significant impact on system performance. When human cognitive attention is divided on multiple tasks, it is less likely that the operators are able to recover from disturbances (ibid.).

Challenges relevant for the maritime domain:

- Monotonous work from monitoring autonomous ships could lead to boredom
- Mishaps can happen during handoffs
- Lack of “feel” of the vehicle/ship and surroundings – tacit knowledge
- Management by rejection may lead to decreased engagement

5.4 Defence Systems

A central operating concept in the military sector, is agile command and control, which, enhances responsiveness, flexibility, creativity, and adaptation in order to meet the needs of task (Wahlström, Hakulinen, Karvonen and Lindborg, 2015). In line with this, NATO has applied the Effects Based Approach to Operations (EBAO). This includes planning actions based on the operation needs, rather than short-term military imperatives (Essens, Spaans, Treurinet, 2007). Challenges in remotely operated warfare has been identified with implications to unmanned ship operations. Ethical concerns have been associated with unmanned military operations (Wahlström et al., 2015), and this might be relevant for how unmanned ships operated remotely would lack a similar empathy and sensitivity towards their surroundings, this could be particularly negative in rescue operations.

Hoffman, Hawley and Bradshaw (2014) looked into operator situation awareness related to automated air defence battle management systems. One concern in their work is "lack of vigilance" along with "lack of cognizance" with a resulting "unwarranted trust in automation" (Hoffman et al., 2014). The authors refer to "undisciplined" automation, which is explained as incorporation of constantly more automation without considering potential negative consequences for human performance. With this approach, the authors express concern that operators are left to just monitor the process, and to take control only when the system is not accurate. Research and operational experience indicate that such a role is difficult for operators to execute adequately (Woods and Hollnagel, 2006).

Hoffman et al., (2014) pointed to some possible negative outcomes from "undisciplined automation". One outcome is that automation unreliability has not been satisfactorily addressed during weapon system software upgrades and is not reflected in operator training and operating procedures. Furthermore, the organizational culture emphasizes the importance of trusting the weapon system without question, and the training is focusing on mastering routines (crew drills) rather than critical thinking and adaptive problem solving. The training does not produce the necessary levels of operator competence required when the role of the air battle management crew changed from a traditional operator to a supervisory controller (Soller and Morrison, 2008).

It has been claimed that automation will reduce operator workload. However, extensive use of automation in battle command does not eliminate the need for operator expertise (Hawley, 2011). To the contrary, the supervisory control approach that is increasingly used to manage "advanced" technology requires human expertise and training to a much higher level of proficiency than the traditional operations (Bradshaw, Hoffman and Woods, 2013).

Challenges relevant for the maritime domain:

- Unmanned ships could result in lack empathy and sensitivity towards surroundings
- The sense of presence may change (virtuality feel)
- It can be challenging to be able to differentiate between e.g., help -seekers and pirates
- How to handle automation unreliability in training and procedures
- How to address critical thinking and adaptive problem solving as well as technical skills in training

5.5 Aerospace

The aerospace is highly technical, and space operations are generally managed by remote control from earth. Remote operations have been a necessity for satellites, which are designed to stay operational for a long time without any intervention. Satellites include a complex arrangement of sensors and control devices, with a high degree of redundancy and "self-healing" capability (Farrelly and Records, 2007).

The mission control centre (MCC) is the hub of control that oversees crucial aspects of space flights. Only about 10 percent of the MCC operators time is spent on controlling missions, while around 75 percent is spent on planning, organizing, and updating procedures. The remaining 15 percent is devoted to their own training and education. MCC workers practice responses in simulator training, where unexpected events require fast thinking and logical responses. The system consists of generic procedures relevant for launch, as well as mission-specific procedures tailored for a specific situation. Some part of the operator work includes adapting specific procedures (NASA, www.nasa.com). NASA explains that Mission Control is divided into flight-control, and ground-team workers. The ground team gathers data from the spacecraft and launch facilities, while the flight control team analyses data to support decisions on how best to proceed. A high degree of redundancy is practiced in mission control in order to achieve safety of the space missions (ibid.). This includes both responsibilities and roles in the team, as well as technical redundancy.

Presently, humans play a central role in launch flight safety. This is to a large extent achieved through selection, training, and certification. Training is continuously improved based on improvements in technology, and experience from accidents investigations and successful mission completions (Sgobba, 2018). Experience has shown that humans can be both effective and efficient in decision-making even under time pressure. In space operations, it has been found that humans´ strength over the machine lies on the ability to adapt to unknown situations (ibid.).

Challenges relevant for the maritime domain:

- Redundancy – both technical and human is needed
- Risk of losing vigilance and to become bored, fatigued when monitoring automated systems where very few human interventions are needed

5.6 Aviation

A Human Factors team in Federal Aviation Administration (FAA) conducted a detailed study of automation-related aviation accidents in 1996. They found that challenges with automation were systemic (not related to one specific airline or manufacturer) and indicated inadequacy in design of the pilot automation interfaces, as well as the processes used for design, training, testing, and regulation (Federal Aviation Administration, 1996).

There has been a culture of blaming the pilots when aviation accidents occur. This approach has not been helpful in correcting the systemic issues that underlie aviation accidents (Endsley, 2019). When investigations of air traffic accidents are performed, it is often found that the underlying factors often are caused by design flaws that do not take the human operator's capabilities and limitations into account (ibid.).

When Johnson, and Pritchett (1995) recreated one specific automation-related aviation accident, they found that 10 out of 12 pilots made the same error as the pilots in the accident when confronted with the same conditions. Furthermore, Gawron (2019) investigated automation-related accidents between 1972 and 2013 and found that the pilots were significantly challenged in understanding what the automation was doing, and how to interact with it correctly. Another study of factors underlying automation accidents found that significant contributing factors were inadequate understanding of automation and poor transparency of the behaviour of the automation (Funk, Lyall, Wilson, Vint, Niemczyk, Suroteguh, and Owen, 1999).

Several authors have pointed to skill-degradation as a result of automation in aviation over the last few decades. Pilots´ skills for manual performance and decision-making has been detoriating over time, after they have become used to, and rely on automation (Lee and See, 2004; Jacobson, 2010).

Also, as recent educated pilots are often trained primarily to operate via automation, they do not develop skills for manual aircraft operations (Board, 2010; Endsley, 2019). If pilots experience situations where the automation fail, it is important with effective training on how to overcome automation failures, both to detect, diagnose, and respond to such events (Orlady, 2010).

Achieving a high level of situation awareness has been found to be challenging when automation is involved (Woods and Cook, 2017). Pilots with a low level of SA because of lack of information about how the automated systems are operating, are said to be "out-of-the loop." Low level of SA when working with automated systems originate mainly from three sources (Endsley and Kiris, 1995):

- Poor information presentation
- Vigilance decrements, which can be due to over-trust in automation, and because people in general are poor at maintaining vigilance when passively monitoring
- Engagement - level of engagement decreases when moving from actively performing a task to passively watching another entity performing the task. With low engagement, it has been found that people have a much lower understanding of what is happening than when they are performing tasks themselves.

Automation can actually increase pilot workload during high workload periods, as pilots often have to take over manual control, which can be quite challenging (Wiener and Nagel, 1988). Also, in low workload periods, new problems associated with lack of vigilance and poor monitoring can occur (Warm, Dember and Hancock, 1996; Molloy and Parasuraman, 1996). This has been referred to as "the irony of automation", (Bainbridge, 1983). Endsley reviewed research on automation, and found that the more reliable automation is, and the more automation is added to a system, the more likely it is that operators will not be aware of critical information presented by the system - and they will more likely fail in taking over manual control when needed (Endsley, 2017).

Challenges relevant for the maritime domain:

- Automation creates high workload spikes and long periods of boredom, resulting in detoriating workload capacity
- Overreliance on automation is common
- Detoriating of manual operating skills
- Lack of adequate training about automated systems, and how to operate fully manual

5.7 The nuclear industry

In a complex system as a nuclear plant, automation is undoubtedly invaluable. Automatic systems help to ease some of the burden on the operator during normal operation and in an emergency, and have been incorporated into several different functions, such as monitoring, detection, situation assessment, response planning, and response implementation (O´Hara, Higgins, Fleger and Barnes, 2010). Nuclear plants in the western world operate using a 'defence-in-depth' approach, with multiple safety systems which activates if something should go wrong. Modern NPPs are designed so that the automatic systems can safely run down the reactor in the event of an incident.

Schmitt (2012) analyzed three of the largest nuclear accidents in the world, and traced automation as a contributing factor to these events. At Three Mile Island (TMI), the operators did not fully understand the automation as a misunderstanding of a control room light caused the event. "If the operators had not intervened, the plant would have saved itself. They [the designers] had thought of everything except what would happen if the operators intervened" (PBS, 1999, in Schmitt, 2012). The author further suggests, that in Chernobyl, one of the contributing factors to the accident, was a management chain that did not fully believe in the automation of the systems (ibid.). In order to perform testing to see if they could draw emergency power out of a powered down turbine, they shut down several automatic safety systems without approval of regulators and design engineers. Also, in Fukushima, the accident may have had less serious consequences if all safety shut down systems had been fully automated (Schmitt, 2012).

Large amounts of research have been performed related to automation within the nuclear power domain (e.g., IAEA, 1992; NRC, 2004). O´Hara et al. (2010) saw the need for developing guidance to conduct safety reviews of the operator–automation interaction in nuclear power plants. The guidance includes principles related to automation displays, interaction and control, automation modes, automation levels, adaptive automation, error tolerance and failure management and HSI integration.

The topic of human-automation interaction has been investigated in NPP simulators at the HRP for more than two decades, and include two main topics: transparency of automation (e.g., Nihlwing, Hurlen, Teigen & Jokstad, 2010; Skraaning Jr., Eitrheim, Lau, Nihlwing, Hurlen & Karlsson; 2010; Eitrheim, Skraaning Jr., Lau, Nihlwing, & Karlsson, 2011) and levels of automation (e.g., Skjerve, Andresen, Saarni, & Skraaning Jr.2001; Massaiu, Skjerve, Skraaning Jr., Strand & Wærø, 2004; Skjerve, Strand, Skraaning Jr., Nihlwing, Helgar, Olsen, Kvilesjø, Meyer, Drøivoldsmo & Svendgren, 2005a; Skjerve, Strand, Skraaning Jr. & Nihlwing 2005b). Skraaning Jr. and Jamison (2017) has documented and summarised this research. They propose to increase automation transparency at the component level by making responsibility, goals, activities and effects of interlocks, controllers, limitations, protections and / or automatic programs observable to the control room operators. Furthermore, they recommended to develop an automation strategy and operational concept together to prevent unforeseen and adverse human performance effects when the human-automation system is taken into use. It is furthermore recommended to be careful in relying on operators' preferences on level of automation as design guidance, as operators' preferences are not necessarily related to their performance. The report concludes that general human-automation principles and models are not inevitably applicable to a specific domain. Therefore, more work is recommended to achieve a realistic appraisal of the safety of the automation for the domain at hand (ibid.).

The nuclear industry has started to address a design concept called "small modular reactors", where it is envisaged that several smaller nuclear units will be controlled from a central control room. Experiences from this concept are currently not available. Although research from the nuclear domain is highly relevant in terms of general human-automation challenges, there are currently not many experiences that are directly applicable to the maritime concept on remote operation of autonomous ships.

Challenges relevant for the maritime domain:
- Lack of competence in and understanding of the automatic safety systems
- Human-automation principles need to be adapted to the actual domain
- Inconsistency between automation strategy and operational concept can lead to unforeseen human performance effects

5.8 Autonomous Cars

Autonomous cars have gained increased interest in recent years. This development is partly motivated by the idea that technological autonomous support systems in cars will support safe driving (Banks and Stanton, 2016). Trucks, (i.e., bumper-to-bumper driving) has been tested for a number of years and will engage in commercial operation within a relatively short period of time (Danish Maritime Authority, 2017). For passenger cars, a number of technologies have been developed, such as: warning systems when changing lanes; automatic distance and braking control; as well as parking assistance. Recently, Tesla and Mercedes have launched models that are, to a wide extent, capable of driving by themselves in motorway-like stretches (ibid.).

The main findings from driver studies indicate that reaction time to critical incidents is slower, and that drivers are generally less aware of their surroundings when performance in automated driving is compared to manual driving (Louw and Merat, 2017). However, the results are sometimes mediated by other factors.

Merat, Jameson, Lai, Daly and Carsten (2014) performed a driving simulator study to investigate drivers´ ability to resume control from a highly automated vehicle. They found that operators' ability to take manual control was better if they were expecting automation to be switched off. In a study by Strand, Nilsson, Karlsson and Nilsson (2014) it was found that driving performance was degraded when the level of automation increased.

Zeeb, Buchner and Schrauf (2016) conducted a driving simulator study, collecting data from 79 participants. The objectives were to examine response times and manual take-over quality. The drivers had to resume control in four different scenarios while they were engaged in secondary tasks. In the study, there was a control group which did not perform secondary tasks. The results showed that the drivers in the two groups returned their hands to the steering wheel equally fast. However, take-over quality, deteriorated for distracted drivers.

Louw and Merat (2017) performed a study where they found that by withholding only some information, drivers were more engaged in the driving task, compared to if all information about the automation was removed. They also found that drivers´ understanding of the automated system increased as time progressed.

In car driving, behavioural adaption has been observed where drivers who often use intelligent systems have lower perceived risk than infrequent users of the system (Saffarian, Winter, Happee, 2012). In the nautical context, this phenomenon might imply if the pathways of two ships cross close to one other, the operators might rely on the system to plot the unmanned ship's route with margins, which is technically correct (in view of sensor data), but in practice risky.

Winter, Happee, Martens and Stanton (2014) reviewed previous studies with regard to effects of adaptive cruise control (ACC) and highly automated driving (HAD) on drivers´ workload and SA. They found that ACC frees up mental capacity such that drivers with ACC respond faster to artificial stimuli than manual drivers. However, for HAD, it seemed like drivers has slower reaction times than during normal driving. Both ACC and HAD can result in improved SA compared to manual driving. However, if drivers are engaged in non-driving tasks, their SA detoriating for HAD compared to manual driving. They also found that HAD drivers are more inclined to engage in non-driving tasks than ACC drivers. Another important finding is that HAD, and ACC evoke long response times and an elevated rate of near collisions in critical events compared to manual driving. However, driver response times appear to be moderated by whether the driver is pre-warned as well as by the type of scenario. If the automation failed unexpectedly with very little time for the human to respond, then almost all drivers crashed. But if drivers received a timely warning, then almost all drivers safely avoided the collision (ibid).

Challenges relevant for the maritime domain:

- Adaptation to automation may lead to overtrust and a lower level of perceived risk
- Skill degradation – with reliance in automation and in lack of manual driving/steering, skill degradation can occur

- Cognitive underload and/ or reduced trust to the automatic system may lead to increased response time to unexpected hazards compared to manual driving

5.9 Summary

In the ROC, the role of the human operator needs to be adequately defined. To succeed with remote operation, lessons from other domains indicate that one should not undermine challenges in implementing and integrating the technologies and challenges related to ensure that the solution addresses all the relevant aspects of people, process, information and technology. If the human operator is placed in a situation with little or no knowledge of the system's current status, it is possible that the operator ends up taking actions that could additionally harm the system. On the other hand, if the human operator is given all the necessary information about current system status simultaneously, the human will experience cognitive overload, lose track of the system state, and be prone to errors. The challenge is to identify high priority information that has to be communicated to the human to ensure sufficient situational awareness to handle possible disturbances, to ensure sufficient training in the automation and to ensure an adequate level of trust in automation.

6 Summary results of findings relevant for ROC

This chapter summarizes findings chronologically from the previous chapters focusing on findings relevant for design. LOAS will contribute to performing research that need to be carried out in order to make more robust recommendations.

6.1 Regulations for autonomous ships

- Main areas that are challenging are regulations for how to handle: jurisdictional issues; preventing collisions at sea; assist persons in distress at sea; protection of the maritime environment; and cyber-security issues.
- IMO has identified four levels of autonomy, from level one (some automated processes) to level four (fully autonomous ship). The LOAS project is typically at level three and four.
- The Norwegian national regulatory framework DNVGL explains how autonomy shall meet a safety level equivalent or better than conventional vessel operations.
- The DNVGL covers areas such as: safe state; normal operation; redundancy; alternative control; barriers; self-contained capabilities; self-diagnostics and supervision. The guideline is to be further detailed based on more R&D.
- Danish Maritime Authority suggest that the remote operator could be the shipowner´s representative vis a vis the authority.
- COLREG explains how there should at all times be a proper look-out (sight hearing) to avoid collisions. This could be met (COLREG) by electronic sensors (electronic bridge), which might be considered manned.
- Performing assistance to others at sea can be challenging, the focus should be on notifying search and rescue to a shore centre.
- Operators at shore centre should have competence equivalent to navigating officers, operational experience and engineering competence.
- Environmental problems and waste must be handled on-board through sensors and cameras.
- Ship owners must handle cyber and anti-terror threats.

6.2 Theoretical concepts and empirical findings

- Autonomous ships must support operators in all three levels of Situation Awareness (SA). One: do we have the necessary data (the sensors and systems)? Two: are these data sources integrated and presented for operators in a meaningful way? Three: Can operators use this information to predict into the near future, what is happening?
- Operators must be able to efficiently react to data driven information (typically alarms) and perform structured top-down planned operations.
- So-called out-of-the loop situations, where the operator can´t comprehend and understand the automated systems must be avoided. It is important to keep competence to be prepared for when and how to take manual control.
- Operators should be kept in a state of acceptable cognitive workload. Both too high (information overload, fatigue, shift work), or too low (boredom) can challenge human performance.
- Both unreliable systems and over-confidence in the systems challenge human trust and performance.

6.3 R&D cases in the maritime domain

- The Yara Birkeland is soon a fully autonomous ship (2022) and will be sailing 12 nautical miles of the Norwegian coast, operated from a remote center.

- The objective of the Munin case (ended 2015), was to develop and verify a concept for an autonomous ship. A key area was to avoid collision in accordance with international regulations.
- The unmanned and battery powered ReVolt, has a focus on how to operate advanced control systems and navigational software.
- The AAWA (initiated 2015) has the purpose of bringing together and to build general competence. The project will produce specifications and design for autonomous ships.
- The Autosea project (start 2015) has a focus on making know how for technical systems available for autonomous ships. The project has a particular focus on collision avoidance.
- The Autoship (start 2020) will focus on developing improved methods, establishing international standards and improved communication systems for autonomous shipping.
- Cyber enabled ships (2016) have focused on risk areas in relation to cyber-enabled systems.
- Amos (start 2013) focused on: autonomous vehicles; robotic systems; environmental structures and operations.

6.4 Experiences with remote operation from other domains

- Automation experiences in the petroleum domain include challenges related to low perceived risk due to the distance to the safety critical process, insufficient training in how the automatic system operates, and challenges in handling situations where a rapid change in mental state (from passive monitoring to active handling a critical condition) is needed.
- Experiences from UAV operation indicate that operators have a reasonable SA and trust in automated solutions when monitoring up to four UAVs. Operating UAVs may further challenge the operators in their situation understanding, due to limited cues from the surroundings.
- Defence systems highlights ethical aspects related to empathy and sensitivity to the environment in remote warfare in that those who handle remote equipment can have a "virtual" feel of the situation. Another experience from defence is that software updates have not been sufficiently reflected in training and operating procedures.
- Challenges in aerospace include a risk of losing vigilance and become fatigued when monitoring automated systems needing few human interventions
- In aviation, they have experienced overreliance in automation and loss of manual skills. The more automation added, and the more reliable it is, the more likely it is that operators will fail in taking over manual control when needed. Also, high workload peeks in situations when manual control is necessary has been noted.
- Some accidents in the nuclear domain may be related to an incomplete understanding of the functionality of automatic systems.
- Results from research on autonomous cars show similar findings as in aviation, including skill degradation and adaptation to automation leading to overtrust.

6.5 Further work within the LOAS project

In this report we have addressed four questions related to the current state-of-the art for remote operation of autonomous ships: 1) How is operation of autonomous ships incorporated into governing documents? 2) What are important theoretical concepts related to the human operator in remote operation centers? 3) What are the recent and ongoing research and development cases in the maritime domain relevant for autonomous ships? and 4) What are experiences with remote operation from other domains? The findings in this report are mostly on a general level, not directly usable for performing the detailed systems design. Today, the greatest challenges in a new operational concept with unmanned ships do not lie in technological solutions. We are confident that we will find technical solutions that can serve an operator in a land-based operating room. What is important, is to make sure that the information displayed to the operators is correct, adequate and provided at the right time, supporting situation awareness, efficient communication and collaboration. To meet the objectives of the LOAS project, the next step will be moving into more details necessary for performing design of technical systems supporting remote operation (see Lunde-Hanssen, 2020). We will thus document information needs for safe and effective monitoring of autonomous ships from a ROC, and to start developing a design based on an iterative design process.

7 References

AAWA, Remote and Autonomous ships. The next steps. (2016). Position Paper, Rolls-Royce plc. https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf. (visited 15 May 2020)

Ackerman, P.L., Calderwood, C., & Conklin (2012). Task characteristics and fatigue. In In Matthews, G., Desmond, P.A., Neubauer, C., and Hancock, P.A. (eds.). (2012). The Handbook of Operator Fatigue (2012). Ashgate.

Ahvenjärvi, S. (2016). TransNav. The international journal on marine navigation and safety of sea transportation. 10, 3. DOI: 10.12716/1001.10.03.18

AMOS (https://www.ntnu.edu/amos)

Autosea (https://www.ntnu.edu/autosea/about

Autoship (https://www.sintef.no/en/latest-news/sintef-makes-important-contributions-to-autonomous-maritime-transport/)

Banks, V.A., Stanton, N.A. (2016). Keep the driver in control: Automating automobiles of the future. Applied Ergonomics, 53, 389-359

Bainbridge, L. (1983). Ironies of Automation, Automatics, Vol. 19, No 6, 775-779

Bertram, V. (2016). Autonomous ship technology – Smart for sure, unmanned maybe. London, RINA, Royal Institution of Naval Architects.

Benjamin, A., Dezfuli, H., Everett, C. (2016). Developing probabilistic safety performance margins for unknown and underappreciated risks. Reliab Eng Syst Saf;145:329–40. http://dx.doi.org/10.1016/j.ress.2015.07.021.

Board, N. T. S. (2010). Aviation accident report: Loss of control on approach Colgan Air, Inc. operating as Continental Connection Flight 3407 Bombardier DHC-8-400, N200WQ Clarence Center New York, February

Bradshaw, J.M., Hoffman, R.R., Johnson, M., Woods, D.D. (2013). The seven deadly myths of "Autonomous systems". Human Centered Computing, IEEE Computer Society

Boksem, M.A.S., & Tops, M. (2008). Mental fatigue: Costs and benefits. Brain research reviews, 59, 125–139

Braseth, A.O., Toppe, A., Randem, H.O., Fernandes, A. (2020). Applying haptics to interactive large screen displays. In: E.L. Nunes (Ed.): AHFE 2020, AISC 1207, pp. 1-7, 2020.

Chen, H., Stavinoha, S., Walker, M., Zhang, B., Fuhlbrigge, T. (2014). Opportunities and Challenges of Robotics and Automation in Offshore Oil & Gas Industry, Intelligent Control and Automation, 5, 136-145. http://dx.doi.org/10.4236/ica.2014.53016

Cyber-enabled ships. (https://www.lr.org/en/latest-news/early-adopters-and-innovators-in-connected-assets-on-ships/) (accessed on 16 March 2020)

Danish Maritime Authority (2017). Analysis of regulatory barriers to the use of autonomous ships. Final report. Available online at www.dma.dk (accessed on 16 March 2020)

Drury, J. L., Scott, S.D. (2008). Awareness in unmanned aerial vehicle operations, The International C2 Journal, 2, 1–10

Dekker, S. (2005). Ten Questions about Human Error: a New View of Human Factors and System Safety, Lawrence Erlbaum, Mahwah, N.J. (NY, US: CRC Press)

DNVGL-CG-0264. Class Guideline. Autonomous and Remotely Operated Ships. Available online: http://rules.dnvgl.com/docs/pdf/dnvgl/cg/ 2018-09/dnvgl-cg-0264.pdf (accessed on 16 March 2020).

DTU Elektro (X). A pre-analysis on antonomous ships. Technical University of Danmark, DTU Elektro, Lyngby. https://www.dma.dk/Documents/Publikationer/Autonome%20skibe_DTU_rapport_UK.pdf (accessed on 16 March 2020).

Eitrheim, M., Skraaning, G. Jr., Lau, N., Nihlwing, C., Karlsson, T. (2011). Out-of-the-loop performance: Results from the 2009 HAMMLAB experiment. Halden Work Report, OECD Halden Reactor Project, HWR-997

Endsley, M.R. (1995). Toward a theory of situation awareness in dynamic systems. J. Human Factors Ergonom. Soc., 37, pp. 32-64, DOI: 10.1518/001872095779049543

Endsley, M. R. (1996). Automation and situation awareness. In Parasuraman, R. & Mouloua (Eds.) Automation and Human Performance: Theory and Applications, 163-181. Mahwah, N. J.: Lawrence Erlbaum Associates.

Endsley, M.R. (2000). Situation models: an avenue to the modeling of mental models

Proceedings of the Human Factors and Ergonomics Society Annual Meeting, SAGE Publications, UK (2000), pp. 61-64

Endsley, M. R. (2017). From here to autonomy: Lessons learned from human-automation research. Human Factors, 59(1), 5-27.

Endsley, M. (2019). Human Factors & Aviation Safety Testimony to the United States House of Representatives Hearing on Boeing 737-Max8 Crashes. Human Factors and Ergonomics Society. Lewis-Burke associates LLC.

Endsley, M.R., Jones, D.G. (2011) SA Demons: The Enemies of Situation Awareness. In: Designing for Situation Awareness: An Approach to User-Centered Design, chap. 3, pp. 31–41. CRC Press.

Endsley, M.R., Jones, D.G. (2012). Designing for situation awareness: An approach to human-centered design (2nd ed.). London: Taylor & Francis

Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. Human Factors, 37(2), 381-394.

Eitrheim, M.H., Skraaning, G. Jr., Lau, N., Nihlwing, C., Karlsson, T. (2011). Out-of-the-loop performance: Results from the 2009 HAMMLAB experiment. OECD Halden Reactor Project, HWR-997.

Essens, P., Spaans, M., Treurniet, W. (2007). Agile networking in command and control, The International C2 Journal. 1, 177–210.

Farrelly, C.T., Records, L.R. (2007). Remote operations centres – Lessons from other industries. Austrailian Mining Technology Conference, 2-4 October 2007.

Federal Aviation Administration Human Factors Team. (1996). The interfaces between flight crews and modern flight deck systems. Washington, DC: FAA

Funk, K., Lyall, B., Wilson, J., Vint, R., Niemczyk, M., Suroteguh, C., & Owen, G. (1999). Flight deck automation issues. The International Journal of Aviation Psychology, 9(2), 109-123.

Felski, A., Zwolak, K. (2020). The Ocean-Going Autonomous Ship—Challenges and Threats. J. Mar. Sci. Eng. 2020, 8, 41; doi:10.3390/jmse8010041.

Gawron, V. (2019). Automation in aviation accidents: Accident analyses McLean, VA: MITRE Corporation.

Gopher, D. (1993). “The skill of attention control: acquisition and execution of attention strategies,” in Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience, eds D. E. Meyer, and S. Kornblum, (Cambridge, MA: The MIT Press), 299–322.

Goodrich, M.A, Cummings, M.L. (2015). Human factors perspective on next generation unmanned aerial systems. In: Handbook of Unmanned Aerial Vehicles, pp. 2405–2423. Springer, Netherlands.

Grech, M.R., Horberry, T., Koester, T. (2008). Human Factors in the Maritime Domain. CRC Press, Boca Raton, Fla., US.

Hancock, P. A., Williams, G., Manning, C. M., and Miyake, S. (1995). Influence of Task Demand Characteristics on Workload and Performance. Int. J. Aviat. Psychol. 5, 63–86. doi: 10.1207/s15327108ijap0501_5

Hart, S.G., Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In Hancock, Peter A.; Meshkati, Najmedin (eds.). Human Mental Workload. Advances in Psychology. 52. Amsterdam: North Holland. pp. 139–183. doi:10.1016/S0166-4115(08)62386-9. ISBN 978-0-444-70388-0.

Hawley, J.K. (2011). Not by Widgets alone, Armed Forces J., Feb. 2011; www.armedforcesjournal.com/not-by-widgets-alone.

Herman, D., Galeazzi, R., Andersen, J.C. & Blanke, M. (2015). Smart Sensor Based Obstacle Detection for High-Speed Unmanned Surface Vehicle. IFAC-Papers Online, 48(16), pp. 190-197.

Hockey, R. (1996). Skilled Performance and Mental Workload. In: (Ed.) P. Warr: Psychology at Work. 4. ed. Suffolk, UK: Penguin Books, pp. 13-39.

Hoff, K.A., M. Bashir (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. Human Factors, Vol. 57, 407-434.

Hoffman, R.R., Bradshaw, J.M., Ford, K. (2014). Myths of automation, Part 2: Some very human consequences. Human Centered Computing, IEEE Computer Society

Hopstaken, J.F., van der Linden, D., Bakker, A.B., and Kompier, M.A.J. (2015). A mulitfaceted investigation of the link between mental fatigue and task disengagement. Psychophysiology, 52, p. 3015-315.

Howard D., Dai, D. (2014). Public perceptions of self-driving cars: the case of Berkeley, California. Transp. Res. Board 93rd Annu. Meet., vol. 14; p. 21.

Hurlen, L., Skjerve, A.B., Bye, A. (2019). Sensemaking in high-risk situations. The challenges faced by dynamic positioning operators. Proceedings of the 29th ESREL conference. doi: 10.3850/981-973-0000-00-0 esrel2019-paper.

MUNIN (http://www.unmanned-ship.org/munin/) (accessed on 16 March 2020)

IMO: Strategic plan (2017). Strategic plan for the organization for the six-year period 2018 to 2023. Available online: http://www.imo.org/en/About/strategy/Pages/default.aspx (accessed on 20 April, 2020).

IMO: MASS trials (2019). Interim guidelines for MASS trials. MSC.1/Circ.1604. Available online: http://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx (accessed on 20 April, 2020).

IMO: Autonomous shipping. Available online: http://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx (accessed on March 23, 2020)

International Atomic Energy Association (IAEA). (1992). The role of automation and humans in nuclear power plants. Vienna, Austria: International Atomic Energy Association (IAEA).

Jacobson, S. (2010). Aircraft loss of control causal factors and mitigation challenges. Proceedings of the AIAA Guidance, navigation, and control conference (pp. 8007).

Jamson, A.H., Merat, N., Carsten, O.M.J, Lai, F.C.H. (2013). Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions, Transportation research part C., 30, 116-125.

Johnson, E. N., & Pritchett, A. R. (1995). Experimental study of vertical flight path mode awareness. Proceedings of the 6th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design and Evaluation of Man-Machine Systems (pp. 185-190). Cambridge, MA: MIT

Kaarstad, M., Nystad, E. (2019). Impact of degraded process information on operator trust. Proceedings of the 29th European Safety and Reliability Conference, ESREL. doi: 10.3850/981-973-0000-00-0 esrel2019-paper

Kaber, D. B., & Endsley, M. R. (1997). Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety. Process Safety Progress, 16, 126–131.

Komianos, A. (2018). The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges." TransNav: International Journal on Marine Navigation and Safety of Sea Transportation 12. doi:10.12716/1001.12.02.15.

Körber, M., Cingel, A., Zimmermann, M., & Bengler, K. (2015). Vigilance decrement and passive fatigue caused by monotony in automated driving. Procedia manufacturing, 3, 2403-2409.

Lal & Craig (2001). A critical review of the psychphysiology of driver fatigue. Biological Psychology, 55, p. 173-194.

Lee, J. D. (2008). Review of a pivotal human factors article: “Humans and automation: Use, misuse, disuse, abuse”. Human Factors: The Journal of the Human Factors and Ergonomics Society, 50, 404–410. https://doi.org/10.1518/001872008X288547

Lee, J.D., Moray, N. (1992). Trust, control strategies and allocation of function in human machine systems. Ergonomics, 22, 671-691.

Lee, J.D., Moray, N. (1994). Trust, self-confidence, and operators’ adaptation to automation Int. J. Hum Comput Stud., 40, 153-184, DOI: 10.1006/ijhc.1994.1007

Lee, J. D., See, K. A. (2004). Trust in automation: Designing for appropriate reliance. Human Factors, 46(1), 50-80.

Levander, O. (2017). Autonomous Ships on the High Seas. IEEE Spectrum, Issue February, 27-31.

Lunde-Hanssen, L. (2020). Identification of information requirements in ROC operations room. IFE/E-2020/007. ISBN: 978-82-7017-932-9. Institute for Energy Technology, Halden.

Lloyd’s Register (2016), “Cyber-enabled ships. Deploying information and communications technology in shipping” – Lloyd’s Register’s approach to assurance First edition, February 2016.

Louw, T., Merat, N. (2017). Are you in the loop? Using gaze dispersion to understand visual attention during vehicle automation, Transportation Research Part C, 76, 35-50

Madni, A.M. (2010). Integrating humans with software and systems: technical challenges and a research agenda. Syst. Eng. 13(3), 232–245

Man, Y., Lund, M., Porathe, T., MacKinnon, S. (2015). From Desk to Field - Human Factor Issues in Remote Monitoring and Controlling of Autonomous Unmanned Vessels. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015)

Man, Y., Lund, M., Porathe, T. (2014). Seeking Harmony in Shore-based Unmanned Ship Handling From the Perspective of Human Factors, in N. Stanton, G. Di Bucchianico, A. Vallicelli, S. Landry (Eds.), What Is the Difference We Need to Focus on from Being Onboard to Onshore? Advances in Human Aspects of Transportation, 231-239.

Manzey, D., Bahner, J.E., Hueper, A.D. (2006). Misuse of automated aids in process control: Complacency, automation bias and possible training interventions. Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting, 220-224.

Massaiu, S., Skjerve, A.B., Skraaning, G. Jr., Strand, S., Wærø, I. (2004) Studying Human-Automation Interactions: Methodological Lessons Learned from the Human-Centred Automation Experiments 1997-2001. Halden Work Report, OECD Halden Reactor Project, HWR-760

Matthews, G., Desmond, P. A., Neubauer, C., & Hancock, P. A. (Eds.). (2012). The handbook of operator fatigue. Aldershot, UK: Ashgate Press.

McKendrick, R., Feest, B., Harwood, A., Falcone, B. (2019)- Theories and methods for labelling cognitive workload: Classfication and transfer learning. Front.Hum.Neurosci., doi.org/10.3389/fnhum.2019.00295

Meister, D. (1965). Human factors evaluation in system development. New York: Wiley and Sons

Merat, N., Jamson, A.H., Lai, F.C.H., Daly, M., Carsten, O.M.J. (2014). Transition to manual: Driver behavior when resuming control from a highly automated vehicle, Transportation Research Part F, 27, 274-282.

Miller, G. (1956). The Magical Number Seven, Plus or Minus Two: Some limits on our capacity for processing information. Psychological Review. 63 (2): 81–97.

Muir, B.M. (1994). Trust in automation: Part I. Theoretical issues in the study of trust and human intervention in automated systems. Ergonomics, 37, 1905-1922.

Molloy, R., & Parasuraman, R. (1996). Monitoring an automated system for a single failure: Vigilance and task complexity effects. Human Factors, 38(2), 311-322

Mosier, K.L., Skitka, L.J. (1996). Human decision makers and automated decision aids: made for each other? In: Parasuraman, R., Mouloua, M. (eds.) Automation and Human Performance: Theory and Applications, Human Factors in Transportation, pp. 201–220. Lawrence Erlbaum.

NASA (www.nasa.com https://www.nasa.gov/audience/foreducators/k-4/features/F_People_Behind_the_Astronauts.html) (accessed on 15 May, 2020)

Nihlwing, C., Hurlen, L., Teigen, A., Jokstad, H. (2010). Transparent Automation Displays - Design and Evaluation. Halden Work Report, OECD Halden Reactor Project, HWR-935

Nordby, K., Gernez, E., Mallam, S. (2019). OpenBridge: Designing for Consistency Across User Interfaces in Multi-Vendor Ship Bridges. Conference: Ergoship 2019, Haugesund

Norris, J.N. (2017). Human factors in military maritime and expeditionary settings: Opprtunity for automomous systems? AHFE, 139-147.

Nuclear Regulatory Commission. (2004). Human Factors Engineering Program Review Model. Washington, DC: Nuclear Regulatory Commission

O´Hara, J., Higgins, J., Fleger, S., Barnes, V. (2010). Guidance for Human-system Interfaces to Automatic Systems, BNL-93751-2010-CP

Ordoukhanian, E., Madni, A.M. (2016). Toward development of resilient multi-UAV system-of-systems. In: AIAA SPACE 2016, vol. 5414

Orlady, L. M. (2010). Airline pilot training today and tomorrow Crew resource management (pp. 469-491): Elsevier

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 30, 286–297. https://doi.org/10.1109/3468.844354

PBS. (1999). Meltdown at Three Mile Island. Arlington, VA.

Porathe, T., Hoem, Å., Rødseth, Ø., Fjørtoft, K., Johnsen, S.O. (2018). At least as safe as manned shipping? Autonomous shipping, safety and “human error”. Safety and reliability – Safe societies in a chaning world – Haugen et al. (Eds) Tyler & Francis Group, London (2018).

Porathe, T., Prison, J.,Yemao, M. (2014). Situation awareness in remote control centres for unmanned ship, In Proceedings of Human Factors in Ship Design & Operation, London, UK, 26-27.

ReVolt (https://www.dnvgl.com/technology-innovation/revolt/index.html) (accessed on 16 March 2020)

Ringbom, H. (2019): Regulating Autonomous Ships—Concepts, Challenges and Precedents, Ocean Development & International Law, doi: 10.1080/00908320.2019.1582593

Ruff, H.A., Narayanan, S., Draper, M.H. (2002). Human interaction with levels of automation and decision aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. Presence 11, 335–351

Saffarian, M., De Winter, J.C.F., Happee, R. (2012). Automated driving: human-factors issues and design solutions, In Proceedings of the Human Factors and Ergonomics Society Annual Meeting 56, Sage Publications, 2296–2300.

Sadeghniiat-Haghighi, K., & Yazdi, Z. (2015). Fatigue management in the workplace. Industrial psychiatry Journal, 24(1), 12-17.

Sandhåland, H., Oltedal, H., Eid, J. (2015). Situation awareness in bridge operations – A study of collisions between attendant vessels and offshore facilities in the North Sea, Safety science, 79, 277-285, https://doi.org/10.1016/j.ssci.2015.06.021

Schmitt, K. (2012) Automations influence on nuclear power plants: a look at three accidents and how automation played a role. Work 41 (2012) 4545-4551 DOI 10.3233/WOR-2012-0035-4545 IOS Press

Sgobba, T. (2018) Space Safety and Human Performance. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-101869-9.00013-3

Sivak, M., Schoettle, B. (2015). Road safety with self-driving vehicles: general limitations and road sharing with conventional vehicles. Ann Arbor.

Sheridan, T.B. (1993). Space teleoperation through time delay: review and prognosis. Robotics and Automation, IEEE Transactions on, 9 (1993) 592– 606.

Sheridan, T.B. (1992). Telerobotics, automation and human supervisory control. The MIT Press Cambridge, Massachusetts London, England.

Skjerve, A.B., Andresen, G., Saarni, R., Skraaning, G. Jr. (2001). How Automation Malfunctions Influence Operator Performance. Study Plan for the HCA-2000 Experiment. Halden Work Report, OECD Halden Reactor Project, HWR-659

Skjerve, A.B., Strand, S., Skraaning, G. Jr., Nihlwing, C., Helgar, S., Olsen, A., Kvilesjø, A.Ø., Meyer, G., Drøivoldsmo, A., Svengren, H. (2005). The extended teamwork 2004/2005 exploratory study. Study plan. OECD Halden Reactor Project, HWR-791.

Skjerve, A.B., Strand, S., Skraaning, G.Jr., Nihlwing, C., Helgar, S., Olsen, A., Kvilesjø, H.Ø., Meyer, G., Drøivoldsmo, A., Svendgren, H. (2005a) The Extended Teamwork 2004/2005 Exploratory Study. Study Plan. Halden Work Report, OECD Halden Reactor Project, HWR-791

Skjerve, A.B., Strand, S., Skraaning G. Jr., Nihlwing C. (2005b) The Extended Teamwork 2004/2005 Exploratory Study. Preliminary Results. Halden Work Report, OECD Halden Reactor Project, HWR-812

Skraaning, G. Jr., Jamieson, G.A. (2017). Twenty Years of HRP Research on Human-Automation Interactoin: Insights on Automatino Transparency and Levels of Automation. OECD Halden Reactor Project, HPR-387.

Skraaning, G. Jr., Eitrheim, M., Lau, N., Nihlwing, C., Hurlen, L., Karlsson, T. (2010) Coping with Automation in Future Plants: Results from the 2009 HAMMLAB Experiment. Halden Work Report, OECD Halden Reactor Project, HWR-937

Soller, A., Morrison, J. (2008). The Effects of Automation on Battle Manager Workload and Performance. Institute for defense analysis IDA Document D-3523. https://apps.dtic.mil/dtic/tr/fulltext/u2/a482741.pdf

Strand, N., Nilsson, J., Karlsson, I.C.M.A., Nilsson, L. (2014). Semi-automated versus highly automated driving in critical situations caused by automation failures, Transportation research Part F, 27, 218-228.

Strand, S., Nystad, E., McDonald, R. (2019). Operator mental fatigue-the concept, its relation to performance, and mitigation strategies. OECD Halden Reactor Project, HWR-1262.

Stratmann, T.C., Boll, S. (2016). Demon hunt – The role of Endsley´s Deons of Situation Awareness in maritime accidents. International conference on Human-Centered Software Engineering International Working Conference on Human, Error, Safety and System Development.

Strauch, B. (2017). Ironies of automation: Still unresolved after all these years. IEEE Transactions on HumanMachine Systems, 48(5), 419-433.

Teigen, K.H. (1994). Yerkes-Dodson: A law for all seasons. Theory & Psycnology, 4: 525-547. Sage Publications, DOI: 10.1177/0959354394044004

Thieme CA, Utne IB. (2017). Safety performance monitoring of autonomous marine systems. Reliab Eng Syst Saf;159:264–75

Tomotsugu, N., (2016) "Existing conventions and unmanned ships - need for changes?". World Maritime University Dissertation 527. http://commons.wmu.se/ all_dissertations/527 (Accessed October 2017).

Tvaryanas, A.P. (2006). Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (No. HSW-PE-BR-TR-2006-0001).

Yara Birkeland (https://www.kongsberg.com/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/)

Wickens, C. D. (2008). Multiple resources and mental workload. Hum. Factors 50, 449–455. doi: 10.1518/001872008x288394

Wagstaff, A.S., Sigstad Lie, J.A. (2011). Shift and night work and long working hours − a systematic review of safety implications. Scandinavian Journal of Work Environment and Health, 37, 3, 173–185.

Wahlström, M., Hakulinen, J., Karvonen, H., Lindborg, I. (2015). Human factors challenges in unmanned ship operations– insights from other domains. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015).

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. Automation and human performance: Theory and applications, 183-200.

Wiener, E. L. (1985). Beyond the sterile cockpit. Human Factors, 27(1), 75-90.

Wilson, K., Korn, J.H. (2007). Attention During Lectures: Beyond Ten Minutes. Teaching of Psychology, 34: 2, 85–89.

Wiener, E. L., & Nagel, D. C. (Eds.). (1988). Human Factors in Aviation. San Diego: Academic Press.

Winter, J.C.F. (2014). Controversy in human factors constructs and the explosive use of the NASA-TLX: a measurement perspective. Cogn. Technol. Work 16, 289–297. doi: 10.1007/s10111-014-0275-1

Winter, J.C.F., Happee, R., Martens, M., Stanton, N.A. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness. Transportation research Part F 27, 196-217.

Woods, D. D., Cook, R. I. (2017). Incidents–markers of resilience or brittleness? Resilience Engineering (pp. 69-76): CRC Press.

Woods, D.D., Hollnagel, E. (2006). Joint Cognitive Systems: Patterns in Cognitive Systems Engineering, Taylor & Francis.

Wróbel, K., Montewka, J., Kujala, P. (2017). Towards the assessment of potential impact of unmanned vessels onmaritime transportation safety. Reliability Engineering and Systems Safety 165, 155-169

Zeeb, K., Buchner, A., Schrauf, M. (2016). Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving, Accident Analysis and Prevention, 92, 230-239.

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