RCC-CERT

The drafting of a study on the definition and organisation of a Remote Control Centre (RCC) with a view to its CERTification

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1 Executive summary

The development of remote-controlled MASS and is progressing in large steps. The first remote control centers will be started in the near future. MASS will then be used not only in national waters, but also on international routes. However, internationally binding agreements are still lacking for the implementation of international MASS concepts.
The aim of this study is to show which requirements must be placed on a remote-control centre for MASS in order to be able to approve and certify it.
In 2022, the IMO's Regulatory Scoping Exercise on autonomous shipping was completed. From the perspective of an RCC, the aspects of SOLAS and the attached codes as well as STCW are particularly important. Based on these findings, this study is based on the following assumptions:

> An RCC is part of the MASS system. Without an RCC, safe operation of MASS at sea is not possible.
> International conventions such as SOLAS and STCW are also to apply to MASS systems according to their size and purpose. An additional specific MASS-Code and correspondingly binding rules and guidelines are to be expected in these conventions.
> The operators of an RCC are integrated in the international ship traffic, sailing a MASS according to a crew of a seagoing vessel, and are to classify similar as seafarers. However, the labour law of the State in which the RCC is located shall apply.
> The terminology "Master" is only used in the case that a crew is on board. If there is no crew on board, this study speaks of a supervisor who acts in the sense of a fleet captain.

Based on this study, it is possible that Belgium can define interim guidelines and regulations in cooperation with the states through whose waters a MASS is to sail.

As a basis for the study, research and application projects in which RCCs are developed or used were analyzed. The projects are listed and discussed in Appendix A.

As a reference, two use cases have been defined in which the requirements for an RCC are discussed. In use case A, a MASS in short sea traffic is considered, which transports dry cargo on voyages between international ports. It is assumed that the fleet includes 6 MASS’s, which do not have a crew on board. In use case B, on the other hand, MASS are treated, which carry out missions such as dredging or surveying in coastal waters. For a control center, a smaller fleet of about 3 MASSs is assumed, which are equipped with mission-specific technologies.

Planning, implementation and verification must take place in regulated steps. It has been worked out that the authorities must be informed at a very early stage of planning. It is recommended to grant a permit for the implementation of a project on the basis of a “Concept of Operation”. This includes not only a technical representation of the MASS system, but also the consideration of the human factor and the operational envelope. This increases the probability of successful implementation and subsequent acceptance and certification.

For the two use cases, the study presents the core functions and processes of a voyage and the associated sea passages. A human factors-centered design (HFCD) approach usable for different expected degrees of automation has been defined. The HFCD approach encompasses steps to define and evaluate functions, tasks, roles, organisations, work stations and control room designs for RCCs. In the study the HFCD approach has been applied to use case A. First, functions, tasks and roles that take over and implement the conventional core functions and processes of a voyage have been defined. High-level tasks as well as operational processes have been developed and associated high-level requirements have been derived. These requirements were used to implement an RCC organization.

With regard to the degrees of automation, it is assumed that the development of the MASS systems will result in different levels of individual applications that will exist in parallel in a MASS system. For example, there will be navigation systems that can work fully autonomously, but on the other hand there will also be technical systems on deck or in the engine room that can only be used semi-automatically and require direct intervention. Thus, it is also to be expected that in a transitional period of indefinite length, additional people will be on board in the discussed use cases to support the less automated processes. Overall, however, it is assumed that the functionality of an RCC is aimed at taking full control of the operations of a MASS.

In a concept study, the structure of workstations and a complete RCC design for the example use case A is presented. This concept study has been performed as part of the HFCD approach. The workstations for direct control take over the maneuvers and activities for which direct intervention with a fast reaction time may be necessary. This requirement exists, for example, in port maneuvers, in restricted waters or heavy weather situations. In direct control mode, a single MASS is controlled, a second navigator can also be used at this station if required. If the MASS is in an area where they are sailing independently, the monitoring station takes over. From there, several MASS are observed simultaneously by one operator. The expected reaction times are longer, so a single MASS can be delivered to a direct control station if limits are exceeded. Working in an RCC requires special attention to keep situational awareness at a high level which is considered in the design by many parameters.

The safety and security-relevant concerns for an RCC are explained. Risk assessments must be carried out in various fields. The topics are named in this study.

Finally, the content of a Concept of Operations (ConOps) is proposed. In this concept, all decisive parameters must be defined and evaluated by the operating institution at a very early stage of a project to set up a MASS system. This approach is very important because there is little experience with MASS systems and technical development is progressing rapidly. The depth and scope of the ConOps will be subject to change. Adjustments and changes to the system must be entered into ConOps and presented as a revision as well.

Based on all considerations, approvals and certificates are listed that are relevant to a remote-control center. This proposal should be carefully examined and clarified in substance. The certification of the mobile MASS itself must be clarified independently.

This study can be used as a basis for further discussion on the approval and certification of an RCC as part of a MASS-system. There is room for interpretation in several topics. Too narrow a definition of rules should be avoided. MASS systems are under development and require the necessary freedom. Rules and guidelines should therefore focus on the safety-relevant aspects that enable the safe use of MASS at sea.

2 Remote Control Centres in the maritime domain

This chapter offers a detailed examination of the latest advancements in Remote Control Centers for autonomous shipping. While numerous studies, projects, and industry initiatives have been undertaken and initial outcomes have been demonstrated, our intention is not to present a comprehensive catalogue of these research endeavours. Instead, we aim to spotlight current trends, concepts, and challenges by providing a curated selection of the most pertinent projects and initiatives. In our study we use the term Remote Control Centres (RCC). Several other terms are commonly used in the community for autonomous shipping: Shore Control Center (SCC), Shore Operations Centre (SOC), Remote Operation Center (ROC), Base Control Station (BCS) to name just a few. In essence, these terms refer to the same concept, a centre, located onshore, for monitoring and controlling one or more ships. The operators at these centres are physically separated from the ships they are monitoring and controlling. In more advanced projects (like MUNIN, LOAS), monitoring takes place during normal operation and human control is only necessary in situations that exceed or are approaching the limitations of the onboard automation. In other projects (like Seafar, FernBin), the RCC is designed for remote steering of a ship with limited automation onboard. The active involvement of human operators in both cases is crucial for the safe operation of the ships.

An important consideration in the design of RCC is how to ensure that the operator remains informed and able to intervene when necessary, or how to quickly bring her/him back in the loop when necessary. Accepted guidelines for the design and certification of a RCC are currently missing. Therefore, early projects just replicated the ship bridge and moved it to a shore-based control centre (e.g., Dybvik, Veitch, Steinert 2020). A crucial question in this line of thinking is to what degree a level of "ship sense" must be replicated (Dybvik, Veitch, Steinert 2020): smell, sound, touch, sight, vibrations, movements. Ship sense includes e.g., "the experience of how a hull performs in different wave patterns", „Risks of broaching in following seas, or slamming if you head too fast into breaking waves?" (Porathe 2021). Designers might strive to install technology to copy the same feeling a mariner would have onboard, using e.g., motion beds, vibrating seats, and smell alarms. On the other side, we must ask if this approach stems from a mental fixation to the old model of seafaring and if new sensors are maybe much more reliable than the human senses (Dybvik, Veitch, Steinert 2020). Either way, it is important to recognize that the requirements for remote control differ significantly from those of direct on-board control. Some RCCs existing today realize a one-to-one relation, meaning that there is one operator directly controlling/steering one ship. In the future this will very likely not be the case. More and more autonomous ships will be approved, and one operator will be able to oversee more than one ship, at least in normal operation situations. In certain aspects, the tasks of the remote operator resemble those of Vessel Traffic Service (VTS) operators. VTS operators monitor several ships of different types. However, while VTS operators primarily monitor and assist remote ships, the remote operator in an RCC may perform direct control in certain situations. It is crucial to understand these distinctions and to define a new role for RCC operators. This role must be supported by implementing sophisticated design solutions to ensure safe and efficient operation. Developers and certification organizations are faced with new challenges when designing or approving an RCC:

- Which roles must be present in an RCC and how do they cooperate?
- How many ships can be monitored by an operator at the same time?
- How to support an adequate situation awareness via the human-machine interaction (what information, when, in what form) and how to compensate for not being on-board the ship?
- When should operators in the RCC take manual control?
- How do legal aspects influence the design of an RCC?

- How to design robust cybersecurity measures to protect against potential cyber-attacks that could compromise the safety and operation of the ship?
- Will RCCs be operated by ports, by shipping companies, by VTS centers, or by private companies?
- Will there by different RCC for different parts of the voyage with associated hand-over procedures?
- Will one RCC be able to operate very different types of ships?

The results of the state-of-the–art review can be found in the Appendix A of the report. The appendix presents selected projects and shows how the challenges from above have been addressed. Each of the selected projects has been analysed according to the following questions:

- Which automation use-cases are investigated?
- How is the RCC structured and organised?
  This includes workstations, operator roles, cooperation, tasks, HMI.
- How have safety and security for RCCs been addressed?
- Which legal aspects have been considered?

3 Use cases and operational envelopes

3.1 Use cases

The application and so named use cases for MASS can vary widely. The design and organization of an RCC must correspond to the respective use case. In a study commissioned by the German Maritime Centre (DMZ), criteria for the differentiation of use cases were worked out (DLR, HSB, ISL, PCCG, 2022). The top differentiation for the use of MASS are the various shipping clusters. These are named as

> Transport of dry cargo
> Transport of liquids and gases
> Transport of passengers
> Offshore works
> Service Works in port and fairways
> Research, exploration and surveying
> Sovereign tasks
> Leisure boating

For these shipping clusters, the use cases have been broken down further. It is evident that the performance profile and the resulting requirements have an impact on the design of the overall system. For example, the use of remote-controlled systems in exploration is very different from operating a shipping line to transport goods. These differences can be shown on the basis of other criteria.

A distinction can be made between four different types of "routes":

> Planned tracks – these are planned in relation to the respective application, for example for surveying work or tugboat manoeuvres.
> Standard routes – here the same berths are regularly called, such as in the liner service of container ships.
> Changing routes – the MASS regularly calls at different destinations with a wide variety of conditions.
> Manoeuvres – in limited areas, manoeuvres are very situation related, e.g. influenced by the environmental conditions.

The "routes" differ for example with regard to the respective available data basis (e.g. surveying) or the available Automated Facility Services AFS (e.g. sensor systems).

Furthermore, voyage relations and passage times are an essential element. Three areas can be differentiated for the use cases:

> Inland – use on inland waterways up to maritime borders.
> Regional – use in spatially limited areas, such as short sea traffic or offshore operations. Passage times are about less than three days.
> Worldwide – use over long distances and long duration of voyages.

This is a rough differentiation, but it becomes clear that the requirements can be very different. An RCC must be staffed according to the duration of the voyage, very different support systems (navigation, positioning, communication) can be available, the environmental requirements (weather, sea conditions) can be very different, the levels of automation can differ.

Another aspect are the propulsion and auxiliary systems technologies used, and the operational technical requirements of MASS. From today's perspective, electric drives will initially be used. The necessary accumulators can be charged in port, but depending on the load and duration of the voyage, recharging may be required. This then demands other systems such as solar panels, wind propellers or generators powered by biofuel. Furthermore, supporting propulsion systems are possible, which use the wind like rigid sails. Propulsion systems can therefore have very different complexity, which affects operation, control, alarm management and maintenance.

Ultimately, the requirements for an RCC are defined by the size of the fleet and its degree of automation. The number of MASS and the necessary effort in their control results in the dimensioning of an RCC with regard to workstations and their technical equipment as well as the necessary number of people and how they are organized.

Remote Control Centers will be technologically and organizationally aligned to the respective use case. In this study, only sailing a MASS from berth to berth is considered. Other operational functions attributable to the type of vessel are not included. This would include activities such as supervising underwater work, loading and unloading the vessel or operations at offshore structures.

The use cases will be subject to a very dynamic development with a high level of innovation in the coming years. From today's perspective, technological progress cannot be fully predicted and will lead to new insights, also with regard to the operation of RCC.

For this study the operational envelope of two for Belgium most probable use cases will be outlined.

Case A: transportation of dry cargoes in shipments in short sea traffic.

Case B: operating in missions as surveying or dredging on coastal waters.

The use cases are not specified in detail yet. For this case study they are used to stay focused and to have references for this study.

3.2 Operational envelope

3.2.1 Content of an operational envelope

The term of an “operational envelope for MASS” is getting established in the maritime industry. Definitions can be found in several guidelines of different classification societies. Also, the operational envelopes are defined in the ISO/TS 23860 (ISO, 2022). When taking the different definitions into account, the operational envelope shall contain …

a. … the definition of the MASS system and its use case,
b. … the geographic area of operations, including traffic systems and traffic density,
c. … the description of the environmental conditions,
d. … the description of operations with the stages of the voyage which shall be executed,
e. … the system conditions which mean the level of automation and autonomy,
f. … the functions (processes) for the required operations, and
g. … the division of responsibilities between humans and automation.

The two use cases are explained below with reference to points (a.) to (d.). Subsequently, the automation levels (e.) as well as the processes and functions (f.) are discussed across the board. Finally, the structures and tasks of the RCC and the division of responsibilities are discussed (g.).

3.2.2 Use Case A – dry cargo transportation

<u>MASS system and its use case</u>

The basic application is the transport of dry cargo between Belgian seaports and ports in neighbouring countries. Cargo is issued by containers (standardized cargo), break bulk (semi-standardized cargo) or bulk and neo-bulk cargo.

The MASS is determined with a maximum size of about 5000 GT. This corresponds to ship dimensions of approx. 100m length, 17m beam and 4 to 6m draught.

The loading capacity is about 6,400 tdw (deadweight). This is approx. a cargo of 430 20’-container or 6,000 t bulk cargo. It is assumed that the MASS are designed in such a way that they can also call at smaller ports with water depths of up to 7m. They are not suitable for navigation on inland waters because of lower fairway depths and bridge heights.

Due to the expected relatively short passages, an electric propulsion is assumed. The accumulators are charged in port, but charging must also be possible at sea. This will require sufficient storage capacity and additional generator sets on bio-fuel. Also, flettner rotors might be possible to support propulsion.
The MASS is propelled by a CPP (controllable pitch propeller) and has electric bow and stern thrusters for better maneuverability. Equipped in this way, manoeuvring from a remote-controlled position is also possible in stronger winds and currents.
The speed of the MASS is set at 9 to 12 kn to keep the consumption of energy low. As maximum speed 15 kn should be possible to be able to meet also harsh weather conditions.
The MASS is controlled by an RCC in Belgium. The size of the RCC is determined by the size of the fleet to be controlled. This use case assumes a fleet of up to 12 vessels. At the start there will be fewer, but the dimensioning is based on the expected fleet size.
The MASS will sail the Belgian flag.
In general, it is to mention that the MASS will not have the same design as today's ships. The designs will be adapted to the innovations to be able to drive autonomously.

<u>Area of operations</u>
In principle, it is assumed that the MASS sails in Belgian waters and calls international ports in neighboring countries. With the introduction of greater automation of shipping and the use of remote control, it is very likely that only certain ports will be called. The MASS will operate on standard routes and serve the same berths. In the targeted short sea trades, borders are crossed, which means that both national and international regulations must be observed.

The area in which MASS are to be used is very demanding. At first some examples of exemplary voyages:

Gent (BE) – Le Havre (FR)	ca. 260nm	duration 24h – 36h
Antwerp (BE) – Rotterdam Waalhaven (NL)	ca. 165nm	duration 18h – 24h
Brugge (BE) – Hull (UK)	ca. 210nm	duration 24h – 36h

Figure 1: Exemplary voyages for MASS in short sea traffic (maps from www.Ope SeaMap.org)

The sea area is characterized by various navigational challenges:

> The available space at sea is limited:
  - The water depths near the coast are in many areas low;
  - There is a high density of offshore structures at sea;
  - A large number of navigation marks and traffic separation schemes regulate the flow of traffic.

> The traffic density is very high;
  - There are many ports in this area with many approaching and leaving ships;

- The courses of the ships often passes by crossing courses;
- The sizes of vessels in the area range from small boats and fishing vessels to the largest container ships and tankers.

Environmental conditions

The MASS will operate in the Schelde estuary and in the southwesterly North Sea. The environmental conditions in this area are very challenging and variable:

> High wind speeds can prevail at short notice from different directions;
> Strong tidal currents are recorded along the coasts;
> The swell is characterized by a short and steep wave;
> Visibility can be very restricted;

A ship of 5,000 GT is quite a small ship at sea. The weather and environmental conditions need to be observed very carefully, changes predicted by forecasts must be considered in an early stage of a passage. With the small expected speed of the MASS it can need time to reach sheltered waters.
The trips across the open North Sea require sufficient motorization. The wind and sea conditions in the planned region can change significantly in the short term, in addition to strong tidal currents. The MASS must be able to steam against stronger currents and against swells. The speed reserve must be so large that strong drift and associated drift-angles remain small.

Stages of a voyage

The stages of the above-mentioned short sea voyages have the same sequence:

> Prepare the ship for departure, make it seaworthy and ready to leave;
> Departure, leaving the berth, casting off all connections;
> Manoeuvre the ship to the fairway;
> Pilotage out of the port, through fairways and rivers, passing of locks;
> Sea passage to the approach of the port of destination, all through coastal waters
> Anchoring or positioning for waiting or if required
> Pilotage through fairways and rivers into the port of destination;
> Manoeuvre the ship to the berth;
> Arrival in the port of destination, connect the ship to shore, all systems to port operations.

The interface for the RCC is to take over a MASS at a berth, prepare for the passage to the port of destination, and to sail the MASS to the berth in this port.
The stages are explained more detailed in the chapter with the process descriptions.

3.2.3 Use Case B – surveying and dredging operations

MASS system and its use case

Applications in the field of offshore services are very diverse. Unlike cargo ships, these vessels are equipped with very specific technologies to perform certain tasks at sea. Thus, the definition of a specific use case is difficult, and it must be focused on the similarities. The aim of this study is to work out the requirements for an RCC from the perspective of operating a sea passage. Specific work for which these types of vessels are built must be considered separately and will not be covered in this study.
It is assumed that a MASS for this use case and under international regulations starts at a length of about 40m up to 120m. One area of application will be surveying. These MASS carry specific measuring instruments and devices that can work largely autonomously. Such MASS can be between 40 and 60m in length. Another area of application are dredgers that ensure the guaranteed water depths of the fairways. These dredgers are about 100m long. These MASS' are equipped with complex systems,

depending on the technology used. These dredgers transport the dredged material out of the rivers and dump it at sea.

Due to the simpler operation, electric drives can be assumed for the smaller units. The accumulators can be charged in the port, but requires appropriate break times. For larger units with high mechanical equipment, a significantly higher energy consumption is to be expected. Thus, biofuels with heat engines are to be expected which in turn can supply electric drives and machines with electrical energy. Accordingly, a higher maintenance effort is necessary for these machines.

The propulsion power can be up to 5,000 kW. The technologies of propulsion can be very different, from POD-systems to simple fixed propellers. Speeds will range from dead slow speed when they are in operation, up to 12 or 15 knots when calling an area of operation or a port.

The MASS is controlled by an RCC in Belgium. The size of the RCC is determined by the size of the fleet to be controlled. This use case assumes a fleet of up to 4 vessels. The small number is assumed due to the fact that in one operating area not so many vessels of one type will operate.

The MASS will sail the Belgian flag. In general, it is to mention that the offshore vessels will not have the same design as today's ships. The designs will be adapted to the innovations to be able to drive remote controlled and autonomously.

<u>Area of operations</u>

It is assumed that the MASS will sail in national waters, but will also operate in international or other national waters. The MASS has one home port and starts the operations from one berth. From the home port the ship will sail planned routes, sailing back when the work orders are fulfilled. The routes are not standardized and may change with each operation order. Also, the home port may change frequently.

The duration of passages depends on the area of operation. It can be many miles offshore, or only a small area in a fairway. For dredgers the range of operation is usually restricted by the draught and freeboard of the vessel based on the mass of loaded material. In general, the distances sailed are expected to be less than 150 nm in the days run. For this study operations at daytime are assumed, with sailing to the mission area and back it will be less than 18 hours. For that a 24 hour service of the RCC is not required.

Anyway, the challenges of traffic and navigation of the sea area are the same as discussed in the operational envelope before.

Figure 2: Sea area off the Belgian coast (map from www.Ope SeaMap.org)

Environmental conditions

The environmental conditions correspond to the challenges described in the previous operational envelope for the short sea traffic.

In bad weather conditions, many jobs at sea can no longer be carried out safely or efficiently. Thus, ships in offshore operations have a better chance of staying in port or sheltered areas when conditions deteriorate.

Stages of a voyage

The stages of the above-mentioned voyages have usually the same sequence:

- Prepare the ship for departure, make it seaworthy and achieve readiness for the mission;
- Departure, leaving the berth, casting off all connections;
- Manoeuvre the ship to the fairway;
- Pilotage out of the port, through fairways and rivers, passing of locks;
- Operate missions at sea or on the river, depending on the type of ship;
- Anchoring if required;
- Pilotage back into the home port, through fairways and rivers;
- Manoeuvre the ship to the berth;
- Arrival in the home port, connect the ship to shore, all systems switched to port operations.

The interface for the RCC is to take over the MASS at a berth, to prepare for the voyage, to fulfill the mission, and to sail the MASS back to the berth in the home port.

The stages are explained more detailed in the chapter 4.2 with the process descriptions.

3.3 Degrees of autonomy

For the remote control of a seagoing vessel very different technical tasks are necessary. It cannot be assumed that all these tasks will have the same degree of automation.

For the use cases mentioned, the following subtasks must be expected at a minimum. These tasks depend on the entire sensor technology as well as on the automation functions and human-machine interfaces.

- Plan and perform navigation from A to B (position, courses, fallback rules, ...)
- Control of all navigation systems (echosounder, lights and shapes, ...)
- Perform data communication with stations on land and at sea
- Control of the entire ship propulsion (such as machines, propellers, rudders, ...)
- Control and maintaining of the entire technical support systems (power management, lines and pumps, ..)
- Control and maintenance of all deck systems (winches, anchor spill, gangway, ventilation, ...)
- Control systems for cargo (ventilation, temperature control, cargo securing, ...)
- Management of safety-relevant alarms (fire, water ingress, emergency towing, ...) and initiating the required response actions
- Condition monitoring and control of critical systems

The technical subsystems are subject to ongoing technical innovation and will continue to increase their level of automation. But they also have a life cycle in which they are applied. This results in a large variation in stages of technical development that will influence the degree of autonomy.

Basically, it can be assumed that there will not be a single level of automation or autonomy. Each MASS system with all subsystems must be evaluated individually.

The design of an RCC must be aligned with the level of autonomy of the MASS. The IMO regulatory scoping exercise for MASS distinguishes four levels of autonomy. In this study, it is assumed that there is no crew on board and that the MASS is controlled from shore. This corresponds to level 3 of the IMO exercise (MASS with no crew on board).
In the MSC 100/5/6 a proposal was made[1] in which the levels were specified in a little more differentiated way. This is explained in the table below.

For the described use cases and operational envelopes, the combination A2-B0 is assumed in this study in general. Thus, it is assumed that the MASS can sail autonomously and can make all decisions and actions itself on the voyage. A remote operator does not have to give permission to these decisions. However, the operator must always be kept informed, he must actively observe the MASS. In case of deviations, the remote operator can always intervene and override the system (which means to switch down to A1 or A0 level).

The systems of a MASS will develop at different speeds in the near future. It is to be expected, for example, that navigation systems with a very high degree of autonomy can be used. Thus, these systems would grow into level A3-B0. Based on defined parameters, the system can alert the operator if the limits are exceeded. This is associated with a different situational awareness than in level A2-B0. On the other hand, there will be systems that have not yet reached a high degree of automation. This can be, for example, an anchor manoeuvre that still requires an active command from the operator. This would put the system down to level A1-B0.

Table 1: Levels of autonomy and control (source: proposal MSC 100/5/6)

			No qualified operators on board but qualified operators available at a remote location	Qualified operators on board
Levels of autonomy	A0	**Manual** Manual operations and control of ship systems and functions, including basic individual system level automation for simple tasks and functions.	X	A0-B1
	A1	**Delegated** Permission is required for the execution of functions, decisions and actions; the operator can override the system at any stage	A1-B0	A1-B1
	A2	**Supervised** The qualified operator is always informed of all decisions taken by the system. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the system at any stage.	A2-B0	A2-B1
	A3	**Autonomous** The qualified operator is informed by the system in case of emergency or when ship systems are outside of defined parameters. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the ship system when outside of defined parameters. Provided the boundaries of the ship system are not exceeded, “human control” becomes “human supervision”.	A3-B0	A3-B1

[1] By the states of Australia, Denmark, Finland, France and Turkey, at 12.10.2018

Another approach to the characteristic of automation is developed in the project AUTOSHIP (Roedseth, Wennersberg, & Nordahl, 2021).
This approach takes into account that the degree of automation or autonomy for the subsystems may vary, and that different response times are necessary for the subsystem to safely perform the assigned actions.
This is expressed with the value $\mathbf{T_{DL}}$, i.e. the **response deadline**, which is the minimum response time so that processes and functions can be carried out safely. As example, the response deadline for an alarm about engine temperatures developing into a critical value can be 20 minutes, but an alarm on a suddenly apparent banking effect and interaction of the ship with the seabed needs a response deadline of less than one minute.
On the other hand, there is the degree of human control. The value $\mathbf{T_{MR}}$ represents the **maximum response time** in which an operator must reach the control station, gain situational awareness and be ready to perform the required actions. In the example before an engineer can arise from his resting place and walk to the location of alarm (on board or in the RCC). But in case of a banking effect the navigator (in case the automated systems is not able to solve the situation) must be available within a response time which is equal or less as the response deadline of the subsystem.
In the Table 2 the authors make a proposal for possible degrees of automation and human control. In practice it is to expect the degrees will be very individual for each subsystem and the limit between the degrees will be more floating.

Table 2: Degrees of automation and human control in MASS (Roedseth, Wennersberg, & Nordahl, 2021)

Degree	Of automation	Of human control
0	Low ($T_{DL} = 0$)	None ($T_{MR} = \infty$)
1	Partial ($T_{DL} > 0$)	Available ($T_{MR} >\sim 20 min$)
2	Constrained ($T_{DL} > t$)	Discontinuous ($T_{MR} >\sim 1 min$)
3	Full ($T_{DL} = \infty$)	Continuous ($T_{MR} \sim 0$)

The degrees of automation and human control are related to each other by the authors and presented as combined degrees of control (C_m) and automation (DA_n). The characteristic of autonomy resulting from the combinations is defined as:
FA – full autonomy (no operator at control position, automation can operate all required tasks)
AC – autonomous control (the operator is not present close to the control station, but is alerted and back in sufficient time)
OA – operator assisted (the operator is close to the control station, leaving the control position is on own judgement)
OE – operator exclusive (operator permanently at control station)
The combinations are shown in the left-hand side of the Figure 3. The authors derive a simplified representation in which they assume only two characteristic cases (*AC* and *OA*) instead of four. The reason is that *FA - full autonomy* is equivalent to the case of a very long absence of the operator at *AC - autonomous control*. The combination *OA - operator assisted* involves the situation of *OE - operator exclusive* is because the discontinuous presence changes to the state of continuous presence.

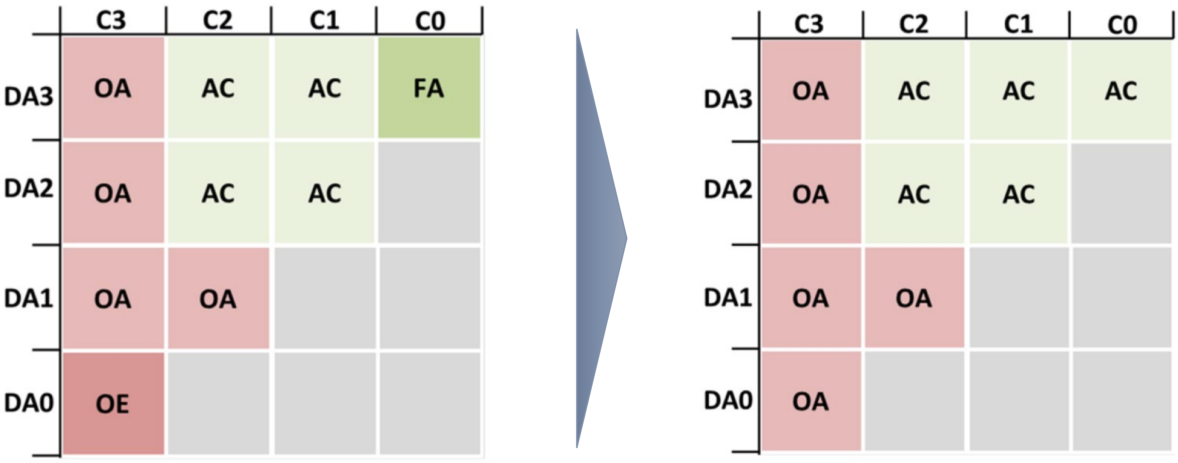

Figure 3: Possible combined degrees of control [C] and automation [DA] (Roedseth, Wennersberg, & Nordahl, 2021)

From the explanations, it is obvious that the degree of autonomy is an important aspect that must be considered in the certification of remote-control centers.
The different systems and subsystems will have different degrees of autonomy. Thus, the degrees of automation and human control are to be assigned to the individual systems. This is necessary at least for the safety-relevant systems. Safety-relevant can be the availability of certain systems, but also critical traffic situations or critical behavior of the ship. It is essential that the response deadlines of safety-relevant systems are defined and that the maximum response time of the operators in the organization of the RCC is ensured.
Basically, this study assumes that all necessary functions and activities can be done from the RCC and that there is no crew on board.

3.4 Players and stakeholders in development and operation phases

3.4.1 Phases of development of a Remote Control Center

The development of an RCC goes through different phases before operations can start.

Figure 4: Phases of planning and realization of an RCC (source: HSB/IfMS)

The phases are:
1 Requirements – Definition of the business or application case and documentation of the concept of operations. The outcome of the first phase is the description of the vessel, the RCC and the whole control system based on the operational envelope.
2 Planning – Detailing the concept of operations and preparation of a preliminary plan for the MASS, RCC and the whole system. After approval development of the detailed plans and specifications. Based on these the tendering and bidding process starts. Outcome of the second phase are placed orders for realization of MASS, RCC and subsystems.
3 Construction – Manufacturing starts with pre-assemblies of all components as well as software development works. The MASS/ship is constructed and the RCC with all control systems is built. The outcome of the third phase are the vessels, an RCC and the available hardware and software. Factory acceptance tests (FAT) can be done.
4 Commissioning – The phase starts with the integration of all components and sub-systems. After integration the system is tested in sea trials and site acceptance tests (SAT). If all systems are tested

and in working conditions the acceptance tests will finalize the project. The outcome of the fourth phase is the whole system ready to start operations.

This is a rough description of such a project to set a general overview. After completion and start of operations it will be followed by guarantee works and audits.

3.4.2 Players and stakeholders

In the planning, certification and realization process four groups of players and stakeholders are to identify. In the Figure 5 the most important players are shown.

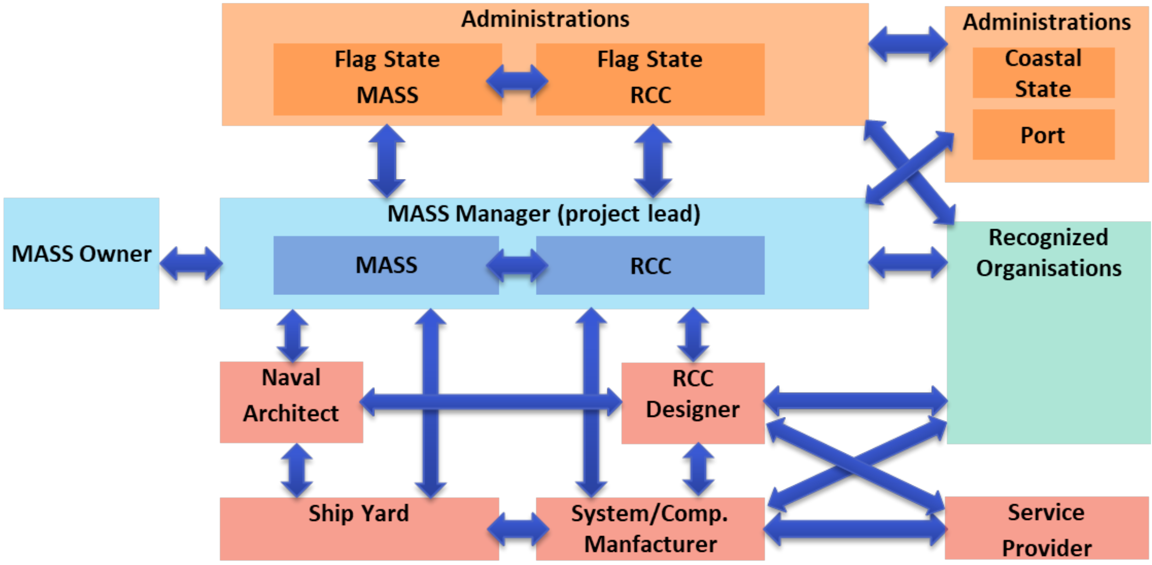

Figure 5: Correlation between players in the implementation of a MASS/RCC system (source: HSB/IfMS)

In the center of the project are the owner and the managers of the MASS system. They have the overall responsibility to plan and implement a system that meets all requirements. The MASS and RCC manager have the project management and must coordinate all actors.

The MASS and RCC manager use various planners, such as the naval architect for the MASS and a system planner for planning the architecture and functionality of the RCC. A wide variety of compositions are conceivable. Thus, the RCC managers can also take over the planning of the RCC if they have the appropriate competencies. Also in this group are the manufacturers, such as the shipyard or system manufacturers. The MASS and RCC managers places orders with them, which they implement in close coordination with the planners.

Service providers as for communication services, satellite services, navigational aids services or facility services (e.g. for berthing) are to consulted, too. Interfaces to such systems and their capabilities must comply with the MASS and RCC system.

Recognized organizations as classification societies can be named as a further group. They define the rules and requirements for a MASS system, which must be observed in planning and implementation. They can also be entrusted with the task of conformity testing for equipment and systems. Finally, they take over the auditing of the implemented technical system of MASS and RCC.

The Administration is to be named as the regulating and auditing entity. The Administration of the flag state is responsible for supervision of the MASS, for the RCC the local state authority is responsible. If the RCC is in a different state as the flag state for the MASS, the state is competent for the RCC within the state. The administration of the coastal states whose sea areas are to be navigated by the MASS shall be integrated. For example, requirements of the MASS and RCC system must be coordinated with the other states so that they are compatible. If necessary, requirements must also be coordinated with the administrations of ports and waterways. These consultations should take place directly between administrations. In this entire process the MASS itself is the driving element. The RCC design and operations must be according to the requirements of the MASS. It is necessary to ensure that all requirements of the MASS are considered in the RCC.

Basically, the question arises as to which administration is responsible for the overall system. As described in Chapter 4.1.2 , different constellations of RCC's and MASS are possible. In addition, an RCC can be installed in a state other than the flag state of the MASS or the remote-controlled ship.
In the absence of internationally binding rules defining the safe operation of MASS it is necessary that involved states collaborate and coordinate. Three cases are to be differentiated.

Case 1: The flag of the MASS is the same as the state of RCC, and the MASS are operating only in national waters.
Case 2: The flag of the MASS is the same as the state of RCC, and the MASS are operating in international waters.
Case 3: The flag of the MASS is different with the state of the RCC, and the MASS is operating in international waters.

In case 1, national rules may be issued. A match between MASS requirements and RCC performance can be achieved and verified by national authorities.

In case 2, national rules for MASS and RCC can also be issued, and their interaction approved. Since the MASS sails in international waters, additional agreements with the coastal and port states are necessary. The other coastal and port states must approve the overall MASS system for operation in their own national waters. Since there is no responsible Master on board of a remote-controlled MASS, it must be clarified how the responsible ship management in the state of the RCC can be prosecuted in a liability case.

In case 3, coordination between the MASS under another flag and the state in which the RCC is operated is also necessary. It is essential that the MASS fleet, which is to be controlled by an RCC, sets the requirements for the RCC system. The RCC must meet these requirements and demonstrate in the test that the entire system can be operated safely. The MASS fleet and the RCC must be coordinated.

Anyway, in a case of an incident of a MASS at sea, always the flag state of the MASS is to be contacted. From this perspective it is obvious that the flag state of the MASS will need an agreement on the integration of an RCC located in another state.

3.4.3 From concept check to certification

Many players and stakeholders are involved in the development and construction of an RCC. The players and stakeholders have specific responsibilities and liability for the implementation and operation of remote-controlled MASS. They can be differentiated for the phase of development and the phase of operation which is outlined in the next chapter. The phases can be further detailed, in this study only the high level is discussed. The owner or manager of a MASS is responsible for the process of recognition and verification. The operator of an RCC is responsible that the system matches the requirements of the MASS.

When establishing the approval process the IMO MSC.1455 GUIDELINES FOR THE APPROVAL OF ALTERNATIVES AND EQUIVALENTS AS PROVIDED FOR IN VARIOUS IMO INSTRUMENTS is to consider. The process discussed in this document takes these guidelines in account, but has a general and specific view to realize an RCC. So, the authors recommend to grant an approval before construction work starts, but to issue certificates not before all tests of the entire system and including human performance integration is successfully done.

The certification process should start quite early. It is proposed to have three steps (compare Figure 6):

O – the operational concept check

Based on the concept of operations the remote-control system is to be checked. The objective is to identify in the most early-stage issues which are a risk for the project. Also, it should be decided whether the project will be allowed for realization. A risk assessment is to be prepared by the MASS manager (risk-based approach) and the authorities will check it on conformity with legislation and that the risks are acceptable. The MASS manager will get a pre-approval and allowance to prepare the preliminary plans and documentations. As recommendations hints will be given to improve the system.

A - the approval

Based on the preliminary plans and documentation the approval procedure starts. Objective is to check the entire planned system. It is to determine which requirements the system must fulfil. The procedure should be designed in way that it gets not too complex and time consuming. The project team will get the approval to realize the system as described in the preliminary documentation. Obligations and recommendations are possible.

C – the issuing of certificates

In the last stage of the project audits are needed for the most critical systems and the RCC as a whole. It is possible to check the documentation as well as physically the MASS, the RCC and the single systems. As outcome the required certificates can be issued, if the audits and checks are positively completed.

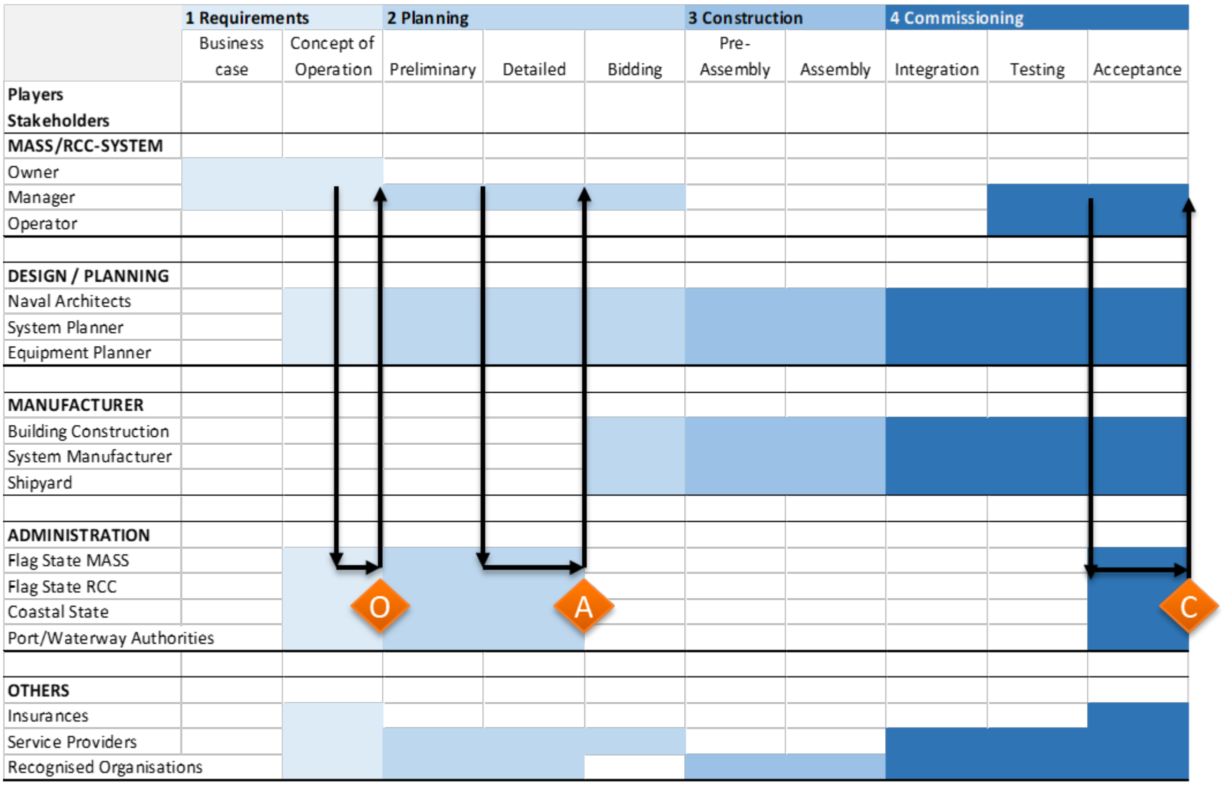

Figure 6: Overview of players and stakeholders in the phases of realization of a MASS/RCC-system (source: HSB/IfMS)

3.4.4 Responsibilities and liabilities of players and stakeholders

In the **first phase** the **requirements** are to be determined.

In the first step, the business case or the use case is determined by the MASS owner. The aim is to draw up a business plan and clarify the financing. For this purpose, the MASS system is dimensioned, and the mission requirements are formulated for corner parameters. The administrations will inform about the regulatory framework to be considered.

In the second step, the Concept of Operations (ConOps) is described. The ConOps also includes the operational envelope of the planned system (a table of content can be found in Chapter 6.2). Naval architects and the planners of the entire control system provide support here. The concept of operations (ConOps) is to prepare by the MASS manager in close cooperation with the RCC operator, and to deliver to all concerned authorities. The ConOps needs an approval by the authorities that the regulatory requirements will be met.

Table 3: Phase 1 Requirements (HSB/IfMS)

Phase 1: Requirements			
Player / Stakeholder	**Major Tasks**	**Responsibilities**	**Liabilities**
MASS Owner	Determine business case	To identify an economic and sustainable business case	Business risk
	Set-up a business plan	To plan all aspects of the business case	Economic risk
	Ensure financing	To plan finance demands and ensure credits	Financial risk

Phase 1: Requirements			
Player / Stakeholder	**Major Tasks**	**Responsibilities**	**Liabilities**
MASS Manager with RCC Operator	Determine operational envelope and concept of operation	To write the operational concept	Operational risk
	Determine the MASS /ship	To define all parameters and levels of automation for the MASS system	All requirements covered
	Determine the scope of the RCC	To dimension the RCC in technology, organisation and operational requirements	All requirements covered
	Make a risk assessment	To identify and evaluate all risks, finally to determine mitigating measures	Risks ALARP
	Submit concept of operations to authorities	To communicate with all involved authorities	Risk to get no approval
Naval Architects (as contractor of the MASS Manager)	Specify the MASS and required functionalities	To sketch and specify the MASS	Conformity with operational concept
System Control Planner (as contractor of the MASS Manager)	Specify the system and subsystems control systems and functionalities	To sketch and specify the communication, data transfer and control systems	Control system covers requirements
	Specify control equipment	To use approved equipment	Equipment meets requirements
	Specify hazards for the system and input for risk assessment	To identify system risks and cyber security requirements	Risks are identified
	Specify the functions of the RCC	To align processes and functions	Functionality is according to requirements
Recognized Organisations	Provide guidelines	To make sure that the ship is designed according to class guidelines	Correct guidelines
Service Providers	Providing technical specifications, parameter and interfaces	To specify the parameters that a MASS system is able to be operated safely	Correct specifications
Administration of Flag State MASS	Inform about regulatory frame	To set the administrative framework	Transparency of regulatory frame
	Determine the required information	To request an operational concept	
	Receive concept of operation		
	Confirm concept of operations and set administrative requirements	To determine specific requirements	Possible integration in traffic system and safety of MASS system
Administration of RCC State	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	Agreement on system parameters and requirements.	

Phase 1: Requirements			
Player / Stakeholder	**Major Tasks**	**Responsibilities**	**Liabilities**
Administration of Coastal State	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	Agreement on system parameters and requirements.	
Administration of Port States and Waterways	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	Agreement on system parameters and requirements.	

The **second phase** covers the **planning** of the MASS-System, the MASS itself and the RCC. This phase will be distinguished in sub-steps as preliminary planning, detailed planning and bidding.
The preliminary planning can be started by the planning team based on the released ConOps. The entire system is described and the documents for approval are compiled. For this purpose, the ConOps is further specified and, in particular, the documents required by the administration are completed. These are given by the MASS/RCC manager to the authorities for review and approval.
In step 2 of this phase, the detailed planning takes place. This includes the design documents for the MASS and the RCC. It also includes the detailed specifications for the hardware and software as well as the equipment elements.
Parallel to the detailed planning, the verification process is carried out by the authorities. The process concludes with the approval of the concept of the MASS and RCC system. The approval may contain obligations and recommendations.
With the approval, the procurement phase can be initiated with the bidding process. In this step, clarifications are made with suppliers until contracts for the ship, the RCC, the equipment as well as hardware and software can be awarded.
It is possible that these steps overlap and are carried out in parallel to each other.

Table 4: Phase 2 Planning (HSB/IfMS)

Phase 2: Planning			
Player / Stakeholder	**Tasks**	**Responsibilities**	**Liabilities**
MASS Manager with RCC Operator	Detail concept of operations for preliminary plans	To detail the preliminary planning with the specific requirements of the authorities	
	Detail the MASS requirements	To set the detailed requirements to the MASS	
	Detail the scope of the RCC for planning	To set the detailed requirements to the RCC	
	Deliver the preliminary plan and documentation to authorities	To get the preliminary plans from the planners	Complete and correct preliminary plan
	Get the approval of authorities before placing orders		Order in conformity with approval
Naval Architects (as contractor of the MASS Manager)	Preliminary and detailed plan of the MASS with required functionalities	To plan the MASS	Apply regulatory framework concerning design and construction of MASS
	Tender the MASS	Planned scope and technical specifications are determined correctly	The specification is correct

Phase 2: Planning **Player / Stakeholder**	**Tasks**	**Responsibilities**	**Liabilities**
System Control Planner (as contractor of the MASS manager or RCC operator)	Preliminary and detailed plan of the system control and functionalities	To plan the remote control system	Apply regulatory framework concerning design and realization of the remote control system
	Preliminary and detailed plan of the equipment as - workstations - hardware - control equipment - communication equipment - software and applications	To plan the equipment	
	Preliminary and detailed functional plan of the RCC	To plan all functions	
Architects and Engineers	Preliminary and detailed plan of - the buildings - the rooms - the infrastructure	To plan the space for the RCC	Fulfilment of all frameworks concerning design and realization
Manufacturer of Systems	Offer critical and safety related equipment	The equipment must meet the official requirements	All concerned equipment has an approval for conformity
Building Construction Companies	Offer building and its equipment	The buildings with equipment must meet the official requirements	The buildings get approval of authorities
Recognized Organisations	Provide guidelines	To design the ship according to class guidelines	Correct guidelines
	Check for conformity of used equipment	To provide maritime equipment with conformity declarations	
Service Providers	Stating the required performance (availability, capability, reliability)	To confirm the performance parameters	Correct specifications
Administration of Flag State MASS	Collect all relevant documents and plans of the preliminary planning		
	Check the documents, plans and parameters	The project applies all regulations	
	Coordinate with other concerned authorities	The systems are accepted by all other authorities	
	Give approval for realisation		The planned system meets all regulations
Administration of RCC State	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	Agreement on system parameters and requirements.	The planned system meets all regulations

Phase 2: Planning Player / Stakeholder	Tasks	Responsibilities	Liabilities
Administration of Coastal State	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	Agreement on system parameters and requirements.	The planned system meets all regulations
Administration of Port States and Fairways	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	Agreement on system parameters and requirements.	The planned system meets all regulations
	Provide all required shore-based systems		The approved system is able to sail in the designated waters

The **third phase** is the **construction** of the entire system. In general, it is the construction of the building or rooms for the RCC, the realization of the technical systems with hardware and software for control and communication, and the manufacturing of the MASS itself.
It is divided into the steps of pre-assembly and assembly. In the pre-assembly single components will be manufactured or prepared, e.g. parts of the workstations or specific hardware and software. The final assembly is done in the following step. All components are put together, for the MASS in the shipyard, for the RCC in the location of this.
The outcome of this phase is the delivery of the remote-controlled ship and the RCC with all control systems.

Table 5: Phase 3 Construction (HSB/IfMS)

Phase 3: Construction Player / Stakeholder	Tasks	Responsibilities	Liabilities
MASS Manager with RCC Operator	Check delivered scope of the RCC against planned scope	Project on scope, on time, on budget	
	Do factory acceptance tests	The FAT are to be done	The systems are manufactured in compliance with approval and regulations
Naval Architects	Check the scope and quality of the construction of the MASS	The MASS is constructed according to the plans	Functionality of the MASS
System Control Planner	Check the scope and quality of the construction of the system control and functionalities	The RCC is manufactured according to the detailed specifications	Functionality of the RCC
Architects and Engineers	Check the scope and quality of the construction of the building and infrastructure	The RCC is constructed according to the detailed specifications	Functionality of the building
Manufacturer of systems	Manufacture equipment		
	Factory acceptance test (FAT)		
	Deliver equipment	The equipment must meet the official requirements	Equipment is delivered according to specifications
Ship Yard	Manufacture MASS		

Phase 3: Construction Player / Stakeholder	Tasks	Responsibilities	Liabilities
	Deliver MASS	The MASS must meet the official requirements	MASS is delivered according to specifications
Building Construction Companies	Construction of building		
	Deliver building	The building must meet the official requirements	Building and infrastructure is delivered according to specifications
Recognized Organisations	Auditing of specific construction works	The realization of the entire system is according to the guidelines and regulations	Conformity with guidelines and regulations

In the **fourth phase** the system is **commissioned**. All systems are readily constructed and manufactured. The first step is to connect all systems and integrate them into the overall system. When the integration is finalized, the next step starts, in which the overall system is tested. A site acceptance test (SAT) is carried out for the RCC. The MASS carries out sea trials. All systems must comply with the requirements and with all rules.
The scope is not only about the perfect working state of all equipment, hardware and software but the whole RCC concept from an operational point of view. The tests should include realistic scenarios, including failure scenarios and demonstrate that the RCC perform safely in these circumstances. It should be done as in the aviation industry, where by certification flights the aircraft is pushed at the edge of its operational envelope and the flights demonstrate that it is also safe there. This will include physical parameters as well as emergency scenarios.
When the entire system is fully tested, functional and expected as safe and secure, the corresponding certificates can be issued in the last step.
The commissioning phase can also be parallelized in its sub-steps.

Table 6: Phase 4 Commissioning (HSB/IfMS)

Phase 4: Commissioning Player / Stakeholder	Tasks	Responsibilities	Liabilities
MASS Manager with RCC Operator	Participate in the testing (SAT and sea trials)	All tests are carried out for full satisfaction	
	Give acceptance to the finalized and tested systems		Taking over the risk for the operational systems
	Application for certificates	Deliver all required information for certification	To get all certificates to be able to start operations
	Inform all authorities about the start of operation		
MASS Operator	Check and test all functionalities (MASS, RCC, systems, …)		
	Train the operators on the system	Understand all systems and gain knowledge for the start of operation	The operation of the MASS/RCC-system starts with competent staff
Naval Architects	Get MASS running		

Phase 4: Commissioning Player / Stakeholder	Tasks	Responsibilities	Liabilities
	MASS sea trials	Functionality of MASS according to specifications	Functionality and performance
System Control Planner	RCC and system trials	Functionality of RCC according to specifications	Functionality and performance
Shipyard	Get MASS running		
	MASS sea trials	To deliver MASS according to the specified requirements	Quality, functionality, reliability
Manufacturer of systems	Get remote control systems running		
	Site acceptance tests (SAT)	To deliver systems and equipment according to the specified requirements	Quality, functionality, reliability
Building Construction Companies	Deliver building and infrastructure	To deliver building and infrastructure according to the specified requirements	Quality, functionality
Service Providers	Integration into the services	To provide service within the agreed requirements	Service availability, reliability, performance
Recognized Organisations	Check conformity with all requirements, guidelines and regulations		
	Issue certificates with acceptance to start the operations		All requirements are fulfilled
Administration of Flag State MASS	Check the components of the system (technology, organisation)	To check all	
	Coordinate with other concerned authorities	To assign the certificates to the authorities as stipulated	
	Issue certificates with acceptance to start the operations	To issue all required certificates	All requirements are fulfilled
Administration of RCC State	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.	To issue certificates required	All requirements are fulfilled
Coastal State	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.		
Administration of Port States and Waterways	Same tasks, responsibilities and liabilities as the flag state, but focussed to its own scope of proving.		

Phase of operation of a Remote Control Center

When the RCC and MASS got the final approvals, the **operation phase** starts. With start of operations the entire system is in operation.

The system is to be followed-up by audits of authorities, port state control and recognized organisations.

The entire approval process should be detailed. The guidelines of MSC Circ. 1455are to consider. For example the content of the ConOps is to specify or the definitions how to perform risk assessments are to determine.

4 Organisation of the RCC

4.1 Operating a voyage from berth to berth

4.1.1 Process Map

Before considering the core functions of an RCC, it should be shown which functions are necessary for the voyage of a conventional ship. The scope of observation includes the preparation and operation of a passage from berth to berth.

To determine the functions of the RCC, the processes are defined which are operated for a voyage from A to B. In general, a process is defined by a trigger (an input), followed by subsequent activities, and resulting in an outcome (an output). By this process-oriented view, the functions are considered completely. Since the output of one process is the input of the next process, there are no breaks between the functions and the associated activities. The following consideration focuses on the core processes and the underlying main processes. This approach results in a process map that serves as an overview.

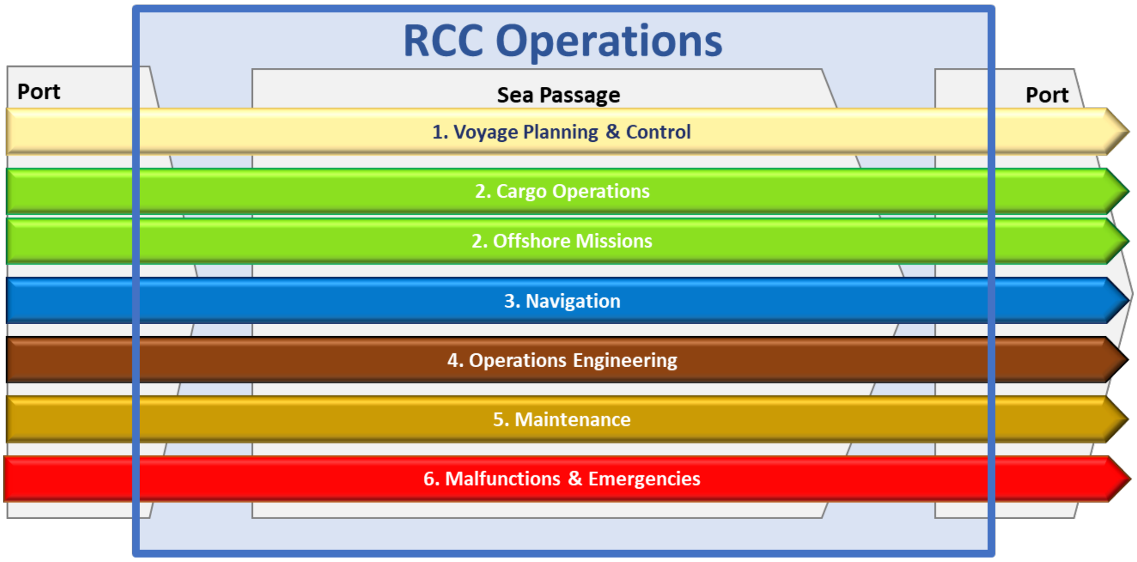

Figure 7: Process map of all core processes covered by the RCC (source: HSB/IfMS)

The named core processes are universal for all ships. The core processes are to be broken down into their detailed sub-processes. A large proportion of the subprocesses will be the same for all use cases, but there are also subprocesses that occur specifically in individual use cases. In the figure the process 2 is different. The cargo ship has different processes for "cargo operations" as the dredger for the "offshore mission".

In this process analysis and its break-down, it is referred to the operational envelopes as described in the previous chapters. The functions and tasks are derived from a multi-day short-sea voyage with a cargo ship and a dredger operating in coastal waters.

The core processes at the center of the graph include the overarching functions that arise on the passage of a seagoing vessel. When considering the overall system of the entire shipping company that operates ships, further processes must be considered. In the context of this study, however, only the core processes directly related to the implementation of a sea passage are discussed. The management processes and the support processes are mostly done within the shore organization of a shipping company. Of course, such processes will matter for a RCC, too. But it will not have a direct impact on the operational control of a MASS when sailing from A to B.

4.1.2 Interface between RCC and Fleet Operation Center

To be able to describe the task of an RCC, it is to determine how it will be integrated in the allocation of tasks and functions to operate a ship in the maritime domain.

Ships as well as MASS have an owner. The owner uses a ship manager who can be within its own organization, but also a third party. The task of a ship manager is to operate a ship (or MASS) in the best possible and cost-efficient way, to keep it in good technical condition and to staff it with a competent crew. With this ship, the ship manager sails voyages to carry out transports or fulfill other missions. It’s obvious that the ship manager will keep tasks which influence the business success of the enterprise under the own responsibility.

Some of the tasks are strongly interlinked with the sea voyage, for example:

- The planning of the task or mission,
- The preparation of a timetable or deployment plan,
- The provision of cargo and equipment,
- The planning of the maintenance of the ship,
- The coordination with ports and terminals,
- The use of agencies to represent shipping company interests.

For the sake of simplicity, this study assumes that the core tasks of the ship manager are carried out in a Fleet Operation Center, distinct from the RCC. This can vary greatly. An office from which coordination is carried out is conceivable, but it is also possible to have centers that are intensively connected with ships (and MASS), exchange a lot of information and data, and track their fleets very closely and optimize their use. In the following, these tasks are summarized under the term Fleet Operation Center (FOC).

An RCC now takes on the task of driving the ship from a port to a port of destination or in a mission area. So far, this has been an original task of a ship's crew, which the ship's manager uses for this. Ship crews today are increasingly provided by crewing agencies, while they continue to receive their instructions for carrying out the voyage from the ship manager. The possible constellations and distribution of tasks between crewing agencies and ship managers are manifold. In conclusion, RCCs can also be associated with a ship manager in various constellations.

In the business model I the ship managers operate their own RCCs for their own fleet in all areas.
In this model the used technologies and communication lines can be very specific to the manager and operator. An exchange of remote-controlled ships (or MASS) is not an objective. The allocation of tasks of the FOC and the RCC can be very different. Many ship managers would prefer such a model because they are concerned about sharing data and information of their ships with other involved parties.

The flags of the vessels can be different than the home state of the RCC (which is the country of location), but it can be also one flag for a fleet plus RCC.

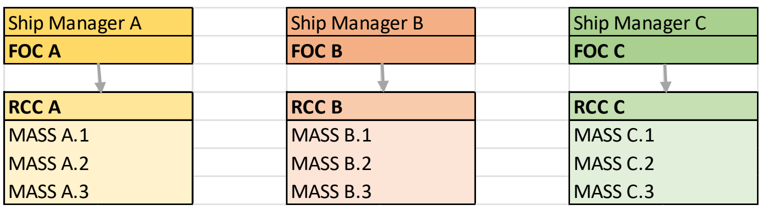

Figure 8: Model I: RCC’s for own fleet (source: HSB/IfMS)

In the model II the RCC services are offered as a service for certain regional areas. If a MASS changes the area, it must be transferred to another RCC. In this case more standardization is required. The RCC would act as a third party to take over the task to sail a vessel from A to B from the ship manager.

Another fact is that the RCC's are focused to a certain area. An RCC can be specialized to an area, it has a bigger knowledge about environmental situations and is knowing all institutions in this area. The MASS manager needs to have contracts with the different RCC's.
In this model it is to assume that the vessels flags will be different to the home state of the RCC.

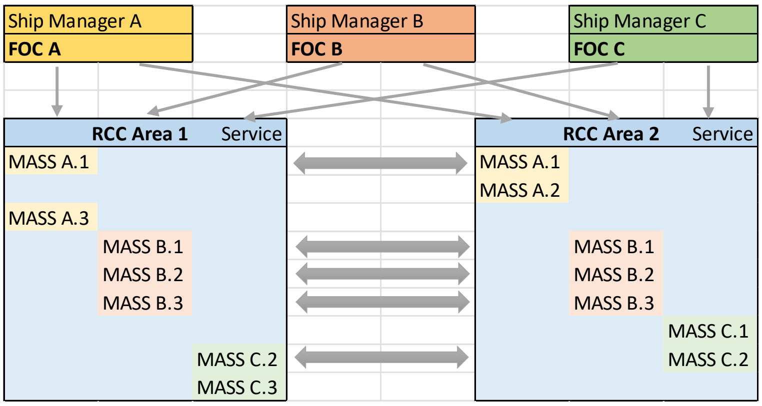

Figure 9: Model II: RCC's for areas (source: HSB/IfMS)

In model III the RCC services are offered for fleets. A ship owner can assign his ship or MASS to different RCC's operating in unlimited areas. The RCC's can be specialized on ship types, e.g. for container liners or for dredgers or for other types. The advantage is that they can be integrated much better into the specific operations, e.g. as the container loading and discharging and cargo care process, or into the dredging processes with all technology requirements.

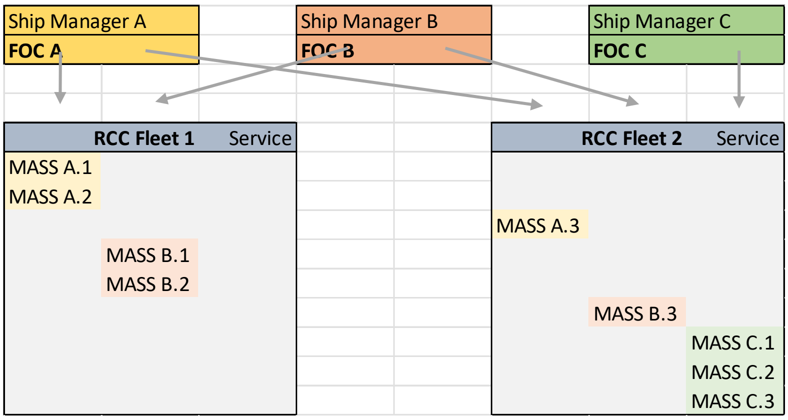

Figure 10: Model III: RCC's for different fleets (source: HSB/IfMS)

It is obvious, that the distribution of responsibilities between ship managers and remote operator services is to consider. The business models can vary in several other constellations. In this study we exclude certain processes from the functions and tasks of the RCC. But it is to mention that this is a framework. The operational envelops and degrees of automation will have influences on the allocation of tasks.

4.2 Core processes and functions

The core processes to sail and control a voyage include:

- > The planning of a voyage as well as its tracking,
- > The transportation of cargo, or operation of a mission (depends on the use case),
- > Sailing the ship,
- > The operating of the ship's technical facilities,
- > The maintenance of the ship and its equipment,
- > The treatment of malfunctions and emergencies.

These processes can be divided into sub-processes. They start in the port of departure, continue with the sea passage, and end in the port of destination.

The processes are detailed in the tables in the next chapters.
The column “Conventional Ship” notes which sub-processes in the conventional organization of a seagoing vessel are carried out by whom.

Crew = the on-board crew of the conventional vessel
Office = the shipping company's land organization

The column “MASS/RCC” determines which unit will take over the tasks for a remote-controlled vessel.

Terminal = the port organization in the broader sense
FOC = the Fleet Operation Center
RCC = the Remote Control Center

4.2.1 Process “Voyage/Mission Planning and Tracking”

Before a ship sails, the voyage or its mission must be planned. The voyage plan or the mission plan is not to be confused with the passage plan. The voyage plan for the use case “cargo ship” includes the entire voyage, the schedule, the clarification of terminals and the procurement of necessary services. The mission plan will specify the tasks for the use case “dredger” which contains the operating area and technical information. The passage plan itself is the navigational planning of the passage from berth to berth, which is done on each ship.

The process of planning a voyage or a mission usually takes place in the land organization (“office”). However, the crew of the ship is involved to provide data and information.

Once the voyage or mission has started, it must also be tracked to detect deviations in time and to take appropriate measures to ensure that the voyage or mission can be completed successfully. Of increasing importance is the collection of all information and data about the voyage or mission. These are to be evaluated to gain insights for the optimization of further voyages or missions and the economic and safe use of the ships. Most of the tasks of tracking as gathering voyage data are done on board of a ship by the crew today. But as shipping organizations develop, more and more data is being automatically transferred to the land organization. For this purpose, so-called Fleet Operation Centers are increasingly being found in the organizations that take on these tasks.

The coordination of deviations with ports, terminals or ship agents is usually done by the office. As well the office takes care of changes in the tasks of a mission. The general process is listed in the table below, the sub processes and tasks are assigned to the most probable organization doing the jobs for a conventional ship respectively for a MASS.

The table compares how the various processes, functions and tasks are assigned with conventional ships, and how they could be in future scenarios with MASS supported by an RCC and a FOC.

Table 7: Process "Voyage Planning and Tracking" (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
1.	**Voyage Planning and Tracking**		
1.1.	**Voyage Planning**		
	- Planning a voyage (port calls, schedule)	Office	FOC
	- Arrange all facilities such as pilots, terminals and other port facilities	Office	FOC
1.2.	**Voyage tracking**		
	- Track the voyage	Crew	FOC
	- Check for deviations and consider required changes	Crew	FOC
	- Coordinate with the vessel, the ports and facilities	Office	FOC
	- The voyage plan is adjusted accordingly	Office	FOC
	- Communication with all concerned institutions and facilities	Office	FOC
1.3.	**Voyage documentation and analysis**		
	- Collecting and merging all voyage data	Crew	FOC
	- Documentation of all voyage-related information and data	Crew	FOC
	- Check for deviations (route, ship status, ship's performance)	Crew	FOC
	- Analysing deviation and starting measures to adjust	Crew	FOC

The preparation of the voyage or mission of a MASS will have to clarify considerably more technical and operational questions than for a conventional ship. The clarification of the availability of systems (e.g. AFS Automated Facility Systems) as well as possible interfaces for data and communication must be carried out by persons with appropriate competences. Likewise, significantly more data will be generated, the use of which will have to be planned and whose evaluation must be carried out with the specific know-how. It is therefore to be expected that the preparation and overarching observation of the travel execution as well as the ongoing evaluation of the travel data are new tasks that a Fleet Operation Center must take over. A direct interface to the RCC's is required for data exchange and direct communication.

4.2.2 Processes "Cargo Operations" and "Offshore Missions"

This process depends on the use case and the determination of a MASS. For this reason, this process is shown for each of the two use cases explained above.
First of all, the use case as a cargo ship for the transport of dry goods is discussed. Before the voyage is started, the loading of the ship must be planned. For containers, the loading plans are prefabricated by stowage planning centers and checked by the crew. The responsibility for special cargoes such as dangerous goods or OOG (out of gauge) cargo must be assumed by the ship's management. For bulk and break-bulk cargoes the planning is done completely on board. Finally, the crew must ensure the stability of the ship. Since violent ship movements and strong acceleration forces occur at sea, the cargo must be secured against shifting and tilting. It is also the responsibility of the crew to ensure that the load securing is carried out properly.
In port, the loading of the ship must be controlled, and the seaworthy condition must be ensured.
At sea, cargo care is still necessary. This includes the control of load securing, temperatures and atmospheres, as well as the observation of the behavior of the cargo to avoid any damage.

At the port of destination, the vessel is to be prepared for unloading and the discharging operations are to be controlled. In general, there are the same tasks as for loading.

Table 8: Processes "Cargo Operations" (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
2.	**Cargo Operations**		
2.1.	**Cargo planning**		
	- Accepting cargo, checking cargo and dangerous goods properties - Planning loading and stowage plan - Distribution of masses and volumes of cargoes - Definition of correct stowage and segregation, in particular for dangerous cargo - Considering demands of fuel and consumables - Calculation and distribution of required ballast - Check and approval of stowage and ballast plan - Calculation and assessment of draught and trim, transverse stability, and strength of the vessel	All by Crew	FOC Terminal Terminal Terminal Terminal Terminal RCC RCC
2.2.	**Cargo loading**		
	- Preparing the vessel for loading (prepared cargo holds, opening and closing of hatches) - Planning and supervision of cargo securing against shifting and damages - Monitoring and adjusting of trim, stability and strength values - Operating ballasting the vessel - Communication with shore services	All by Crew	Terminal Terminal RCC RCC RCC
2.3.	**Cargo care at sea**		
	- Checking cargo securing and conditions - Monitoring of temperatures in holds and certain cargoes - Control of ventilation, bilges and wells	All by Crew	All by RCC
2.4.	**Cargo discharging**		
	- The process of discharging covers the same functions and tasks as the loading process	All by Crew	Terminal & RCC

It will be clear that most of the tasks of the crew will be taken over by the RCC and the terminal. In this consideration, we assume that the work of planning, loading and unloading the MASS will be carried out by the terminal (stevedores) as a service. However, the responsibility for the correct loading and stability of the ship is by the RCC.
New tasks can arise from technical innovations in the automation of loading processes which may be connected to ship operations. This depends on the type of ship and cargo and cannot be answered in general.

Ships used for missions at sea, unlike cargo ships, have other processes that are very dependent on the assigned tasks. The focus is on equipping the vessel with all the facilities necessary for the mission. If these are permanently installed, their usability must be ensured. The requirements for stability and seaworthiness are usually ensured by the design of the ships.

Table 9: Processes Mission Operations (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
2.	**Offshore Mission Operations**		
2.1.	**Mission planning**		
	- Planning the mission with its operational tasks - Considering demands of fuel and consumables - Calculation and distribution of required ballast - Check and approval of equipment and ballast plan - Calculation and assessment of draught and trim, transverse stability, and strength of the vessel	Office Crew Crew Crew Crew	FOC FOC FOC RCC RCC
2.2.	- **Mission preparation**		
	- Preparing the vessel for the mission (e.g. survey equipment, dredging equipment and machinery, …) - Monitoring and adjusting of trim, stability and strength values - Communication with shore services - Planning and supervision of proper stowage and securing	All by Crew	Terminal RCC RCC RCC
2.3.	- **Mission operations at sea**		
	- Operating of the mission tasks (e.g. surveys) - Operating of the mission tasks (e.g. dredging and dumping) - Monitoring operational limitations (e.g. environmental conditions) - Operating of ballast operations - Specific manoeuvring as stationary anchoring or floating pumping connections	All by Crew	All by RCC
2.4.	- **Mission termination**		
	- Depending on the mission equipment may be restored or changed	All by Crew	All by RCC

An RCC can take over the tasks of carrying out a mission well. The execution of the mission itself will require most of the RCC's capacity, depending on how highly automated these processes are. However, it is to be expected that in more complex applications a high situational awareness and availability of operators in the RCC must be ensured.

4.2.3 Process "Navigation"

The processes of navigation are the same on each vessel. They are to be operated on a cargo ship in the same way as on a vessel in offshore operations. Of course, the content and used equipment can differ. For autonomous and remote-controlled vessels, the process of navigation is of central importance. The sequence and procedure for passage planning is determined in IMO Resolution A.893(21) – Guidelines for Voyage Planning. In conventional seafaring, the phases of leaving the berth, pilotage, sea passage, as well as on arrival again pilotage and the arrival at the berth are differentiated. These sequences are considered in the following processes.

The process of navigation thus consists of the sub-processes:

- Leaving the port
  - Passage Planning
  - De-Berthing, departure of the vessel
- Outbound pilotage (mostly in confined waters)

- Sea passage (which can be in coastal waters and in open sea)
- Entering the port
  - … Anchoring
  - … Berthing, arrival
- > Port stay

Table 10: Processes "Navigation" (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
3.	**Navigation**		
3.1.	Navigation when leaving the port		
3.1.1.	Passage planning		
	Preparation of passage plan (from berth to berth) Consideration of weather forecasts and conditions Updating navigation systems Planning of navigational system maintenance	All by Crew	All by RCC
3.1.2.	Departure / de-berthing		
	Getting clearance to leave port Security check – all people from board Planning de-berthing manoeuvres, coordinate with VTS and pilot Disconnect all (gangway, power, supplies) Check ship for seaworthy status (integrity navigation system, ship control system, watertight integrity) Cast off all lines Manoeuvre ship to fairway	All by Crew	All by RCC
3.2.	Navigation on pilotage (outbound, confined waters)		
	Fix and check position (Visual, radar, GPS, …) Monitor for water depth, UKC, squat, ship-shore/ship-ship interaction Control course and speed Follow passage plan (waypoints) Incorporation of a pilot (Master-Pilot Exchange MPX) Monitor traffic (visual, radar, AIS), avoid collisions Monitor environmental conditions (wind, current, visibility) Manoeuvre ship for specific manoeuvres (e.g. pilot disembarkation) Communication with VTS, other ships Management of navigational or ship related alarms	All by Crew	All by RCC
3.3.	Navigation on sea passage (open sea)		
	Fix and check position (radar, GPS, …) Control course and speed Follow passage plan (waypoints) Monitor traffic (visual, radar, AIS), avoid collisions Monitor environmental conditions (wind, current, visibility) Communication with VTS, other ships Management of navigational or ship related alarms	All by Crew	All by RCC
3.4.	Navigation on pilotage (inbound, confined waters)		
	Get clearance to enter fairway and port Check controls availability and integrity … all functions and tasks as on outbound pilotage	All by Crew	All by RCC

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
3.5.	Navigation when entering the port		
3.5.1.	Anchoring / Stand-by manoeuvre		
	Planning anchoring or stand-by manoeuvre Operating anchor or stand-by manoeuvre Anchor or stand-by watch (position, environmental conditions, hazards in surrounding area) Heaving anchor, ending stand-by and proceeding passage	All by Crew	All by RCC
3.5.2.	Arrival / berthing		
	Manoeuvre ship to berth Getting clearance for berth Planning berthing manoeuvres, coordinate with VTS and pilot Prepare all stations for berthing Fasten all lines / connections Connect all (gangway, power, supplies) Set-up of security measures	All by Crew	All by RCC
3.6.	Port stay		
	Maintain security watch (access to ship) Maintain safety watch (moorings, fire, …) Monitor shore connections (gangway, supplies, …) Control of non-working ship	All by Crew	Terminal Terminal RCC RCC

In comparison to a conventional ship, the processes for all remote-controlled ships are basically the same. However, the way how they are operated will be different. Examples are:

> Situational perception will take place via a variety of sensors;
> Communication between RCC and MASS, as well as with other maritime participants, will be characterized by a very high level of data exchange;
> The automation will be operated by modified human-machine interfaces;
> The equipment and machinery will feature new technologies.

The challenges for the RCC are driven in the technical area as well as in shaping human’s relationships with automation.

4.2.4 Process “Operations Engineering”

The technical operation of a vessel must be ensured in order to be able to make a safe passage to the port of destination. All systems and facilities must work reliably and have high availability. This applies for each uses case.

The processes are geared to the needs of the technical systems. It is assumed that remote-controlled cargo ships on short sea passages or dredgers will be equipped with electric propulsion. These are characterized by easier operation and lower maintenance. Combustion engines are only used to generate electricity. Larger combustion engines are much more complex and needs more control and maintenance. It is not very likely that they will have a future in remote-controlled shipping. Other technologies which are to be considered are solar panels or wind turbines for energy generation or rigid wind sails for passages on longer distances. Innovations in types of machinery and equipment as well as in combination of them are to be expected.

The technical operation includes all technical facilities and equipment of a seagoing vessel.

- Propulsion, consisting of energy storage, engine, propeller system, rudder and thrusters;
- auxiliary equipment such as power generation, pumping systems, cooling and heating systems;
- deck operation systems such as anchor windlass, mooring devices and closure devices;
- ship safety equipment as fire detecting and extinguishing systems and rescue systems;
- automation systems as well as high- and low-voltage systems and data lines;

This list is a basic framework and can be broken down into the multitude of individual units. If, for example, remote-controlled ships are equipped with rigid sails, wind turbines or Flettner rotors, these are other technologies with need to be supported.

The following processes are therefore of a fundamental nature and can occur to varying degrees.

Table 11: Processes "Operations Engineering" (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
4.	**Operations Engineering**		
4.1.	Utilisability of all systems		
4.1.1.	Bunker and supply		
	Connect and disconnect electric power Charging batteries by shore connection Bunkering of fuels, lubrication, … Loading spare parts Replenishment of consumables, provisions	All by Crew	All by Terminal
4.1.2.	Systems checks		
	Prepare propulsion system (engine, gear, propeller, rudder, thruster) Prepare auxiliary systems Prepare auxiliary power generation systems Prepare automation system	All by Crew	All by RCC
4.2.	Control of ship performance		
4.2.1.	Auxiliary and machinery systems		
	Control of electric power generation and management Control of auxiliary systems	All by Crew	All by RCC
4.2.2.	Propulsion systems		
	Control of propulsion Keeping engines ready for quick manoeuvres	All by Crew	All by RCC
4.2.3.	Performance		
	Monitoring of indicators for performance, efficiency, consumption, … Monitoring of system status Management of alarms (identify, acknowledge, check, determine actions, …) Fault finding Malfunction correction	All by Crew Experts	All by RCC Experts
4.2.4.	Hotelling		
	Providing services for crew Providing services for riding crew	All by Crew	All by RCC
4.3.	Discharge residuals		
	Discharging waste, waste water Discharging of oily or other hazardous materials	All by Crew	All by Terminal

In terms of content, the processes are strongly driven by the developing technologies. The challenges for an RCC are the same as those for navigation.

It can be assumed that the MASS will still be intensively supported and operated by personnel at the beginning of their deployment in the ports. In the list, the term "terminal" is used. This refers to all personnel involved in the operation of the MASS in the port. This includes loading and unloading work as well as the supply and disposal of consumables or the use of experts for possible troubleshooting's.

Compared to conventional ship systems, a fusion of the engine control station with the bridge equipment is to be expected. In addition to navigation data, an operator will also receive data and information from the engine and other technical equipment.

It is to be expected that an operator will take over the alarm management of the engine and ship equipment part. For more in-depth problem solving, operators with appropriate competencies will have to take over these tasks. The scope and possibilities will depend very much on the type and size of the machinery and must be defined individually for an RCC within the framework of the concept of operations.

4.2.5 Process "Maintenance"

The challenge of a seagoing vessel in comparison to an inland barge are the more complex machinery and the longer duration at sea without any chance for shoreside support.

A distinction must be made between maintenance tasks in port and at sea. Since the condition of a ship and thus also the maintenance costs are in the strong interest of the ship manager, for that reason the planning and monitoring of maintenance will be done in the FOC. From there, the planning and provision of spare parts is also organized. Overhauls and repairs are preferably carried out in port. However, the interest of a ship manager is that a ship fulfills its mission at sea and stays as shortly as possible in port. Thus, there will also be a share of maintenance at sea. The work of corrective measures will then be done by riding service crews. This is to expect more for cargo ships with longer sea passages as on vessels in offshore operations with shorter time at sea and longer port stays with opportunity for maintenance work in the port.

Table 12: Processes "Maintenance" (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent- ional ship	MASS RCC
5.	**Maintenance**		
5.1.	Maintenance in the port		
5.1.1.	Maintenance planning		
	Inspection and monitoring of all technical systems Inspection and monitoring of ship structure Inspection and monitoring of nautical equipment Planning maintenance (planned, condition based) Planning, starting and monitoring work orders	All by Crew	Experts Experts Experts FOC FOC
5.1.2.	Overhaul and repair		
	Repairs on demand (corrective) Maintenance in port Updates of software	Experts Crew Crew	Experts Experts Experts

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
5.1.3.	Spare part control		
	Planning spare part demand Keeping spare part stock on board	All by Crew	FOC FOC
5.2.	Maintenance at sea		
	Inspection of all equipment (planned, preventive, predictive), as Propulsion system Auxiliary equipment Automation systems Deck systems Navigational equipment Safety equipment Updates software Repair on demand (easy or specific level) (corrective)	All by Crew	All by RCC Experts

Maintenance includes all the systems listed in the previous chapter. The tasks that can be moved from a vessel to an RCC will focus on inspections that can be done remotely. A corresponding transfer of data (temperatures, vibrations, ...) or video signals are necessary. Software updates can also be carried out remotely. As already shown, the cost of maintenance will also depend very much on the innovative development of low-maintenance technical equipment.

4.2.6 Process “Malfunctions and Emergencies”

In accordance with SOLAS and the ISM Code each ship needs to be prepared to be able to response to any incident which might happen at sea and in port. The RCC must be seen as a part of the vessel, in case of no crew on board it will take over all response activities.
Risk assessments and development of contingency plans are already done today mostly in the shore organisation. But, the implementation on the vessels or MASS must be done by the crew, respectively by the RCC operators.
In the table below several malfunctions and emergency cases are listed. All of them will need a specific response which is prepared by contingency plans. The response and control of malfunctions will need additional capacities, in manpower as well as in competences. For that reason, it is to assume, that emergency response teams with experts are to set-up in the RCC in such cases.

Table 13: Processes "Malfunctions and Emergencies" (source: HSB/IfMS)

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
6.	**Malfunctions and Emergencies**		
6.1.	Emergency preparedness		
	Performing risk assessments Set-up and implementation of contingency plans Training and drill of crew	Office Office Crew	FOC FOC RCC
6.2.	Malfunction response		
	Handle black-out Handle steering gear failure or loss of propulsion	All by	

No.	Processes and core functions and tasks	Convent-ional ship	MASS RCC
	Handle spills Handle extreme weather and environmental conditions Handle problems with communication and linkage with systems Handle failures of sensors or automation devices Handle cargo problems	Crew	All RCC + Experts
6.3.	Emergency response		
	Respond to structural damages, water ingress, flooding Respond to fire in cargo holds, engine, accommodation Respond to person overboard Respond on medical emergencies and operate evacuation Respond to security related matters Operate evacuation, abandon ship Operate helicopter operations in emergencies Operate SAR activities Handle cyber attacks Handle lost of data and communication connection	All by Crew	All RCC + Experts

Compared to a conventional ship, the emergency organization must be carried out completely in the RCC. An operator who may also supervise several MASS cannot take over these additional tasks. The distraction would be too great, the safety of the other supervised MASS would no longer be guaranteed. Malfunctions and emergencies must be dealt with by an emergency response team (ERT). Depending on the type of incident, this can be composed of operators and experts in different qualifications. The persons who take on these functions must have an appropriate wealth of experience and demonstrate the highest level of competence.
Internet applications can support the teams, e.g. for collecting information and data which can be shared also with external partners as SAR units, salvage organizations or VTS.

4.3 Functions, Roles, Work positions and Room Design for the RCC

Based on the core functions to be performed for a voyage we can now describe the functions, roles, work positions and room design (room layout, lighting, acoustics, HVAC) needed to produce an RCC.

An example use case is used to describe how to proceed with the design of an RCC. This is based on **Use Case A** (Section 3.2.2) and will be specified in more detail in the following subsections. In this example, we assume that a fleet of six dry cargo vessels needs to be monitored and controlled in the example RCC. In the design process important questions arise such as:

> What exactly are the tasks in the RCC for monitoring and controlling the fleet?
> Who is responsible for these tasks?
> What equipment and user interfaces are required for each task?
> How do we organize the RCC in spatial terms, on some building floor?
> How do we ensure the operational environment is optimal for the operators in terms of lighting, acoustics and HVAC?

These questions are answered in the following 10-step Human Factors-Centered Design (HFCD) process (Figure 11). To further clarify the content of these steps, we will always refer to the example use case described above.

Figure 11: Human Factors-Centered Design (HFCD) approach to derive an RCC Design (source: HMT)

Step 1 - Task Analysis: As part of the RCC design, task analysis is used to identify the tasks and activities that operators need to perform to effectively control and monitor remote systems or processes from the RCC. This analysis provides the basis for creating a control room layout and interfaces that optimally support these tasks and minimise the risk of errors or accidents. The task analysis thus provides essential input for the following steps.

Step 2 - Classify tasks into High Level Tasks: The tasks from the first step can be differentiated by the way they are performed (e.g., concentrated work in planning tasks focusing on single values vs. visual scanning and observation of various parameters to detect abnormal conditions and hazards). These pose different requirements for the subsequent design of the RCC to ensure optimal execution. For this reason, the tasks are assigned to the predefined High-Level Tasks (e.g., monitoring, direct control, planning, communication).

Step 3 - Assigning of tasks to roles: The classification from step 2 does not only allow to derive requirements for the design of the RCC (e.g., how user interfaces need to be designed visually or how the spatial structure of the RCC should ideally be designed to optimally support the tasks) but also reveals competencies required for the individual tasks. Thus, different roles needed in the RCC can be derived and the tasks from step 1 can be assigned to these roles.

Step 4 - Describe sharing of responsibilities between human and automation: Depending on the level of autonomy of the ships the cooperation between the human operators and the autonomous systems onboard can be described. This needs to be done separately for different phases of the voyage, because the responsibilities for the tasks are likely to be different e.g., during sea passage and berthing. Furthermore, the cooperation can change depending on the environmental state (e.g., based on weather, traffic density) and internal state of the ship (e.g., based on malfunctions). In general, it is important to consider the operational envelope described in the ConOps of the ships. Because of the dynamics of the sharing of responsibilities also the procedures for hand-over of control from automation to human and back have to be described.

Step 5 - Staffing: Once the roles, their associated tasks and the division of responsibilities between humans and automation have been defined, the number of people required for each role can be calculated. In addition to the tasks itself, a variety of factors influence the decision on how many people are needed per role. These include for instance the number of ships controlled and monitored in the RCC, the schedule (e.g., how many difficult manoeuvres occur simultaneously that require direct control at the same time), workload inducing factors (e.g., traffic area, weather conditions) as well as shift patterns (some roles need to be staffed around the clock (24 hours) to ensure continuous monitoring and response capabilities).

Step 6 - Define Interaction between roles: Some tasks in the RCC require communication and collaboration between roles. Especially in case of emergencies effective interaction is crucial to respond quickly to any unexpected events and to initiate appropriate countermeasures. Such interaction should be optimally supported by the RCC design, and for this reason it should be specified exactly who has to collaborate and communicate with whom (e.g., in the form of an interaction matrix).

Step 7 - Specify information and controls needed for each task: To design user interfaces for individual displays and workstations in the RCC, it is necessary to determine what information and controls an operator needs to perform the task effectively. This specification is important to determine *which* information is displayed (no more or less than is needed for the task), *where* the information is displayed (e.g., information needed in one task should be grouped together) and *how* the information is visualised (e.g., colours are useful for quickly recognising conditions, whereas quantitative values such as speed are better perceived through lengths (e.g. bars)). The same applies to the controls, be they physical devices (e.g., a joystick) or “soft controls” included in the HMI.

Step 8 - Assign roles to work positions: a work position is a position in the RCC where one or more roles can perform their tasks. The work position is composed of a piece of furniture (workstation), technical equipment (displays, keyboards, mice, controls…) and a user. The design of a work position consists in provisioning the position with all the technical equipment and facilities needed for its target role(s) and designing or selecting a workstation with which these can be integrated and positioned in optimal ways for the user.

Step 9 - Design control room including human-machine interaction, room layout, lighting, acoustics and HVAC**. I**n this step …

… the human-machine interaction between the work positions users and their equipment and facilities is specified and developed. The human-machine interfaces are defined at that stage. They will provide the information and the controls needed by the user for the performance of the role they belong to.

… the work positions will then be laid out in space, in the RCC room. This will rely on the interaction between roles previously explored, so that operators that need to frequently interact can indeed do so. Information will also be positioned at this stage outside the work positions, typically on videowalls or large displays that are attended by more than one operator.

… finally lighting, acoustics and HVAC (Heating, Ventilation and Air Conditioning) will be defined, in compliance with the standards, to ensure the operators' comfort and well-being.

Step 10 - Checking the design against the high-level requirements: The design should fulfil the high-level requirements that are associated with the high-level tasks from step 2. In this final step it is checked if this has been achieved.

It is to note that any RCC designer should go through these steps, including ensuring compliance with the ergonomic standards applicable to an RCC (compare Annex B). Compliance to the standards should be mandatory.

4.3.1 Tasks and high-level requirements

An essential basis for deriving the functions, roles and workstations is the task analysis. The task analysis is used to determine all tasks that have to be performed within an RCC by the operators. These may include monitoring the status of the vessels, controlling their speed and direction, responding to alerts and alarms, and communicating with other operators and vessels. The definitions of the core functions and processes (cf. Section 4.2) should be used as a starting point for the task analysis.

Gaining a deeper knowledge and defining a precise specification about the tasks is necessary in various respects:

- A precise definition of tasks leads to a better understanding of tasks with regard to required competences, number of steps, workload induced by individual tasks, type of execution (e.g., possibility of parallel processing of tasks). This in-depth understanding supports the derivation of individual roles to which these tasks can be assigned.
- The precise definition allows to categorise tasks and thus to determine which requirements these types of tasks impose on the RCC (e.g., in terms of structure and available equipment), on the operator (in terms of skills, knowledge and competencies) or on the human-machine interface (HMI). For the latter the task analysis can be used to derive which information and controls are needed within a task to accomplish it efficiently and correctly. This guides the HMI and work position design by, for example, displaying information needed for a task close to each other. If this arrangement of information is not achieved, the operator would have to gather information from different places. This would lead to increased task execution time, increased cognitive load due to memorization processes, and increased error-proneness during task execution.

- The task analysis reveals which roles communicate with each other. Based on this, an interaction matrix can be derived that helps to determine how the spatial structure of the RCC should ideally be designed in order to support the communication of the actors within the RCC and which information and which communication equipment individual roles require in order to optimally enable communication with external parties (who are involved in the task).

4.3.1.1 Task analysis

The task analysis should include the following steps:

1. Break down main task into sub-tasks

2. Specify for each subtask:

   a. Who is communicating with whom within the task?

   b. What information is needed to perform the task?

   c. What equipment/hardware is needed to perform the task?

   d. What is the assumed level of automation?

In Section 4.2, the first step of the task analysis has already been completed and has provided a list of important core tasks for operating a voyage from berth to berth. Within the task analysis, these are specified in more detail. We will demonstrate this with one example.

The main task in this example is *Pilotage* (see Process 3.2 Navigation, Pilotage in chapter 4.2.3. The break-down of Pilotage into subtasks, as well as specification of communication, information and equipment needed to perform the task is shown in Figure 12. The subtasks that need to be carried out as part of pilotage are shown in the centre. These include for instance the communication with other ships passing nearby or the monitoring of conditions of the waterway including its physical characteristics such as depth, width, and current. The listed subtasks may require collaboration and communication with external agents. The external agents are shown on the left side of the figure. External agents involved in pilotage are the vessel traffic service (VTS), pilots and other ships. The dotted line indicates that a communication might take place during task execution. The resources (such as information or hardware equipment) needed to perform the task are shown on the right. Here, hardware, external systems and further equipment is indicated via a dashed border, while information that has to be considered in user interface design for the displays of the workstations is shown in closed boxes.

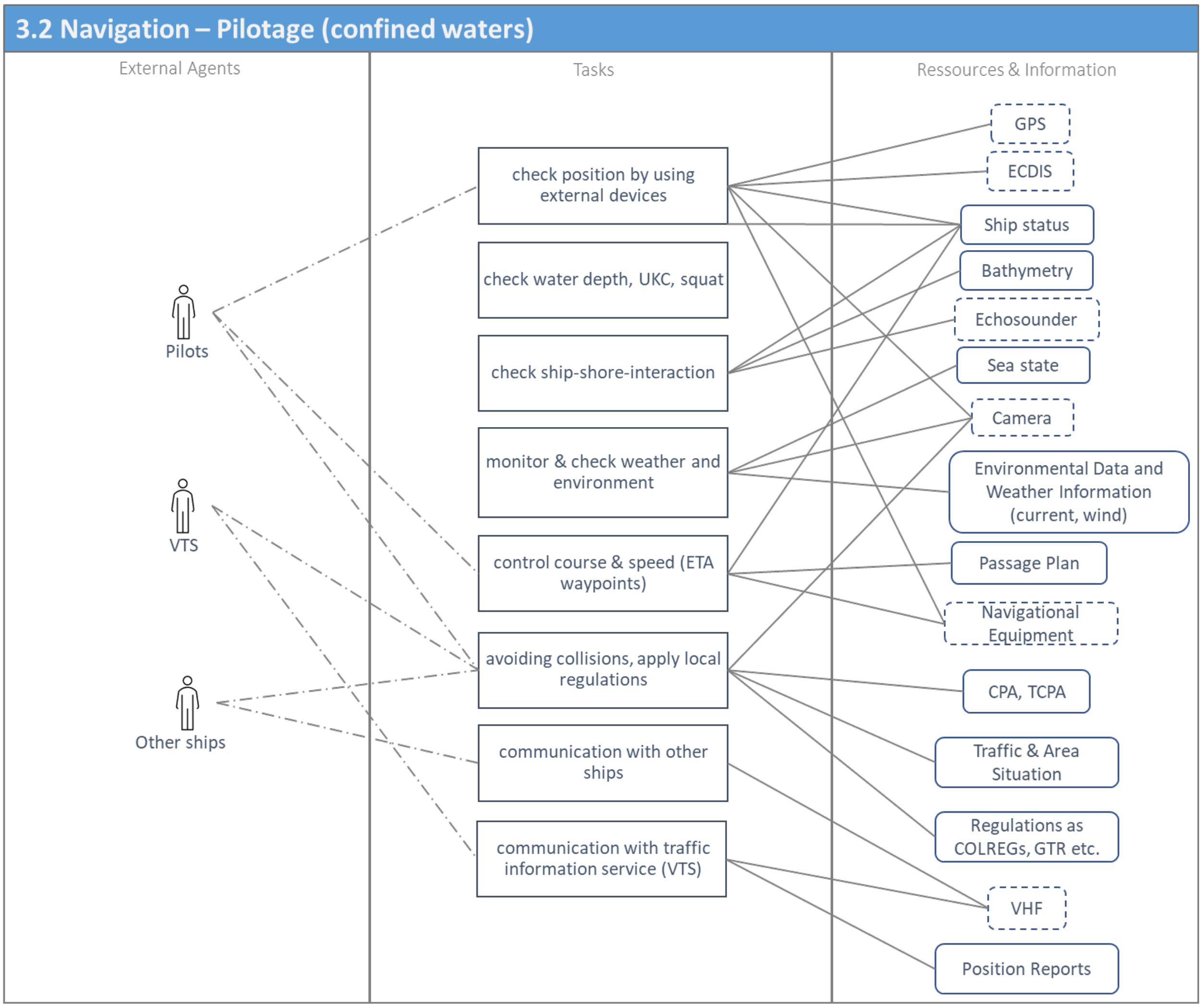

Figure 12: Exemplary Task analysis for Pilotage (source: HMT).

4.3.1.2 High Level Tasks (HLT) and associated High Level Requirements (HLR)

The aforementioned tasks can be classified into High Level Tasks (HLT). These HLT summarize groups of tasks that are performed in a similar manner. This grouping allows to define requirements that this HLT imposes on the design (e.g. for a monitoring task a good situational awareness is required which has to be taken into account by the HMI design). These requirements may relate to the HMI (Human Machine Interface), the operator, or the RCC (Remote Control Center).

The following text describes the HLTs, their associated lower-level tasks and the applicable requirements (HLR). Due to the limited time frame of the present study, this list of requirements is a first draft and would have to be supplemented in further studies.

The first HLT is *Monitoring* (Figure 13). Monitoring refers to the process of regularly observing and measuring key parameters or variables related to a system or process, with the goal of identifying any deviations or abnormalities from expected performance. This may involve using specialized tools and equipment to collect and display data in real-time, as well as interpreting that data to make informed decisions about how to adjust or optimize the system or process. Effective monitoring is essential for ensuring the safety, efficiency, and reliability of complex technical systems, and typically requires a high level of attention to detail and expertise in the relevant domain.

High Level Task	**Monitoring**
	Monitor ship status, environment, progress of processes, status of cargo, automation
Lower Level Tasks	2.2, 2.4 Cargo Loading & Discharging 2.3 Cargo Care at Sea
	3.2, 3.4 Navigation on pilotage 3.3 Navigation on sea passage 3.5.1 Anchoring (anchor watch) 3.6 Port stay
	4.1 Ensuring Utilisability of all systems 4.2. Monitoring ship performance
	5. Maintenance (monitor progress of processes)
	6. Malfunctions & Emergencies (Detecting emergencies/anomalies, monitoring progress made in the handling of emergencies) 7. IT systems and infrastructure, cybercommunications
High Level Requirements	**(HMI-M-R1)** The HMI must be designed in such a way that an operator can monitor more than 1 ship at a time. **(HMI-M-R2)** The HMI must be designed in such a way that an operator has a good situational awareness. **(HMI-M-R3)** The HMI must be designed in such a way that an operator can recognise emergencies or abnormalities within 2 seconds. **(HMI-M-R4)** The choice of visual representations in the HMI must be consistent (e.g. if red is used for critical states, red should not also be used for visual coding of other states). **(HMI-M-R5)** Based on the desired level of safety, it must be decided how quickly anomalies should be detected via the HMI (here, for example, is a significant difference between displaying an alarm detected by the system(e.g., a parameter exceeds a threshold) and displaying deviations and trends to enable an operator to anticipate anomalies). **(HMI-M-R6)** The HMI should consider the perceptual abilities of the operator when designing displays, and the display should be optimized accordingly. (Guidelines and background knowledge about human perceptual skills are helpful to fulfil this requirement. These are for instance provided by Human Factors methods as the Konect method (Harre & Feuerstack 2018)) **(HMI-M-R7)** The HMI should provide no more and no less than the information needed for the task.

Figure 13: HLT Monitoring (source: HMT)

The second HLT is *Direct Control* (Figure 14). Direct Control refers to the ability of operators to directly interact with and control remote systems and processes. This can include activities such as manoeuvring the ship in challenging situations (e.g. in (de-)berthing or for handling malfunctions and emergencies), controlling the automation (e.g. adjusting parameters and states) and controlling ship components (e.g. remotely operate the anchor).

High Level Task	**Direct Control** **Maneuvering the ship, controlling the automation, controlling ship components**
Lower Level Tasks	2.2, 2.4 Cargo Loading & Discharing (e.g. remotely operate systems in port or on board e.g. gangway; ballasting the vessel; adjusting of trim, stability and strength values)
	3.1.2, 3.5.2 Departure/De-Berthing & Arrival/Berthing (maneuvering) 3.2, 3.4 Navigation Pilotage 3.5.1 Anchoring (heaving & dropping anchor)
	6. Malfunctions & Emergencies (maneuvering ship during emergencies) 7. IT systems and infrastructure, cybercommunications
High Level Requirements	**(HMI-DC-R1)** The HMI must be designed in such a way that the operator is not forced to apply cognitive control to a higher level than the demands of the task require (based on SRK framework of Rasmussen (Vicente & Rasmussen 1988)). **(HMI-DC-R2)** The HMI must be designed in such a way that the operator is aware of automation: automation status, automation current goal (e.g., set point(s), way points), automation current actions and effects on the systems controlled by automation. **(HMI-DC-R3)** The HMI must be designed in such a way that the operator can control automation and override it on the 3 aspects above (status/state, current goal, current actions). **(HMI-DC-R4)** The HMI must be designed in such a way that the operator still has appropriate situation awareness in case automation disengages or they have to take control over automation. In particular the HMI must be designed in such a way that situation awareness can be rapidly and effectively built if this occurs. **(HMI-DC-R5)** The HMI must be designed in such a way that the operator has appropriate information and controls for the control tasks they are involved in: state of the systems under control, state of the actuators, prediction of future states (nice to have), trends (nice to have), state of the environment in which the control is performed (e.g. surrounding traffic for a navigation task).

Figure 14: HLT Direct Control (source: HMT)

Besides Monitoring and Direct Control, *Communication* is an essential HLT (Figure 15 and Figure 16). Communication involves the exchange of information and instructions between different roles and agents. The Communication can take place between different roles in the RCC (e.g. collaboration for handling emergencies) or with external agents (e.g. communication with pilots during (de-)berthing).

High Level Task	**Communication (internal)** **Exchange information; coordinate processes with internal agents**
Lower Level Tasks	6. Malfunctions & Emergencies
High Level Requirements	**(RCC-Ci-R1)** The spatial arrangement of the control centre must support the collaboration of operators during emergency management. **(RCC-Ci-R2)** In particular this arrangement must be appropriate for the information flows between operators (or other RCC actors) expected from the execution of operational procedures, during normal and abnormal situations.

Figure 15: HLT Communication internal (source: HMT)

High Level Task	**Communication (with external agents)** **Exchange information; coordinate processes with external agents**
Lower Level Tasks	1. Voyage Planning & Tracking (check and approve plan from Fleet Operation Center)
	2.1 Cargo Planning (check and approve plan from Fleet Operation Center) 2.2, 2.4 Cargo Loading & Discharging (communication with shore services; receive information about process) 2.3 Cargo Care at Sea (receive information)
	3. Navigation (e.g. communication with other ships, communication with traffic information service (VTS), coordination with pilots) (coordinate)
	4. Operations Engineering (receive information, coordinate e.g. receiving information about state of loading spare parts)
	5. Maintenance (receive plan from FOC, receive information about states & processes)
	6. Malfunctions & Emergencies (receive information)
High Level Requirements	**(HMI-Ce-R1)** The HMI must be designed in such a way that it supports communication between operators in a way that they can gain the same situation awareness. **(RCC-Ce-R1)** The operators have to be able to communicate with every ship they have to deal with.

Figure 16: HLT Communication (with external agents) (source: HMT).

An additional HLT in the RCC is *Planning & Organisation* (Figure 17). This HLT refers to the process of developing a comprehensive plan that outlines objectives and strategies for operating the autonomous vessel. This might for instance take place in planning an anchoring manoeuvre or adjusting stowage plans. Planning should be an ongoing process that is regularly reviewed and updated to reflect changes in the operating environment and to incorporate feedback from roles or external agents.

High Level Task	**Planning/Organisation**
	Develop plan for operating the vessel, update plan according to changes and feedback
Lower Level Tasks	1. Manage changes in the voyage
	2.1 Cargo Planning (check and approval of stowage & ballast plan; adjust and update stowage plan as real loading ;calculation and assessment of draught and trim, transverse stability, and strength of the vessel)
	3.1.1 Passage Planning 3.1.2, 3.5.2 Planning (de-)berthing manoeuvres 3.5.1 Planning anchoring manoeuvre
High Level Requireme nts	**(HMI-P-R1)** HMI must be designed in such a way that it supports the operator's ability to predict the impact of actions on the object (representation of object on which changes apply, be able to manipulate object).

Figure 17: HLT Planning/Organisation (source: HMT).

The operation of the fleet in the RCC involves dynamic changes in the scheduling and distribution of tasks e.g. schedule changes may occur due to weather or availability of berths in the ports. In these cases, tasks have to be redistributed between the people in the RCC. This aspect is considered in the HLT Dynamic Human Resource Management (Figure 18).

High Level Task	**Dynamic Human Resource Management**
	Reassigning tasks
Lower Level Tasks	*All tasks assigned to the RCC*
High Level Requirements	**(RCC-H-R1)** The RCC role allocation between the RCC actors must be designed in such a way that task distribution between the actors is dynamic and resilient. **(RCC-H-R2)** In particular, workload must be considered as a significant variable involved in task distribution decisions. Other important factors are fatigue and actor incapacitation.

	(RCC-H-R3) The RCC (spatial arrangement, work positions, HMI, procedures) must be designed in such a way that tasks can be easily and rapidly redistributed between actors when needed. **(HMI-H-R1)** If one or more supervisor are active in a RCC they must be provided with the information needed (direct view, communication, HMI,...) to assess the workload, fatigue and (in)capacitation of the actors under their supervision.

Figure 18: HLT Dynamic Resource Management (source: HMT).

In addition to the aforementioned HLT, the RCC also has *documentation* tasks, such as maintaining the logbook (Figure 19).

High Level Task	**Documentation**
Lower Level Tasks	e.g. electronic logbooks
High Level Requirements	

Figure 19: HLT Documentation (source: HMT)

4.3.2 Roles, responsibilities and staffing for the RCC

4.3.2.1 Definition of roles in an RCC

A role is a work profile or position assigned to persons.
Roles are associated with specific

- Tasks
- Functions
- Duties
- Responsibilities
- Authority and hierarchical relationships with other roles
- Skills or competences, to achieve the above

Producing the specification of the roles for an RCC entails defining these properties for each role.
So far, we have shown the different tasks – and associated High Level Tasks (HLT) - that need to be performed by an RCC during the operation of a MASS or fleet of MASS. The High Level Tasks have associated High Level Requirements (HLR) that need to be satisfied by the RCC once designed and in operation.
A good approach for the definition of roles in an RCC is to start from these tasks and in particular the High-Level Tasks to assign them to specific roles. The above determined HLT are:

> Monitoring
> Direct control
> Internal communication (with other actors within the RCC)
> External communication (with actors outside the RCC)
> Planning/organization
> Dynamic resource management
> Documentation

A definition of a set of roles for an RCC should cover all these High-Level Tasks, and their lower-level counterparts. There are many possibilities and combinations. The table below shows for example two possible options for the definition of the roles in a given RCC, **for the same set of HLTs**.

High Level Task (HLT)	**Roles (option 1)**	**Roles (option 2)**
Monitoring (passage)	Remote monitoring operator	Remote direct control operator
Direct control (voyage)	Remote direct control operator	Remote direct control operator
Internal communication	All roles (based on interaction matrix)	All roles (based on interaction matrix)
External communication	With MASS: • Remote monitoring operator • Remote direct control operator With other external entities • Operation planner • Fleet supervisor	With MASS • Remote direct control operator With other external entities • Fleet supervisor
Planning/organization	Operation planner	Fleet supervisor
Monitoring and control (MASS systems)	Remote engineer	Remote engineer and IT specialist
Monitoring and control (IT systems, infrastructure, cybercommunication)	Systems administrator	Remote engineer and IT specialist
Dynamic resources management	Fleet supervisor	Fleet supervisor
Documentation	All roles (everyone describes what they do in logbooks)	All roles

There are 6 roles in option 1:
- Remote monitoring operator
- Remote direct control operator
- Remote engineer
- Systems administrator
- Operation planner
- Fleet supervisor

But only 3 in option 2:
- Remote direct control operator (he or she also monitors)
- Remote engineer and IT specialist
- Fleet supervisor (he or she also plans/organizes)

In both cases, all HLT are performed. They are just assigned to different roles. The persons chosen for the roles must have the skills and competences expected from their roles, and therefore associated High Level Tasks (HLT). For example, in option 2, the Fleet Supervisor must be capable of acting as an Operation Planner. The Remote engineer must also be an IT specialist.

The choices in the definition of the roles will be dependent on a series of external factors that are peculiar to each RCC and the context in which it operates. This is well captured with the ConOps (Concept of Operations, cf. Section 6.2). The ConOps should be the main input for deciding how to define the roles for an RCC.

Based on the ConOps, the RCC designer will have to address the following questions, **for each role**:

- Can that role safely achieve its tasks (HLTs) in all circumstances? This mostly resorts from the issue of workload. Superposing several HLTs in a single role (and in the end, a single individual) as in option 2 may be too much of a burden for that role in some circumstances?
- Can profiles (skills/competences) capable of performing the role be found on the market, at prices that are affordable?
- Can profiles capable of performing the role be trained to reach the target level of performance for the role?
- How will we have to staff our RCC (i.e., number of persons per role) to safely manage the MASS fleet involved in the ConOps?

An RCC role distribution such as in the option 2 above, with only three types of roles, could be fully appropriate for simple ConOps, with a small fleet operating in a simple and predictable environment, with limited interfering traffic. Option 1, with its 6 roles, could be mandatory for more complex ConOps.

Our general recommendation for the definition of roles in an RCC is therefore to:

- **Make the ConOps explicit.** That's key.
- Derive the tasks, and high-level tasks (HLT) and requirements (HLR), associated with operations in this Conops.
- Define roles to which tasks and high-level tasks are assigned.
- Assess the four questions above to determine if the role definition is appropriate, otherwise revise the role definition.

Once a definition of roles for the RCC is considered appropriate and safe in terms of (High-level) task distribution between the roles, the RCC designer will define, for each role:

- Their duties, mostly derived from their HLTs
- Their responsibilities, mostly derived from their HLTs
- The skills and competences required, again mostly derived from their HLTs
- Their authority and hierarchical relationship with other roles (e.g., fleet supervisor > remote direct control operator > remote monitoring operator)

4.3.2.2 Demonstration on our example use case

For our example use case (Use Case A), as described above, we have assigned tasks to individual roles (see Table 14). In these, an assignment of tasks is made based on the type of task (HLT) as described before. In addition, the required competence is considered. For this reason, a distinction is made

between Remote Monitoring Operator and Remote Engineer, as they must have prior knowledge/competences from different areas of expertise. While the Remote Monitoring Operator has more knowledge about safe operational processes in the field of MASS (navigational expertise), the Remote Engineer has a focus on the technical aspects (engineering). For the latter role, expertise in electrical engineering is becoming increasingly important, as the number and complexity of electrical systems on modern ships is growing rapidly due to the increasing degree of automation of non-electrical systems in propulsion and hydraulics, the digitalization of navigation and monitoring systems, and the growing number of parameters to be monitored by sensors. In addition, there are more and more electrical components in the propulsion system, e.g. electrically operated thrusters, propeller azimuth drives or other diesel-electric forms of propulsion. Larger ships increasingly have powerful medium-voltage networks for power distribution.
Based on above discussion 5 roles are derived:

Table 14: RCC Roles (HMT)

<table>
<tr><th>Role</th><th>Short Description & Tasks</th><th>Competence/Background</th></tr>
<tr><td>Fleet Supervisor</td><td>The Fleet supervisor mainly manages the overall organization of the RCC and has the responsibility for the whole fleet (in this use case all 6 ships). In particular, he takes over dynamic resources management as well as planning and organizational tasks. A detailed assignment of tasks is given in Table 15 .</td><td>We assume that the fleet supervisor is an experienced navigator (who is familiar with the tasks of the employees) and has an overview of the organization. According to STCW, this is a management-level role that also involves experience similar to the current master.</td></tr>
<tr><td>Remote Navigator Direct Control</td><td>The Remote Navigator mainly handles the direct control of one vessel and has to focus on one vessel at a time. A detailed assignment of tasks is given in Table 16.</td><td>This role requires navigational expertise at a high level (management level according to STCW).</td></tr>
<tr><td>Remote Navigator Monitoring</td><td rowspan="2">The Remote Monitor and Remote Engineer mainly perform the HLT Monitoring for multiple vessels at the same time to ensure safe operation. The roles differ based on background knowledge. A detailed assignment of tasks is given in Table 17 and Table 18.</td><td>This role requires navigational expertise on operational level according to STCW.</td></tr>
<tr><td>Remote Engineer</td><td>This role requires background knowledge in engineering and electrical engineering.</td></tr>
<tr><td>System Administrator</td><td>Due to the envisaged IT infrastructure in the RCC, the role of a System Administrator is needed that ensures the proper operation of the entire IT in the RCC. A detailed assignment of tasks is given in Table 19.</td><td>This role has an IT background and knowledge of managing complex IT infrastructures.</td></tr>
</table>

The allocation of tasks between the five roles in the reference use case is shown in Table 15 - Table 19.

Table 15: Assignment of tasks to role "Fleet Supervisor" (source: HMT)

Role: Fleet Supervisor

Communication (with external agents)

- 1. Voyage Planning & Tracking (receive plan from Fleet Operation Center)
- 6. Malfunctions & Emergencies (coordinate)

Communication (internal)

- **6.** Handle Malfunctions & Emergencies (coordinate countermeasures)

Planning/Organisation

- Manage changes in the Voyage
- Additional: ensuring that all processes in the RCC operate/run properly; ensure that work breaks and rest times are kept.

Dynamic Human Resource Management

- (Re-)assign tasks in RCC

Table 16: Assignment of tasks to role "Remote Navigator Direct Control" (source: HMT)

Role: Remote Navigator Direct Control

Direct Control

- 2.2, 2.4 Cargo Loading & Discharging (e.g. remotely operate systems in port or on board e.g. gangway; ballasting the vessel; adjusting of trim, stability and strength values)
- 3.1.2, 3.5.2 Departure/De-Berthing & Arrival/Berthing (manoeuvring)
- 3.2, 3.4 Navigation Pilotage
- 3.5.1 Anchoring (heaving & dropping anchor)
- 6. Malfunctions & Emergencies (maneuvering ship during emergencies)
- Additional: Assess correctness of sensor values; coping with new ways/handles/technic for steering the ship

Communication (with external agents)

- 3. Navigation (e.g. communication with other ships,
  communication with traffic information service (VTS), coordination with pilots)
- 6. Malfunctions & Emergencies (receive information)

Communication (internal) & Handover

- 6. Handle Malfunctions & Emergencies (manoeuvring ship during emergencies)

Planning/Organisation

- Manage changes in the Voyage
- 3.1.1 Passage Planning
- 3.1.2, 3.5.2 Planning (de-)berthing manoeuvres
- 3.5.1 Planning anchoring manoeuvre

Table 17: Assignment of tasks to role "Remote Navigator Monitoring" (source: HMT)

Role: Remote Navigator Monitoring

Monitoring

- 2.2, 2.4 Cargo Loading & Discharging
- 2.3 Cargo Care at Sea
- 3.2, 3.4 Navigation on pilotage
- 3.3 Navigation on sea passage
- 3.5.1 Anchoring (anchor watch)
- 3.6 Port stay
- 6. Malfunctions & Emergencies (Detecting emergencies/anomalies, monitoring progress made in the handling of emergencies)
- Additional: assess correctness of sensor values & actuators; monitor automation

Planning/Organisation

- 2.1 Cargo Planning (adjust and update stowage plan as real loading)

Table 18: Assignment of tasks to role "Remote Engineer" (source: HMT)

Role: Remote Engineer

Monitoring and control

- 4.1 Ensuring Utilisability of all systems
- 4.2. Monitoring ship performance
- 5. Maintenance (monitor progress of processes)
- Additional: Assess state of sensors & actuators

Communication (with external agents)

- 5. Maintenance (receive plan from FOC, receive information about states & processes)
- 6. Malfunctions & Emergencies (receive information)

Table 19: Assignment of tasks to role "System Administrator" (source: HMT)

Role: System Administrator

Monitoring and control

- 7. IT systems and infrastructure, cybercommunications

Communication (internal)

- 6. Support handling Malfunctions & Emergencies

Planning/Organisation

- provide updates of software
- ensure correct functioning of IT systems in RCC

4.3.2.3 Staffing in an RCC

Staffing for the RCC mostly means: “how many instances of each role do I need”?

In Option 1 for the definition of roles above:

- “how many remote monitoring operators do I need”?
- “How many remote direct control operators”?
- “How many fleet supervisors” (there could be several if the RCC is managing several fleets in parallel)?

Staffing is heavily linked with the notion of workload. In no case an individual in a given role should be so overloaded that they cannot safely perform their tasks and duties, at any given time. Workload in a human-machine system that mixes human with highly automated systems will be strongly dependent on these systems’ levels of automation or autonomy.

Workload will also depend on the number of tasks an operator has to perform in parallel. For example, a remote monitoring operator can monitor several MASS in parallel, especially if the level of automation is high, the automation is safe and reliable (i.e., it does not disconnect abruptly), and the operator is provided with high quality information (situation awareness) and suitable alerting systems. A remote direct control operator on the other hand will probably be able to safely handle a single MASS at a time.

Thus again, staffing will strongly depend on the peculiar ConOps the RCC is operating in. The staffing of an RCC depends on various parameters. The use cases described in the operational envelope differ fundamentally. Accordingly, staffing, or Safe Manning, will look different for the different concepts of operation.

The critical ConOps parameters therefore are:

> The degree of automation and control: as figured out in the previous chapter 3.3 the required response deadline of all critical system elements must be covered by the maximum response time of the operators. By evaluation of the time requirements the nominal workload and availability of the operators on the timeline can be determined.

> The number of ships: In relation to the required response times the number of MASS / ships drives the number of operators. A fleet of vessels sailing long distances in waters without restrictions will need much less operators as a short sea ship in very dense traffic, harsh weather conditions and many port manoeuvres.

> The expected manoeuvring times: It depends on the size of the ships and the restrictions in the area how many manoeuvring is required and how long manoeuvres can take which may need more attention by an operator.

> The statistical number of critical events as close quarter situations, environmental related impacts or technical impact are to consider as well.

> The watch system: needs to be in accordance to the maximum work hours with specific perspective to the necessary attention of operators and how they can gain situational awareness in short time.

> The qualification and competences of the operators: all capacities required and responsible for certain parts of the passage of the vessel are to list with required Certificates of Competence or Certificates of Proficiency.

The manning level should be determined by two perspectives, the standard operations and the non-normal operations (e.g. due critical situations or emergencies).

> For standard operations it will be necessary to simulate different scenarios (open sea operations, pilotage, berthing) to find out the minimum standard manning level. On this basis the standard watch system must be determined.

> For the non-normal operations a fall-back organisation with an additional demand to manning has to be calculated. In case of severe weather, critical events as alarms and equipment failure, disturbance in connectivity or emergencies it is assumed that these operations will be taken out of the standard operations, e.g. in a separate control station. The response time of availability must be considered to determine the number of operators which are needed in stand-by to keep the system safely running.

With growing experiences and statistical data of remote-controlled ships it will get possible to set standards, too. But in the beginning of remote-controlled ships the manning must be determined by assumptions and calculations.
A Safe Manning for an RCC should consider assumptions as this example:

<u>Operational Envelope:</u>
> Remote control of six container vessels … <particulars> ;
> Operating on three different relations, from port “X” to port “Y”;
<u>Degree of automation:</u>
> Level ‘1’ partial, time of response deadline > 5 min …< to be outlined per critical equipment>
<u>Degree of human control:</u>
> Level ‘2’ discontinuous, response time > 3 min … < to be outlined per critical function>
<u>Automation degree:</u>
> OA – operator assisted (the operator is close to the control station, leaving the control position is on own judgement) … < to be outlined for all groups of critical functions>
<u>Hours of work / of rest:</u>
> < xx hours work per day, rest periods of yy minutes each zz hours>
<u>Standard operations:</u> < workload in hours based on calculations of average workload per function, weighted by degrees of automation and human control>, e.g.:
> Manoeuvring 8 hours
> Pilotage 18 hours
> Sea passage 8 hours
> <u>Port stay 4 hours</u>
> Total 38 hours <the passage definitions are to adjust to the operational envelope>
<u>Safe Manning for standard operations:</u>
number of each capacity (operators) and the required CoC and CoP, e.g.
> n Operator on Watch (operational level), in three watches
> m Supervisor (management level), in two watches, 5 min response time
<u>Safe Manning for overriding operational conditions:</u>
> n Supervisor (management level), as back-up, 5 min response time

The manning certificate should also require a minimum medical standard. The operators need minimum abilities in seeing and hearing as well as in physical fitness. Medical specialists have to determine such standards compared to STCW section A-I/9.

4.3.2.4 Social legislation

The maximum working hours and the minimum rest hours are regulated in the Maritime Labour Convention 2016 (MLC). In order to reduce the problem of fatigue, the STCW Manila Amendments 2010 harmonized working and rest hours with the MLC. The rules apply to crews on seagoing vessels. It is to consider that crews on board will perform not only watchkeeping duties, but also other tasks in a 7-day week. The regulations [2] are:

- Minimum number of hours of rest is 10 hours in any 24 hour period,
- the rest period must not be less than 77 hours in any seven day period.
- The 10 hours rest may be divided in no more than two periods, one of which must be at least six hours and no period shall be less than one hour. In cases of emergencies, drills or overriding operational conditions the times may be exceeded.
- By STCW an exemption is allowed that Administrations determine that the rest period is not less than 70 hours in any seven day period, but not longer than two weeks.

For further details refer to STCW.

In an RCC, it is not necessary to implement a 7-day week for the employees. Shift times can be introduced as in other occupations. The length of maximum working hours is regulated in national legislation, partly also by agreements between collective bargaining partners, and will have to be based on this.

In an RCC there are many moments spent to monitoring. Keeping attention high is a challenge, especially during night watches and irregular working hours. It is therefore strongly recommended not to exceed corresponding working hours for RCC, to define sufficient break times and to specify minimum rest periods.
Examples are directives and recommendations for maximum worktime at computer monitors between breaks of less than one hour. Another example is the maximum work time between breaks of 45 minutes for Air Traffic Control.
The definition of maximum work times and minimum break and rest times must be set by the social legislation of the “flagstate” of the RCC. It will have a direct impact on the needed capacities of personal and qualifications in an RCC.

4.3.2.5 Minimum safe manning for our example use case

In our example use case, in the peculiar ConOps the RCC will be operating in, with 6 MASS controlled by the RCC, the minimum manning is proposed in the Table 20.

[2] STCW Code: A-VIII/1

Table 20: Minimum Safe Manning of RCC as proposal for the use case "feeder ship" (HMT)

Role	Manning	Motivation
Remote monitoring operator	2	Each operator monitors 3 MASS. This is manageable if the operator is provided with appropriate situation awareness and alarming systems (including predictive alarming systems, trends…)
Remote direct control operator	2	Each operator deals with 3 MASS but only controls one at a time. The MASS schedules are defined in such a way that berthing or de-berthing do not occur at the same time, for any of the 3 MASS controlled by one of the direct control operators
Reserve remote direct control operator	Up to 2	Reserve remote direct control operators take direct control duties when the two remote direct control operators are busy with berthing or de-berthing operations and there is a significant issue detected by the remote monitoring operators. The RCC will be provisioned with 2 additional remote direct control workstations (one in a dedicated room and one in the Emergency Response Center). These reserve control operators can be dedicated to office type tasks when they do not have to intervene as controllers.
Fleet supervisor	1	A single fleet supervisor is sufficient. There is a single fleet, of only 6 MASS.
Remote Engineer	1	A single Remote Engineer should be sufficient, presuming the 6 MASS and associated infrastructure are reliable. On the other hand, we clearly point out that the number of needed Remote Engineers heavily depends on the degree of automation and used technologies.
Systems Administrator	1	A single Systems Administrator should be sufficient for dealing with the IT infrastructure for an RCC dealing with 6 MASS. On the other hand, we clearly point out that the number of needed Systems Administrators heavily depends on the degree of automation and used technologies.

4.3.3 Cooperation analysis and interaction matrix

In the previous section, we have explained how the RCC roles and staffing (number of persons per role) can be determined.

Here we investigate how these roles will work together (cooperation analysis) and how this defines how they interact and exchange information (interaction matrix).

The two aspects are fully determined by the tasks of the roles in charge and the procedures they have to apply when performing these tasks.

For example, if a role is involved in the monitoring of some system working automatically (e.g., remote navigation of some MASS) and something happens on the monitored system that mandates the intervention of another role in the RCC (e.g., remote navigator takes control of the MASS), the two roles will need to interact.

4.3.3.1 Interaction with other RCC stakeholders

Interaction between roles is typically characterized in terms of the modalities involved. For example a typology based on view, listen to, speak with, walk to can be used:

> *View*: a role needs to see what another role is doing. For example, a supervisor will benefit from viewing all the persons they are supervising.
> *Listen to*: a role needs to be able to listen to what another role is doing or saying. This helps gaining situation awareness on the situation handled by the second role, or assess their presumed workload, which can be useful to avoid disturbing them when they are busy.
> *Speak with*: two roles may need to be able to speak together, to exchange operational information, situation awareness, or pass some task like in the example above when a monitoring role gives control of a MASS to a navigator role because the MASS needs to be handled at a lower level of automation.
> *Walk to*: one role must walk to another role’s work position. This can happen between the roles need to work on something together or exchange information.

The interaction matrix with the other RCC stakeholders has a strong impact on how the RCC should be laid out in space (spatial organization). The most frequent or most important interactions between the different roles must be supported and even favored. A badly designed RCC room layout will make such interactions difficult, resources consuming and error prone.

4.3.3.2 Interaction with stakeholders outside the RCC

The tasks associated with a role usually also involve communicating with stakeholders that are outside the RCC. This can be achieved through:

> Verbal communication, with equipment such as a telephone or radio.
> Video communication, through videoconferencing systems for example.
> Text or document exchanges via email or messaging systems.

The interaction matrix with external stakeholders will allow determining the equipment that must be available on the operators (roles) workstations (e.g., telephone, radio…) or in the RCC (e.g., teleconferencing station). This may also have an impact on the future room layout, given that roles that frequently need to interact with external stakeholders may disturb the RCC roles that require a quiet environment (e.g., the remote direct control operators).

Cooperation analysis and the determination of interaction matrices therefore helps:

> Determining how the work positions should be laid out in the room.
> Determining the communication equipment to place on the workstations.
> Determining the other communication equipment to make available in the RCC (e.g., video conferencing table or room).

4.3.3.3 Demonstration on our example use case

Figure 20 shows the interaction for our example use case. The Fleet Supervisor ensures the safe operation of the RCC and assigns tasks dynamically. Thus, this role will communicate to each other role (e.g., for assigning a task, a vessel to be controlled or to get further information about a specific case/manoeuvre etc.).

Direct communication between the Remote Navigator, Remote Monitoring Operator and Remote Engineer is particularly important for dealing with emergencies. For example, the Remote Monitoring Operator may detect a problem with the vessel (e.g., malfunction of steering gear). If the automation reaches its limits, a direct control becomes necessary (e.g., conduct a manoeuvre to bring the ship into a safe condition). This requires efficient and fast communication between Remote Navigator, Remote Monitoring Operator and Remote Engineer.

In addition to internal communication, there is also communication with external stakeholders for the role of Remote Fleet Supervisor (e.g., with fleet operation center, ...), for the Remote Navigator, who, for example, communicates with pilots or tugs or the VTS during (de-)berthing and for the Remote Engineer. The latter must communicate with persons on the ship who can, for example, visually inspect the ship's technical equipment on site and provide additional information back to the Remote Engineer.

	Remote Fleet Supervisor	**Remote Navigator**	**Remote Monitoring Operator**	**Remote Engineer**	**Remote System Administrator**	**External (e.g. Pilots)**
Remote Fleet Supervisor		**X**	**X**	**X**	**X**	**X**
Remote Navigator			**X (handover in emergencies)**	**X (handover in emergencies)**		**X**
Remote Monitor						
Remote Engineer						**X**
Remote System Administrator						
External (e.g. Pilots)						

Figure 20: Interaction Matrix for example use case (source: HMT).

4.3.4 Information and controls, work positions and workstations

4.3.4.1 Information and controls

In order to derive the information and controls that the roles require to fulfil their tasks, the task analysis carried out in the first step is relevant. In Section 4.3.1, the task analysis for the exemplary task *Pilotage* is shown. Depending on the level of automation, pilotage can either take place as *Direct Control* or as *Monitoring* task if the ship is able to navigate autonomously through narrow waters.

These two cases need to be distinguished and different information is needed to perform the task:

For Direct Control, the required information and resources can be seen at a high level of abstraction on the right-hand side of the task analysis in Figure 12 and Figure 22. This includes, for example, information about the ship (e.g. under keel clearance, speed over ground, course over ground, heading etc.) but also information about the current traffic situation and the weather forecast. On existing ship bridges, the ECDIS and radar and conning display are used for this purpose. This can also be applied in a direct control station. A possible set-up is shown in Figure 21 as rough schematic representation.

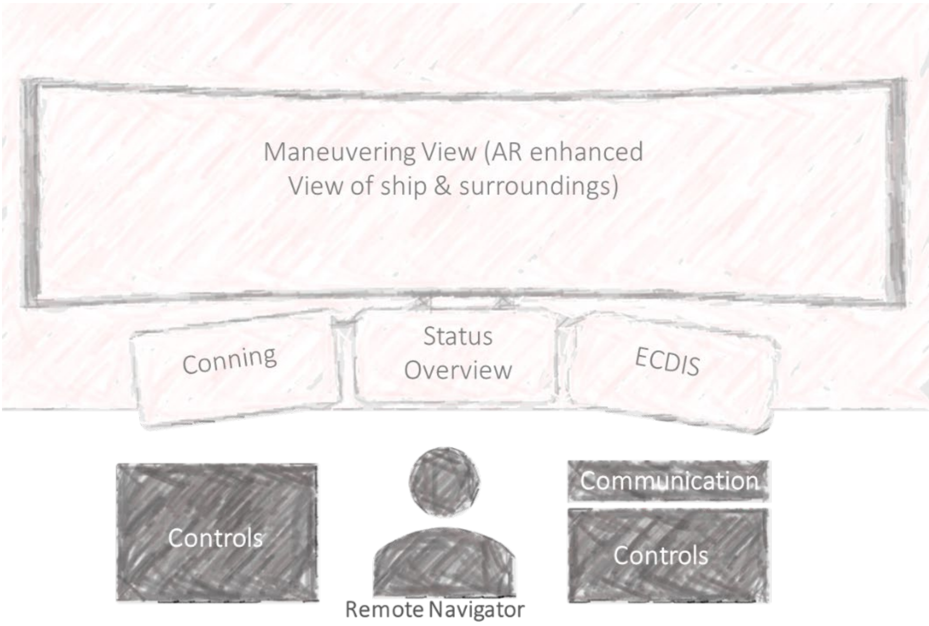

Figure 21: Schematic representation for Direct Control set up (source: HMT).

ECDIS, radar and conning information correspond to the current set-up on the ship bridge. An important difference in the RCC is, that there is no longer a view out of the window. This is replaced by a manoeuvring view, which can add important information directly in the field of vision in form of augmented reality.

While direct control is similar to the current situation on the ship's bridge in our use case (as only one vessel is controlled at a time) the situation for monitoring (if the ship performs pilotage autonomously) is completely different and new user interfaces are necessary. We illustrate exemplarily in the following text how to proceed to derive appropriate information and the user interface design. Due to the limited time and the scope of the study, this is to be seen as exemplary and is in no way to be considered complete.

The starting point are the needed information resources derived by the task analysis (Figure 22) in step 1 of the HFCD approach. For monitoring, in contrast to direct control, information is needed on a different level: The operator must monitor whether the automation can function properly. For this purpose, the operator must not only assess that everything is technically functioning (e.g. sensor states & actuator states), but s/he must also monitor whether the automation is operating within its operational envelope or if it is close to its limits. In the latter case, the operator has eventually to prepare a transfer to direct control from automation to human operator. For this, the current traffic situation or difficult weather situations must be taken into account. The main task of the operator is thus to assess whether the conditions for correct functioning of the automation are given or whether the automation reaches limits in which it can no longer operate properly.

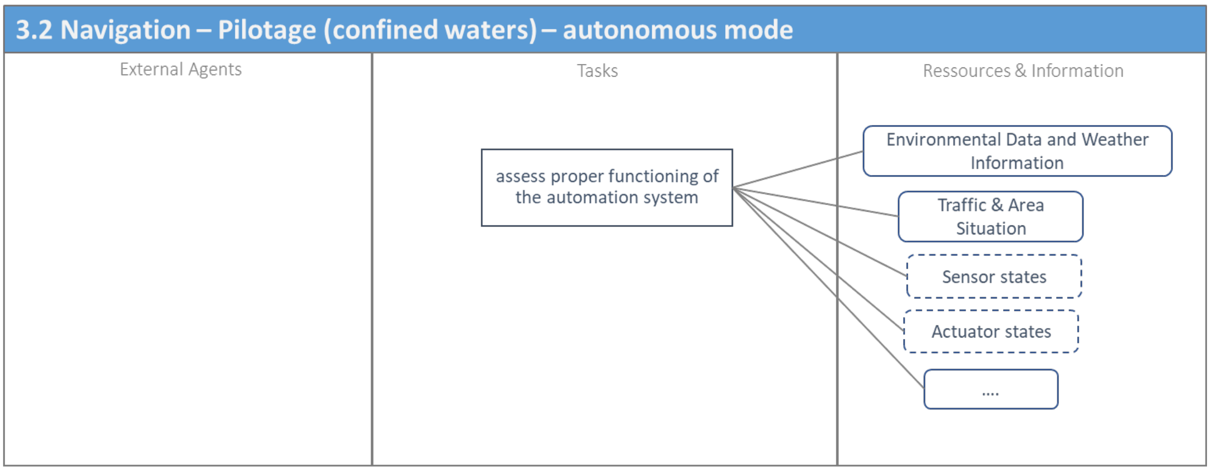

Figure 22: Example Task Analysis for Pilotage in autonomous mode (source: HMT).

In order to derive the information at a level of detail that is applicable for the user interface design process, this must be further elaborated. This is done by examining precisely how operators process the different information involved within the tasks. Table 21 illustrates this aspect for the example of pilotage in autonomous mode.

Table 21: Derivation of detailed information for example task "Pilotage - autonomous mode" (source: HMT)

Task		Information
Assess proper functioning of the automation system	Monitor if automation can handle environmental situation (e.g. weather, wind)	▪ actual environmental situation ▪ environmental situation appropriate for autonomous mode ▪ how close is the weather situation to the limit of what the automation can handle
	Monitor if automation can handle traffic situation	▪ actual traffic situation ▪ traffic situation appropriate for autonomous mode ▪ how close is he traffic situation to the limit of what the automation can handle
	Monitor correct functioning of sensors	▪ status of different sensors ▪ operational limits of different sensors
	Monitor correct functioning of actuators	▪ status of actuators ▪ operational limits of different actuators

In order to derive a user interface from the information described in Table 21, the High Level Requirements (HLR) for HLT Monitoring are to be considered. In particular, to fulfil **HMI-M-R3 (***the HMI must be designed in such a way that an operator can recognize emergencies or abnormalities within 2 seconds*.) as well as **HMI-M-R6** (*the HMI should consider the perceptual abilities of the operator when designing displays, and the display should be optimized accordingly*). Knowledge of human perceptual abilities must be included in the design process. These can be derived from the literature, existing guidelines for user interface design or based on human factors methods like the Konect method (Harre

& Feuerstack 2018). The latter offers knowledge about most efficient visualisations for different usage of information - so-called insights ("How will you use the information?" Do you need an exact value? Do you need to check whether the value is ok? Do you want to compare the value to another value?, etc.). This is based on established findings from psychological research (e.g. human perception). For our example, the insights and most efficient visualisations are shown in Table 22. Here, for example, one would suggest a length for quantitative values (e.g., how close is the weather situation to the limit of what the automation can handle) and colours for nominal information (e.g., is the environmental situation appropriate for autonomous mode).

The last column shows possible ways to combine the individual visual elements into an integrated visual form (a so-called glyph). These combination possibilities are the Gestalt laws. A glyph has the advantage that it can be perceived at one glance and can be better remembered by humans.

Table 22: Including knowledge about human perceptual skills in user interface design (example) (source: HMT)

Information	**Insight**	**Efficient Visualisation**	**Combination**
> how close is the weather situation to the limit of what the automation can handle > operational limits of different sensors > operational limits of different actuators > how close is the traffic situation to the limit of what the automation can handle > actual environmental situation > actual traffic situation	perceive quantitative value (fast)	length (0), slope (1), volume (2), color hue (3), text/not expressive (4), missing (5)	symmetry figure and ground spatial proximity connectedness continuity closure relative size similarity
> environmental situation appropriate for autonomous mode > traffic situation appropriate for autonomous mode > status of different sensors > status of actuators	perceive if value is ok (fast)	color hue (0), shape (1), length (2), slope (3), volume (4), text/not expressive (5), missing (6)	

With these instructions for example a design as shown in Figure 23 can be derived.

The segments stand for different areas to be considered (e.g., weather, traffic situation, status detection of sensors, transmission performance/connection quality to sensors etc.) The length indicates the current state. If it is completely filled, the automation can handle the situation without problems. For example, if there is little wind, the segment is fully filled. If the wind increases, this part becomes smaller (the automation approaches the limit areas). Shortly before reaching the limit area, a colour highlights the segment (orange = limit area soon reached, red = automation can no longer handle the current situation with the wind).

The glyph shows a easy to grasp pattern and the operator can quickly recognize the current state and whether certain areas can lead to problems for the automation. So not only does the operator acquire situational awareness efficiently and can recognize and even anticipate problems within seconds, but s/he can also communicate the current conditions to an operator in Direct Control (e.g., during hand-over). The Remote Navigator in Direct Control can then quickly get into the loop with such a visualisation.

Figure 23: Exemplary visualisation to fulfil High-Level Requirements (especially HMI-M-R3, HMI-M-R6) for Monitoring (source: HMT).

4.3.4.2 Work positions

In this step, work positions are defined and assigned to roles. Each work position and associated workstation must support one or more roles in the RCC.

> Work positions can be specialized, and only target a single role, e.g., remote navigator

> They can support more than one role, with similar requirements in terms of information requirements and access to physical controls, e.g., remote navigator and remote monitor. Remote monitoring is also possible from a remote navigator work position.

> They can support all roles considered for the RCC. In this case the work positions are multi-functional and can be used by any role, typically provided by software configuration of the work position displays.

The more roles the work positions in the RCC support (i.e., the less specialized they are) the more the RCC gains in flexibility and robustness in case of equipment failure (on one of the work positions) or need for task redistribution due to unexpected contingencies.

The work positions and the associated workstations (furniture) are to be designed in such a way that they support the performance of the roles they are intended for. This means that they need to provide, for each role:

> all information sources associated with the role (i.e., the tasks performed by the role).

> all controls associated with the role (i.e., the controls needed to perform the tasks associated with the role).

> all communication equipment (e.g., telephone, radio...) required by the tasks for the role.

Information sources and communication equipment are usually common between many roles, or at least the physical displays on the work position can be easily configured to provide the information needed for a specific role. This is why, multi-functional working positions can usually be easily designed when the roles do not imply physical controls. When one or more roles require specific physical controls (e.g., for remote navigation), it’s usually best to dedicate work positions specific to the roles in question (specialized work positions). A typical RCC will therefore provide a mix of multi-functional and specialized work positions.

4.3.4.3 Spatial organization of equipment for the work position

To determine which workstation – the piece of furniture itself – is adequate for the target roles, the best approach is to first make a list of all equipment that will need to be present at the workstation, and where to best place them, in relation with the target user. And consequently, how much space the equipment will use, and therefore what should be the optimal shape and dimensions of the workstation.

The equipment will need to be:
> Accessible to the workstation user, typically displays and controls, communication equipment, but also documentation, maps, notebooks, sheets of paper for taking notes. This set of equipment is dedicated to interaction with the end user and are typically placed on or above the workstation work surface.
> Integrated in the technical cabinets in the workstation, for some of them. These are hidden technical equipment, such as servers, PCs, KVMs, that need to be part of the workstation. They are usually situated below the work surface.

Both aspects will need to be considered to determine the best shape and dimensions for the workstation: the workstation must be able to receive all the equipment above and position them in ways that are appropriate for the performance of the user's tasks.

As hinted above, three main families of equipment will be associated with a work position:
> Informational equipment, typically displays.
> Physical controls, such as the traditional keyboard(s) and mouse(mice), but also, on specialized work positions more specialized controls.
> Communication equipment, for interacting with stakeholders external to the RCC.

The equipment must be laid out on the work position in the following way:
> The equipment needed for the performance of the tasks associated with the current role must be easily accessible, and with little effort and time needed for reconfiguration if they are not immediately available. For example, it should easy and quick to change the content of a display if this is needed.
  - Equipment on which information must be taken (e.g., displays) should be directly visible from the operator's work position.
  - Equipment with which physical interaction must be performed must be within reach of the operator (e.g., arm length).
> The disposition of the equipment on the working surface should be based on a frequency and criticality principle:
  - Equipment that are frequently used should be in a central position, just in front of the operator, be they informational equipment or physical controls.
  - Equipment that are less frequently used but which are critical for safe operations should also be laid out in a central position.
> The disposition of equipment on the work position should not prevent the exchange of information with other equipment or other RCC actors outside the work position.
  - If the operator at the work position must attend to some videowall or remote display (outside the work position), there should be no visual obstruction between the operator and the corresponding videowall or display. For example, this should prohibit installing visual obstacles

such as two or three rows of displays in front of the operator when the operator needs to see something that is in front of the work position.

- The same applies to interaction with the other actors in the RCC. If the interaction matrix defined for the RCC (based on the information flows required between the RCC actors) specifies that the work position must frequently interact with another one, the disposition of equipment on the work position should not prevent this from happening.

Examples of work position in our example use case

The basic layout of the **workposition for direct control of one MASS** corresponds to the arrangement of the control devices and the operation on a ship's bridge (Figure 26). In special situations, such as sudden extreme weather, mooring manoeuvres under difficult circumstances or failure of individual devices, it must be possible to use another person as co-navigator. For this reason, two workstations are arranged. The conning is the responsibility of the navigator for direct control, the support as additional communication or alarm management is provided by the co-navigator.
In the center of the console is the operation of the propulsion and control systems, which can be operated from both sides. The monitors are arranged in such a way that in the middle is the conning station, which provides all navigational data. On each side, a radar and an ECDIS are arranged so that two navigators can work independently of each other. The two outermost monitors are intended for status control of the MASS system and alarm management. Further operation of equipment on the MASS can be carried out via further movable displays (e.g. tablets).
To be able to provide the navigators with a visual representation of the situation, three large screens are provided. On these, panoramic images or certain perspectives can be zoomed in and displayed, and the associated data (augmented reality) can be imported.
This basic constellation can be adapted and re-arranged for specific ship types (e.g. a dredger). It is necessary that the layout is in conformity with the ConOps.

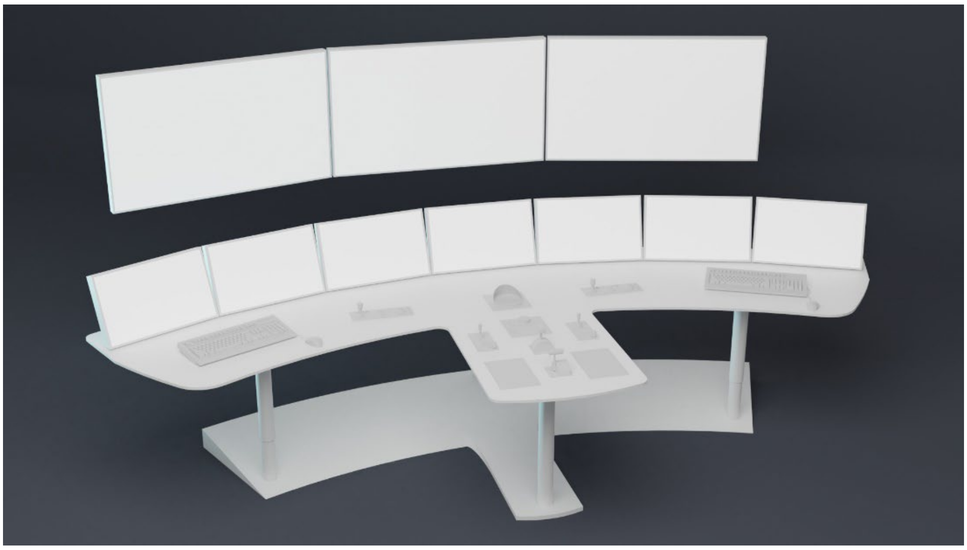

Figure 24: Remote direct control work position (source: Symbio)

The **workposition for monitoring** observes several MASS sailing autonomously (Figure 27). Accordingly, this position is only equipped with the most necessary intervention options. The focus is on the monitoring of a fleet of MASS. In the event of a critical situation, this single MASS is transferred to a direct control station according to MASS.

The upper row of monitors provides an overview. On the screens, the observed fleet is displayed as an overview. In the reference use case, 6 ships are observed on their voyages or 3 special ships in their missions. For this MASS, vision systems can be connected in order to be able to see into a certain sea area or a location on a MASS.

The lower row of monitors includes the display of data and states of individual vehicles. These can be called up as required. The individual screens can be used to display radar images or ECDIS, or more detailed states and data of an individual MASS can be called up. Operational handling is only provided via the displays, no further operating elements are required.

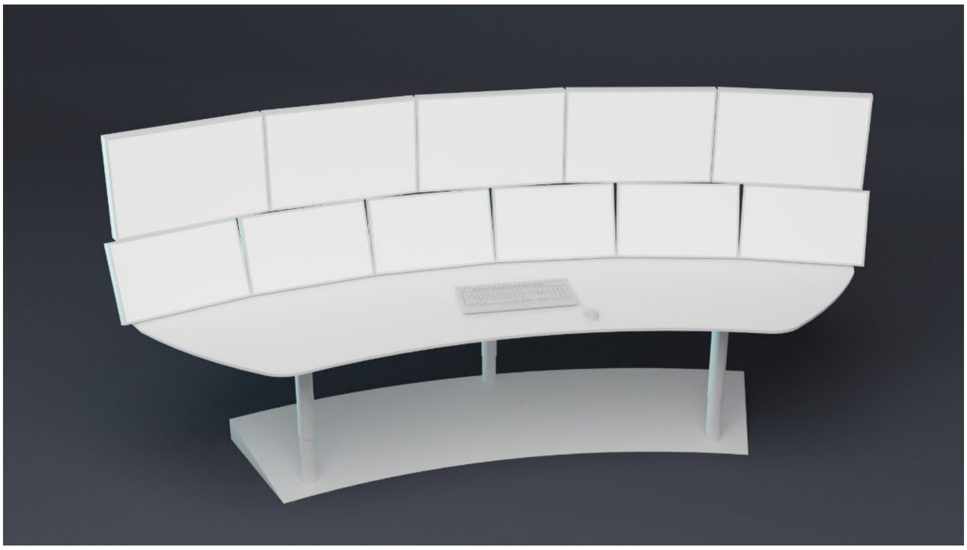

Figure 25: Remote monitoring work position (source: Symbio)

4.3.4.4 Workstations

The workstation is the piece of furniture underlying the work position.

Selection or design of a workstation
Once a 2D and 3D layout for the equipment to place on the workstation (on top of the work surface) and below the work surface (in the technical cabinets) has been determined, a workstation can be:

- either selected from existing workstation models, from external suppliers;
- specifically designed and manufactured for the specific needs of the RCC.

Applicable standards
Given workstations and operating desks more generally are central to modern human work, there are therefore many aspects of their design that are addressed in international standards.
Details about the international standards applicable to an RCC can be found in Annex B.
The standards mostly ensure that:

- The workstation is suited to human anatomy and physiology and does not require for example postures that are detrimental for the operator’s health.
- The workstation is suited for the morphology and size (e.g., height) of the target user population, ideally providing adjustment to different types of users.
- The workstation is comfortable to use, with sufficient room for the operator’s body, in particular for the legs below the workstation.
- The workstation is suited to the tasks or roles of the operators operating on the workstation, in particular in terms of access to information and to controls.

> The standards also address the chairs for the workstation, concerning seated vs standing control workstations, or a combination of both.

Height adjustment

The workstation can be provided with height adjustment capabilities. This for example allows to work while sitting or standing up. It should be ensured in this case that the workstation does not interfere with the information flows in the RCC when it is in the high, standing up configuration. For example, in that configuration

> the work position operator could not see some required information source, such as a videowall, or other RCC actors with which they need to interact.
> other RCC actors may see their own interaction requirements unachievable. Their vision of some information source or interaction patterns with other RCC actors may become impossible if another workstation is in the standing up configuration between them.

Thus, height adjustment is a “nice to have” feature, frequently favoured or requested in recent years. This just has to be addressed with some care and in relation with access to information and information flows within the RCC.

Workstations for our example use case

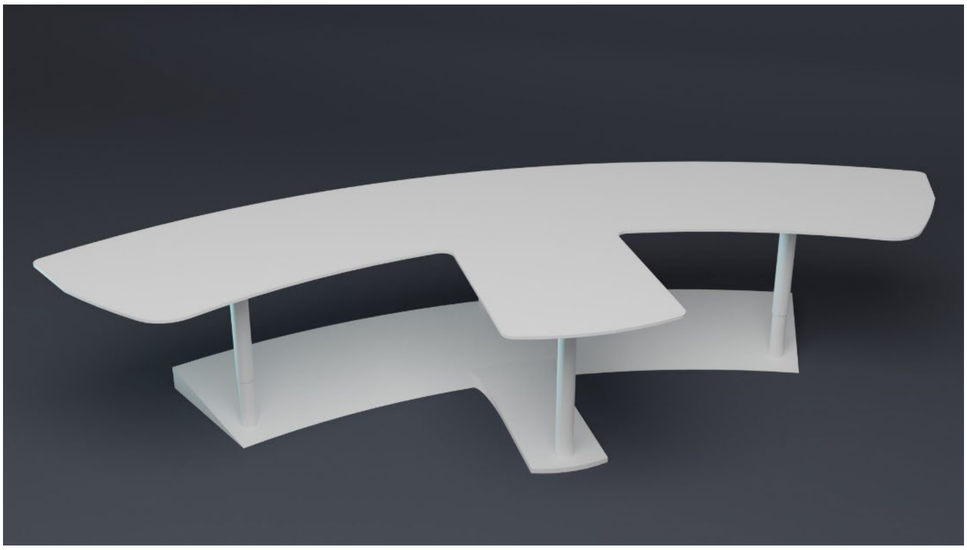

Figure 26: Workstation for the remote direct control work position (source: Symbio)

As can be seen from the Figure 26 above, the workstations are slim and light:

> Most, if not all, electronic equipment, such as computers, servers are not integrated in the workstation. They should be in a dedicated technical room (cf. our proposed room layout).
> The workstations provide ample space for the legs. This is recommended by the standards.
> They integrate a footrest, which typically adds to the user’s comfort.
> They are height adjustable thanks to electric jacks in the workstation feet.
> Data and power cables pass through the workstation feet.

The workstations we have designed for our use case are height adjustable. This would probably only be wise though for the remote direct control workstations. For the other workstations in the RCC this could be an issue because when a workstation is raised, it blocks the view for people in the back. In our RCC room layout (cf. below), if the remote monitoring workstations were raised, they would block the view the Remote Engineer, the Fleet Supervisor and the System Administrator would have on the room, and in particular the remote direct control work positions.

4.3.5 Control room design

The RCC is a control room and, as such, the standards applicable to control room design are relevant. The ISO 11064 on the ergonomic design control centers is the main one to use in this context. The standard strongly recommends to resort to Human-Centered design approach such as the one we are recommending in the report.

For more details, see the Annex B on ergonomic standards applicable to an RCC.

Control room design should proceed in a series of steps:

- Producing a room layout for the RCC. This means positioning the work positions in the future RCC room, as well as secondary information sources, such as videowalls.
- Designing lighting in the room, with an adequate mix of natural (if any) and artificial light. Lighting design should be performed by a lighting specialist.
- Designing acoustics. This is important, given the room users need some quietness but also to interact verbally when needed. As for lighting, this should be performed by a specialist.
- Designing HVAC (Heating, Ventilation and Air Conditioning). This is also important in terms of user comfort. This is again a complex topic that should be treated by a specialist.

4.3.5.1 RCC room layout

Once the RCC roles have been determined and the number of associated workstations determined (based on roles and manning), a physical room for implementing the RCC can be selected or specifically designed.

International standards applicable to the physical room in which a RCC will be installed can be found in Annex B. The standards encourage to pay attention to how human activities in the RCC will be organized, in particular in terms of interactions and workflows within and outside the room. The room layout should really allow information to flow easily and naturally between the persons present in the room. This is the interaction matrix we have recommended above.

Access to information is also key and information in the room (e.g., videowalls, supplementary displays,...) has to be laid out so that everyone who needs to have access to that information, in normal or abnormal circumstances, can easily do it.
The standards, especially ISO 11064 part 1, strongly recommend to involve end users in the design of the RCC, and encourages to have the RCC be designed by a multi-disciplinary team, typically including these users but also other stakeholders involved in the RCC building, installation, operations or maintenance. We also strongly recommend such an approach. They also recommend to take into account the future circulation patterns envisioned when designing the RCC. Enough space must also be reserved for all operations and circulations.
Consideration should also be paid to the position and orientation of the natural light sources in the room (e.g., windows) when arranging the room layout, given these can be a source of nuisance and induce glare on the displays.

4.3.5.2 *How to produce a room layout*

All these aspects should be kept in mind when determining the most appropriate spatial organization for the room (room layout).

The best way to proceed is to establish an interaction matrix as explained before, that specifies for each work position, with which other work position they need to interact and to which information sources in the room (e.g., videowall) they will need to have access to. The frequencies and importance of these interactions should also be considered.
Room layouts that best satisfy that interaction matrix can then be produced and compared. The whole room layout design stage should be performed by the multi-disciplinary design team, including future end users.

4.3.5.3 *Room layout in our example use case*

The figures below show how we have organized the RCC for our example use case.

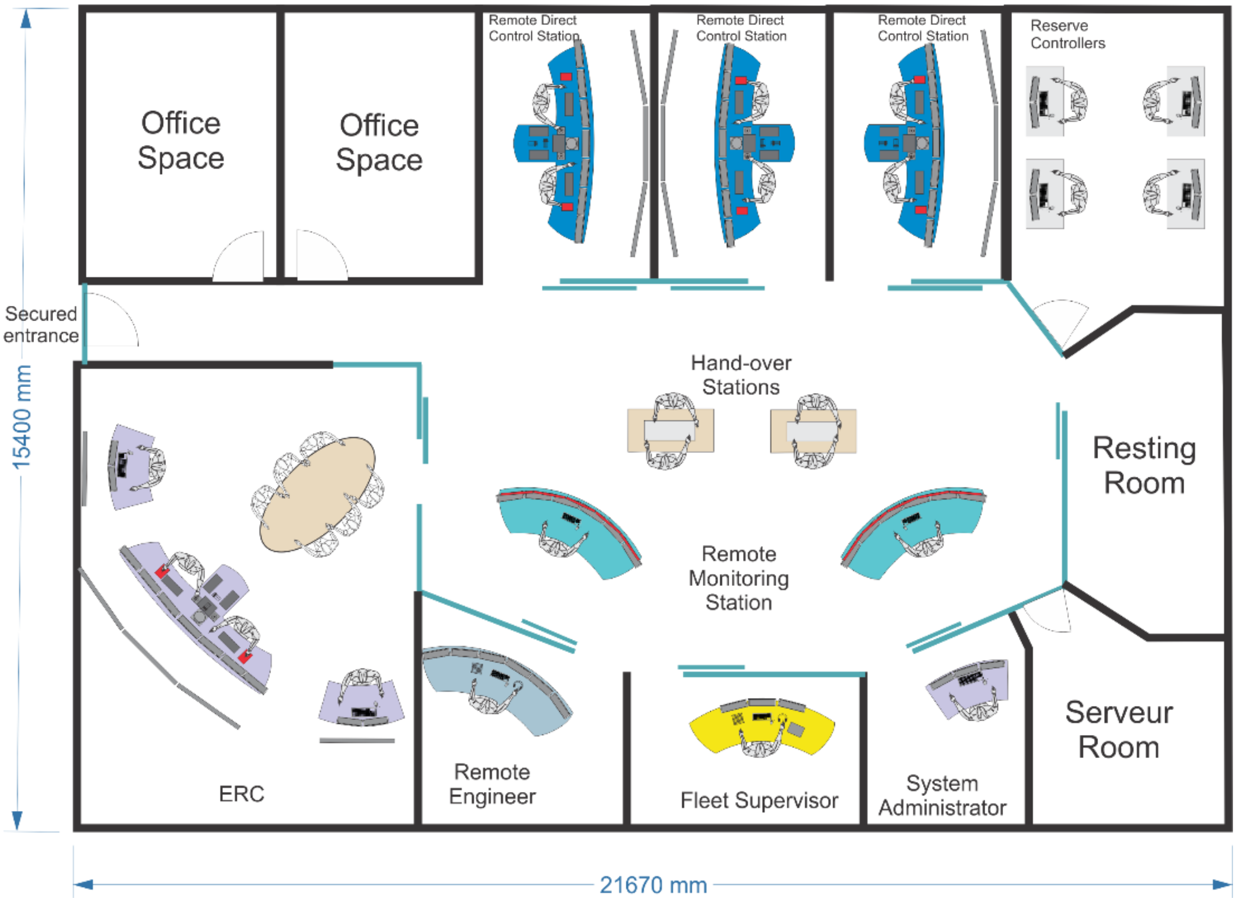

Figure 27: RCC room layout proposed for our example use case (2D) (source: Symbio)

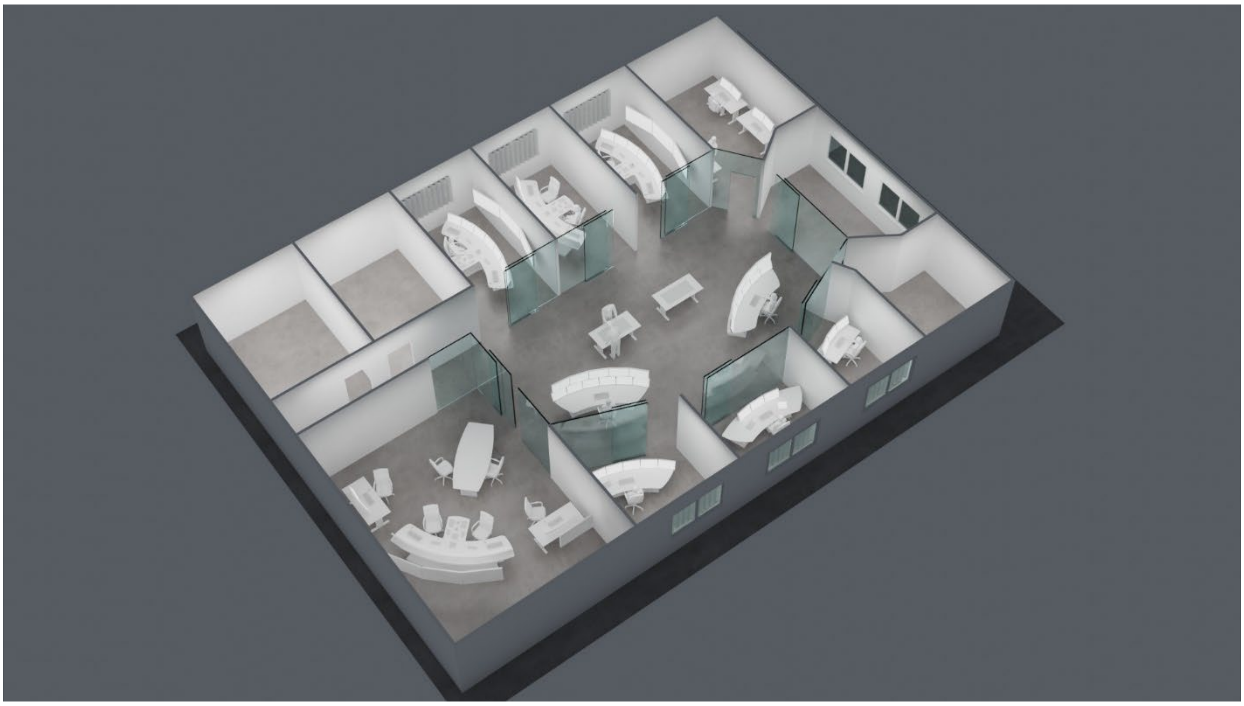

Figure 28: RCC room layout proposed for our example use case (3D) (source: Symbio)

The whole RCC floor is divided into different areas
A central open space area for the two remote monitoring stations and the hand-over stations. The hand-over stations are needed when a remote monitoring controller has to handle a MASS to a remote direct control controller.

Figure 29: Remote monitoring work position in the open space area (source: Symbio)

Figure 30: Central open space area with the Remote Engineer, Fleet Supervisor and Systems Administrator office spaces in the back (source: Symbio)

In front of the open space area and in direct line of sight there are three remote direct control rooms. The rooms are separated from the open area so that the remote direct controllers may be isolated, if needed, from the rest of the RCC. Each remote direct control room has dedicated lighting controls, so that the user can set a lighting ambiance appropriate for them (e.g., if the user is controlling a MASS operating in the night, they may want to operate in a dark ambiance). Sliding doors allow to control how much the room interacts with the rest of the RCC.

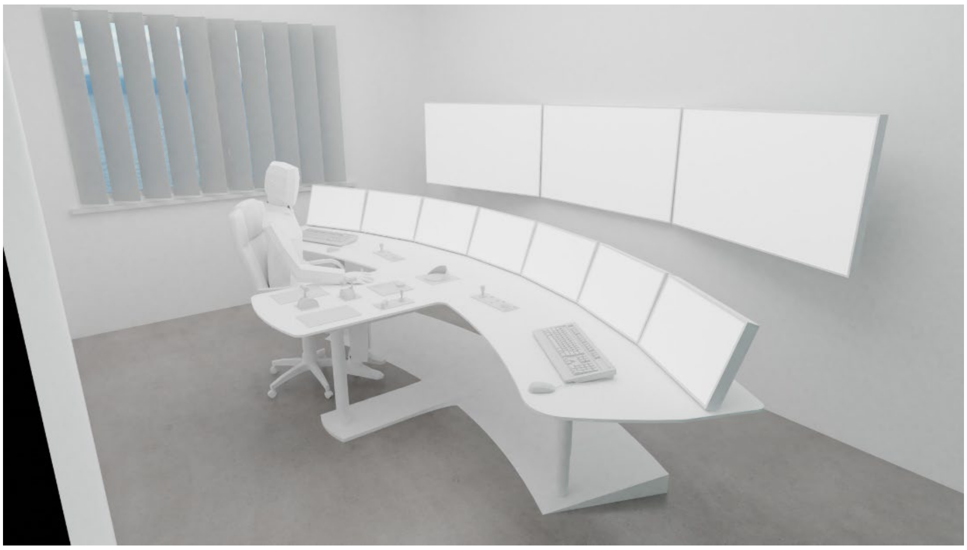

Figure 31: Remote direct control room (source: Symbio)

There are 3 such remote direct control rooms: 2 for normal operations, each controller controlling 3 MASS in our use case. And a reserve room for dealing with abnormal situations on one MASS, when it cannot be dealt with by the two main direct controllers.

On the right of the 3 remote direct control rooms is a room dedicated for up to 4 such reserve direct controllers, which can move to the reserve direct control room if needed. These controllers have office-types work positions, so that they can perform office or administrative tasks when they do not need to intervene.

The three other main actors in the room, the Remote Engineer, the Fleet Supervisor and the System Administrator are all located at the bottom of the RCC, in dedicated office spaces. This allows them to isolate themselves from the RCC if needed (e.g., when performing some administrative tasks or passing a phone call). Transparent glasses allow to see the core of the RCC and interact visually with the other main actors (remote monitoring controllers and remote direct control controllers). Sliding doors (close or open) allow to control noise and the possibility to interact verbally.

An ERC (Emergency Response Center) is provisioned on the left side of the RCC, with all needed facilities, in particular a dedicated remote direct control workstation and specific informational resources (large displays), and two small dedicated work positions. A meeting table is also present in the room. The ERC has ample view of operations in the RCC thanks to transparent glasses. A sliding door allows to close or open the ERC.

Figure 32: Emergency Response Center (ERC) (source: Symbio)

The meeting table in the ERC also allows to use the ERC as a regular meeting room during normal operations.
A resting room, with direct line of sight on the core of the RCC is also foreseen.
A server room, next to the System Administrator is also provisioned.
Space remaining on the RCC floor can be used for example for two additional office spaces.
The whole RCC is secured through a secured door, on the left side. A corridor allows to move inside the RCC, within the open space area.

The organization of the RCC fully complies with the interaction matrix we have previously determined for our example use case.

Lighting
Lighting analysis and design is a particularly important aspect of RCC design. Light is needed for most human operations, especially when data on non-emissive support (e.g., paper) is used or when the user needs to interact with equipment (e.g., physical controls) that need to be seen. Light also has an impact on human health and well-being and nychthemeral cycles.
Besides being an asset, light can also be a nuisance, when it’s not controlled adequately. Natural light coming through windows can for example induce light reflections on the displays. The work positions in the RCC must therefore be positioned (see room design above) to avoid such interferences, or light

control systems (e.g., blinds) need to be used, at least during certain periods of the day. Seasonal aspects should be taken into account in this respect.

Standards for lighting in control rooms such as an RCC can be found in annex B. Of particular importance in the standards are the following considerations:

- An appropriate mix of natural and artificial light is recommended.
- 500 Lux on working surfaces. 300 Lux on circulation zones.
- Glare from artificial lighting systems has to be avoided.

All lighting equipment should be dimmable, under individual user control (e.g., for their work position) or globally for the whole room. Downlight lighting systems can be used to avoid glare on the displays. Lighting study and design should be performed with a lighting simulation software, such as DiaLux.

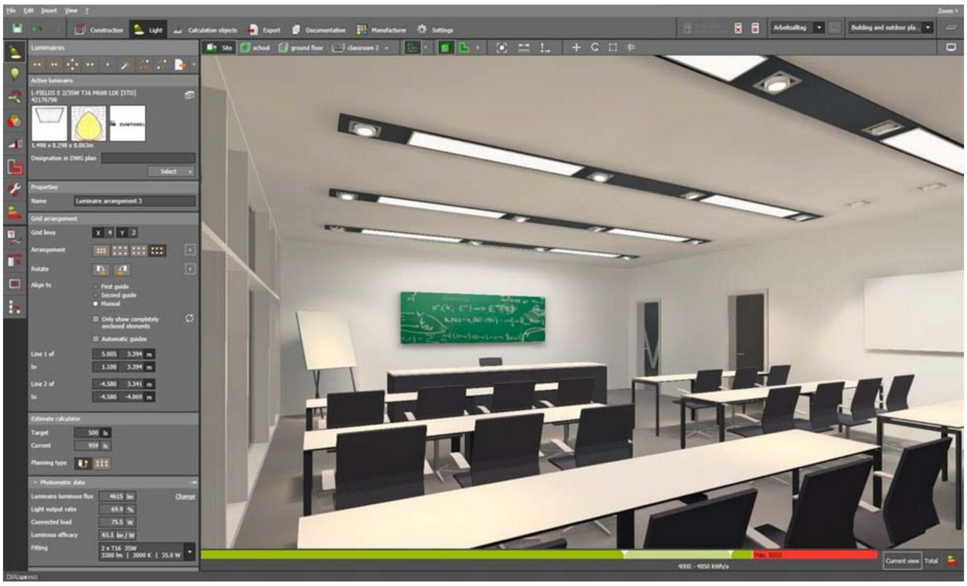

Figure 33: DiaLux lighting analysis and design software.

How to design lighting for the RCC

The best approach when addressing lighting design for the RCC is to work with a lighting design specialist. A lighting design specialist will select the types of lighting equipment to use and position them adequately in the room in order to meet the requirements described by the standards. They will also recommend means of controlling the interaction between artificial and natural light in the room. These days, lighting design specialists resort to lighting simulation software (e.g., DiaLux above). Such software allows simulating different lighting solutions and ensure they meet the standards.

Lighting study and design in our example use case

This has not been addressed in the example use case study.

Acoustics

Room acoustic is key to operations in an RCC. The main issue to deal with is:

- Overall noise levels compatible with the activities performed in the room. It should not exceed 45dB in a control room such as an RCC. This mostly concerns how acoustic energy emitted by various sources (people speaking, equipment, alarms, phone or radio calls…) is channelled or absorbed. Attenuation of noise source external to the room (machines, road traffic...) should also be considered.

- Reverberation times, which should be compatible with a pleasant ambiance and speech intelligibility.
- Ability to crosstalk between some of the work positions, in intelligible ways (speech intelligibility index, or SPI), without disturbing the other operations and raising the overall noise levels. This has to be addressed in relation to the interaction matrix.

Standards applicable to control room acoustics can be found in annex B. Acoustic control is typically achieved through:

- Noise capture devices
- The use of headsets for external communications
- Design of alarm systems that do not require high sound volumes
- Appropriate selection of materials for all visible surfaces (floor, ceiling, walls, partitioning walls, workstation surfaces…) to control acoustic energy in relation with operations.

The RCC room acoustics study and design should be performed by a specialist, typically with acoustic simulation software.

4.3.5.4 Application to our example use case

In our example use case

- The remote direct control work positions are in dedicated rooms, that can be isolated if needed. Communication with the other operators in the room is still possible when the door is open.
- The Remote Engineer, Fleet Supervisor and Systems Administrator are all in small offices, which also allows them to isolate from the rest of the RCC when they need some quietness or on the other end when they need to call external stakeholders, via telephone or radio.
- The presence of glass partitions, needed for allow visual interactions between the different roles, is detrimental to room acoustics in general. There are trade-offs to be made.
- The open space floor, ceiling and walls should consequently be acoustically treated to channel acoustic energy in accordance with the overall noise levels, reverberation times and speech intelligibility requirements.

HVAC (Heat, Ventilation and Air Conditioning)

It is of course also essential. The main objective of the HVAC system is to control the temperature, humidity and purity of the air in the RCC and provide thermal comfort to its users. Standards applicable to HVAC in an RCC can be found in Annex B.
One note that the standards imply different room temperatures during winter and during summer. They also recommend paying special attention to the velocity and direction of the airflows. A typical complaint in control rooms is with cold airflows that are directed on the users.

The room users should also be able to adjust the temperature in the room. HVAC design – and the definition and provision of an adequate HVAC installation – is a complex topic. This should be treated by a specialist.

Application to our example use case
This has not been addressed in our limited example study.

4.3.6 Checking the design

To ensure that the control room design including workstations and user interfaces guarantee safe operation and avoid unnecessary additional sources of potential errors, the RCC design should be checked against the High Level Requirements from step 2. In the following text, we illustrate exemplarily how this can be performed.

In a first sub-step, it must be decided to which High Level Task the design element belongs. Since an assignment was already carried out in step 2, this can be identified with minimal effort in the tables from step 2. If the design element belongs to an HLT, all High Level Requirements for this HLT must be checked for the design element. Due to the large extent of such a check, in the following illustration we only take a few High Level Requirements as examples. In a real check, of course, this would have to be done completely in order to uncover potential sources of error.

The following example refers to the assessment of automation as already used above as an example. This belongs to the HLT Monitoring and would therefore have to fulfil all the High Level Requirements of Monitoring. We show an example check for HMI-M-R3 and HMI-M-R5.

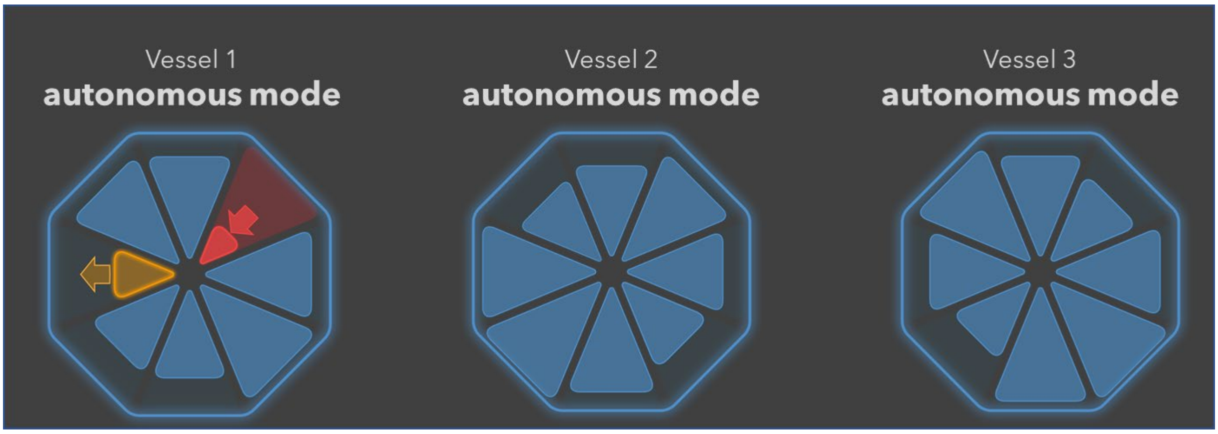

Figure 34: Design concept A for assessing automation (source: HMT).

Table 23: Example Check (Design Concept A) (source: HMT)

Requirement	Check
(HMI-M-R3) The HMI must be designed in such a way that an operator can recognize emergencies or abnormalities within 2 seconds.	**Requirement fulfilled**: The usage of orange and red for indicating abnormalities and emergencies create a so-called pop-out effect and can be perceived pre-attentively by operators.
(HMI-M-R5) Based on the desired level of safety, it must be decided how quickly anomalies should be detected in the HMI (here, for example, is a significant difference between an alarm that comes when the system already detects a limit case violation and the display of deviations and trends with which an operator can anticipate anomalies).	**Requirement fulfilled**: The design concept includes visualizing how close the current conditions are to those conditions that the automation can no longer handle (length of segments). Thus, the design offers the possibility to anticipate problematic situations and preparations to handle these situations can be taken rapidly.
…	…

To demonstrate how this would change for a different design concept, we have also performed the example check for the design concept shown in Figure 38 which was developed as a status overview in the MUNIN project. The check is shown in Table 24.

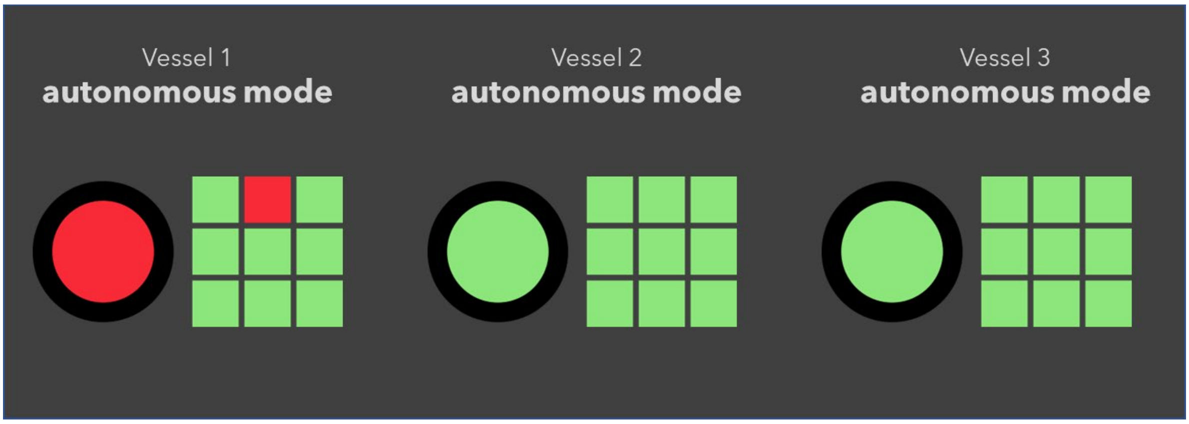

Figure 35: Design Concept B (Status Overview based on MUNIN project).

Table 24: Example Check (Design Concept B) (source: HMT)

Requirement	Check
(HMI-M-R3) The HMI must be designed in such a way that an operator can recognize emergencies or abnormalities within 2 seconds.	**Requirement fulfilled**: The usage of red for indicating abnormalities and emergencies creates a so-called pop-out effect and can be perceived preattentively by operators.
(HMI-M-R5) Based on the desired level of safety, it must be decided how quickly anomalies should be detected in the HMI (here, for example, is a significant difference between an alarm that comes when the system already detects a limit case violation and the display of deviations and trends with which an operator can anticipate anomalies).	**Requirement not fulfilled**: The design concept only visualizes states (alarm, no alarm within a particular area). It is not shown how close the current conditions are to those conditions that the automation can no longer handle.
…	…

It should be noted that the designs differ in particular with regard to requirement HMI-M-R5. As a result, design concept A allows the anticipation of possible problems, while design concept B only visualizes errors that have already occurred (but can then be detected within seconds). Thus, design concept A provides a higher safety level and should be preferred for vessels that require high safety levels (e.g., ferries with passengers on board).

5 Safety and security aspects concerning operation continuity

5.1 Safety related hazards and risks

A shore based remote control center must be permanently ready for all operations. A 100% availability is necessary to always have MASS under control at sea. Thus, the hazards that can lead to failures of an RCC must be defined.
In this study only hazard and risks to an RCC are discussed. The hazards and risks for MASS are not covered.
In the EMSA-project a methodology was developed to determine and evaluate risks and their controls (DNV-GL, 2021). It takes also in account the FSA methodology of IMO (IMO; MSC-MEPC.2/Circ.12/Rev.2, 2018). An RCC should be assessed in a similar procedure to identify hazards and risks and to address risk control measures.

The hazards must first be identified. Malfunctions or emergencies in the RCC will have a direct impact on the remote-controlled ships.
In the evaluation of risks, however, the level to be evaluated must be considered. The individual elements of automation, which are used in many different RCC's and MASS, will have to be evaluated in more details than the individual overall systems within a specific RCC's or a MASS.
The core task of the RCC is to always have the remote-controlled vessels under control. This means that the reliability and availability of the system must be very high. At this point, the mishaps at sea (such as collisions, groundings, personal injury, environmental damage) should not be discussed, the safety of the RCC is our sole object of study. From a higher-level point of view, the hazards can be outlined as follows.

A MASS is not under control for a certain period of time because the **RCC or parts of the RCC are not functional**. Causes can be:
... Damage caused by fire
... Damage caused by accident
… Damage by non-authorized personnel
... Destruction of facilities (antennas, devices) due to environmental influences (elementary damage)
... Loss of energy supply

A MASS is not under control for a certain period of time because the **control functions are not performed**. Causes can be:
... Failures in the technical control systems
... Loss of situational awareness of operators
... Failures in the operation of the systems
... Operators are not available in the required response time
… Workload in the control stations is too high
... Operator failures

A MASS is not under control for a certain period of time due to **external criminal influences**. Causes can be:
... Interruption of the exchange of information and data between RCC and MASS
... Destruction by criminal acts

To be able to assess the risks, they must be assessed and classified individually. That is to differentiate between faults, systematic errors and random failures. The assessments shall be carried out on a case-by-case basis. Based on the concept of operation and defined test scenarios, the risks are to be classified.
A severity index must be defined. For the RCC the major perspectives are the safety of humans and assets. The effects on the environment are secondary risks, caused by to the MASS itself. For that reason they are not outlined in this study.

Table 25: Severity Index (SI) for an RCC (HSB/IfMS)

SI	Severity	Effects on humans	Effects on assets (RCC, MASS)	Effects on environment
1	Negligible	Very minor injuries	Very small damages	n/a
2	Minor	Single or multiple minor injuries	smaller damage to parts of the RCC, no lost of control of MASS	n/a
3	Significant	Single serious or multiple injuries	damages to parts of the RCC, control of MASS is lost for minutes	n/a
4	Severe	Single fatality or multiple serious injuries	severe damages to parts of the RCC, control of MASS is lost for several hours	n/a
5	Catastrophic	Multiple fatalities	total break-down of the RCC, control of MASS is lost	n/a

In most high-risk industries the risk assessments determine the occurrence frequency by using a probability index. This quantitative approach is calculating the probability on statistics or probability calculations. For example, the probability of an incident is less than one per 100 years. The objective is to reduce the probability of the occurrence by mitigation measures. The more data is available for the quantitative approach, the better the outcomes will be. Thus, the longer a system in operation is studied, the more continuous improvements take place, reducing the probability of failures and misfunctions.
For MASS systems, including the RCC, the RBAT-study proposes to use the "effectiveness of mitigation layers" (DNV-GL, 2021). This approach makes sense because MASS systems are a novum and most risks are assumed to be found in soft- and hardware functionalities as well as in human operation of these systems. A focus to minimize risks by having a sufficient number of mitigation layers is helpful in the assessment of such new systems. The effectiveness index (EI) is explained in Table 26.

Table 26: Effectiveness index of mitigating layers (DNV-GL, 2021)

EI	Effectiveness	**Description** (as per RBAT-study)
1	Low	The control functions have some capacities for self-recovery, however for the assessed scenario these are expected to have a limited effect.
2	Moderate	At least one internal mitigation layer that can prevent losses from random hardware failures. The control functions has additional capacities for self-recovery from other types of failures, however, for the assessed scenario these are not effective regardless failure cause.
3	Medium	At least one effective independent mitigation layers that for the assessed scenario can prevent losses regardless failure cause
4	High	At least two effective independent mitigation layers that for the assessed scenario can prevent losses regardless failure cause
5	Very high	At least three effective independent mitigation layers that for the assessed scenario can prevent losses regardless failure cause

Based on the RBAT-study, the following risk matrix results. The aim is to get the residual risk to the level "low" through the mitigation layers. The ALARP principle (As Low As Reasonably Practicable) is to consider in the implementation. If the risk is "low", then no additional measures are necessary.

Table 27: Risk matrix based on effectiveness of mitigation layers (according to RBAT-study)

Effectiveness mitigation layers	**Severity**				
	1 Negligible	2 Minor	3 Significant	4 Severe	5 Catastrophic
1 Low	medium	high	high	high	high
2 Moderate	low	medium	high	high	high
3 Medium	low	medium	medium	high	high
4 High	low	low	medium	medium	high
5 Very high	low	low	low	medium	medium

The analysis of the mitigation layers must be done in a systematic way. It is based on the concept of operation and has to cover the entire MASS system.

Mitigating layers can be very various and will depend on the operational concept, the design of the RCC, the operational envelope and the humans involved in the system. Mitigating layers can be structured into technical, procedural and human-related controls and measures. Without claiming to be exhaustive, here are examples:

Technical mitigation layers:

- Fire detecting and alarm systems
- Fire-protected compartments and extinguishing systems
- Alarms in all critical systems (navigation, propulsion, communication, …)
- Redundancy of critical systems (hardware, software, control stations, antennas, …)
- Standardization of operational equipment (HMI)
- Uninterrupted power supply (UPS)
- Proper and clean workstations
- Regular checks and tests of equipment

Procedural mitigation layers:

- Contingency plans for malfunctions and emergencies
- Test procedures of technical equipment
- Work procedures (e.g. watch take over, departure preparations, …)
- Test procedures for automated functionalities
- Back-up organization
- Quality management system, especially failure identification and continuous improvement procedures

Human-related mitigation layers:

- Only authorized access
- Only operators with proved qualifications (technical, procedural, language, …)
- Availability of a sufficiently planned number of operators
- Regular trainings and drills (emergency response, awareness, limitations of technologies, specific expertise's, …)
- Control system for work and rest times

> Regular communication between operators (e.g. briefings, de-briefings, nautical-technical meetings, …) to gain situational awareness, to identify challenges and opportunities, to implement improvements

Certification requires an appropriate risk assessment. The mitigating layers shall be explained in terms of design and effect. The assessment must be carried out using defined scenarios.

5.2 Cyber security related hazards and risks

Cyber security related hazards are critical for RCCs and have to be analysed systematically. The hazards and related risks have to be fully understood and mitigation measure with clear response and recovery plans have to be defined. In this chapter we present the cyber risk management approach as defined by BIMCO[3] (Baltic and International Maritime Council) which we consider as adequate to be applied for RCCs. To give a general understanding of cyber security, we start by presenting an overview of generic cyber security hazards and relevant mitigation measures.

Generic cyber security related hazards and risk:

(1) Unauthorized access: RCC systems may be vulnerable to unauthorized access by hackers, who may be able to take control of the ship's systems.
(2) Malware: RCC systems may be infected with malware that could disrupt the ship's systems and put the ship and crew at risk.
(3) Distributed Denial of Service (DDoS) attacks: RCC systems may be targeted with DDoS attacks, which could overload the system and prevent it from functioning properly.
(4) Interference: RCC systems may be vulnerable to interference from other electronic devices, which could disrupt the ship's systems or communications between the ship and the RCC
(5) Insiders: RCC may be compromised by insiders with malicious intent or by accident.
(6) Physical security: RCC may be vulnerable to physical attacks such as vandalism, sabotage and theft.
(7) Dependency on third-party systems: RCC systems may depend on third-party systems, and a failure or security breach in those systems could affect the other systems.
(8) Lack of security awareness: RCC systems may be operated by personnel who lack security awareness and may not be able to detect and respond to security incidents.
(9) Lack of incident response plan: RCC systems may not have incident response plan in place, which could make it difficult to respond to security incidents in a timely and effective manner.

Cyber security related mitigation measures:

> Network segmentation: The RCC systems should be isolated from other networks to prevent unauthorized access and limit the spread of malware.
> Firewall: A firewall should be implemented to control incoming and outgoing network traffic, and to block unauthorized access.
> Secure communication: RCCs should use secure communication protocols to protect against eavesdropping and tampering of commands sent to the ship.
> Data encryption: Sensitive data should be encrypted to protect against unauthorized access and tampering.

[3] https://www.bimco.org

> Access control: Only authorized personnel should be able to access the RCC software system, and access should be granted based on the principle of least privilege.
> Physical access: RCCs should be protected against physical access by unauthorized individuals, and access should be controlled using security measures such as biometric authentication or security cards.
> Regular software updates: RCC systems should be kept up to date with the latest software patches and updates to address known security vulnerabilities.
> Intrusion detection and prevention: RCC systems should be monitored for suspicious activity and potential intrusions, and appropriate action should be taken to prevent or respond to an attack.
> Penetration testing: Regular penetration testing should be conducted to identify and address vulnerabilities in the control room system.
> Backups: Regular backups of control room systems should be taken and stored in a secure location to ensure that system can be restored in case of an incident.
> Security awareness training: All personnel who have access to the control room systems should be trained on security best practices and be aware of potential threats.
> Regular security audits: The control room system should be audited regularly to ensure that it is configured securely and that security policies are being followed.
> Incident response plan: A response plan should be in place to address security incidents and minimize the impact of a security breach.

Cyber Risk Management Approach

BIMCO[4] (Baltic and International Maritime Council) together with other shipping communities and organisations has published guidelines for cyber risk management (BIMCO 2018). These guidelines address cyber security for ships but the general approach and many of the suggestions and processes can be applied to RCCs as well. In the following the approach is briefly described and the relevance for RCC is highlighted.

Step 1: Identify Threats

At first threat actors should be identified. Which type of persons are likely to perform a cyber-attack to the ship? Examples are accidental actors, actors like disgruntled employees, criminals, opportunists, states, state sponsored organisations, terrorists. The guidelines illustrate types of cyber threats (untargeted and targeted attacks) and the stages of a cyber incident. This information serves to create an awareness and as a basis to quantify the threat in step 3-. Threat is defined as “the product of the threat actor’s capability, opportunity and intent to cause harm.”

[4] https://www.bimco.org

Figure 36: Process for cyber risk management, copied from BIMCO (2018).

Step 2: Identify Vulnerabilities

In a second step the applications, systems, and procedures of the ship and RCC are analysed in order to identify vulnerabilities. Vulnerabilities are defined as "weaknesses that could be leveraged by potential threats." A list of questions is suggested that should be asked for each system:

- Is the system stand-alone or is it connected to other systems?
- Is the system connected externally, either directly or via other systems?
- Does the system have effective, built-in risk mitigation measures such as e.g., encryption?
- Does the system require regular software updates?
- Does operating the system involve connecting removable devices, for example to obtain diagnostic information?
- Is the system easy to physically access?

A specific analysis should be performed for all systems that communicate with the ship. For an RCC this concerns all systems for communicating ship data to the RCC and for controlling the ship from the RCC. Vulnerabilities exist also when third parties enter the ship of RCC and plug in devices, such as laptops and tablets. The following list of common cyber vulnerabilities can be used to check all the systems onboard the ship and in the RCC:

- obsolete and unsupported operating systems
- unpatched system software
- outdated or missing antivirus software and protection from malware

> inadequate security configurations and best practices, including ineffective network management and the use of default administrator accounts and passwords
> shipboard computer networks, which lack boundary protection measures and segmentation of networks
> safety critical equipment or systems always connected with the shore side
> inadequate access controls to cyber assets, networks etc for third parties including contractors and service providers
> staff inadequately trained and/or skilled to manage cyber risks
> missing, inadequate or untested contingency plans and procedures.

Step 3: Assess risk exposure
In this step the likelihood, the impact and the risk of a cyber security event is assessed.

Step 3.1: Assessing the likelihood involves assessing the likelihood of the threat (from step 1.) and the likelihood of the vulnerability (from step 2). The resulting likelihood of a cyber security event is the product of these two values. It is suggested to use the following scale:

Level	Likelihood description
1	Never heard of in industry. Close to being something unimaginable.
2	Heard of in industry, but only extremely rarely and as the result of a chain of many unfortunate events.
3	Incident has probably occurred in own company, but in the context of faulty equipment or by surprising mistakes made by people involved.
4	Happens occasionally in own company, typically in the context of faulty equipment or by mistakes by people involved (the kind of mistakes that tend to happen on board from time to time).
5	Happens frequently when undertaking the work in question.

Figure 37: Likelihood scale, copied from BIMCO (2018)

Since a database on cyber security events does not readily exist, it is in most cases not possible to do the quantification using statistics. The guideline suggests looking at incidents in other industries with similar threats and vulnerabilities and to deeply think about the three factors of a threat (mentioned already in Step 1): “capability, opportunity and intent to cause harm.” For example, if an intent does practically not exist, then the likelihood of the threat might be very small.

Step 3.2: After the likelihood has been quantified, the impact must be assessed. BIMCO suggest e.g. to use a scale that is based on the CIA model (Federal Information Processing Standards 2004). This model focusses on the loss of confidentiality, loss of integrity and loss of availability of information and data. The corresponding scale is shown in the next figure.

Potential impact	Definition	In practice
Low	The loss of confidentiality, integrity, or availability could be expected to have a **limited** adverse effect on company and ship, organisational assets, or individuals.	A **limited** adverse effect means that a security breach might: (i) result in minor harm to individuals; (ii) result in minor financial loss; (iii) result in minor damage to organisational assets; or (iv) cause a degradation in ship operation to an extent and duration that the organisation is able to perform its primary functions, but the effectiveness of the functions is noticeably reduced.
Moderate	The loss of confidentiality, integrity, or availability could be expected to have a **substantial** adverse effect on company and ship, assets or individuals.	A **substantial** adverse effect means that a security breach might: (i) result in significant harm to individuals that does not involve loss of life or serious life threatening injuries; (ii) result in significant financial loss; (iii) result in significant damage to organisational assets; or (iv) cause a significant degradation in ship operation to an extent and duration that the organisation is able to perform its primary functions, but the effectiveness of the functions is significantly reduced.
High	The loss of confidentiality, integrity, or availability could be expected to have a **severe or catastrophic** adverse effect on company and ship operations, assets, environment or individuals.	A **severe or catastrophic** adverse effect means that a security breach might: (i) result in severe or catastrophic harm to individuals involving loss of life or serious life-threatening injuries; (ii) result in major financial loss; (iii) result in major damage to environment and/or organisational assets; or (iv) cause a severe degradation in or loss of ship operation to an extent and duration that the organisation is not able to perform one or more of its primary functions.

Figure 38: Impact scale, copied from BIMCO (2018)

Step 3.3: Finally, the risk can be assessed. The risk is a combination of the factors considered in the steps before.

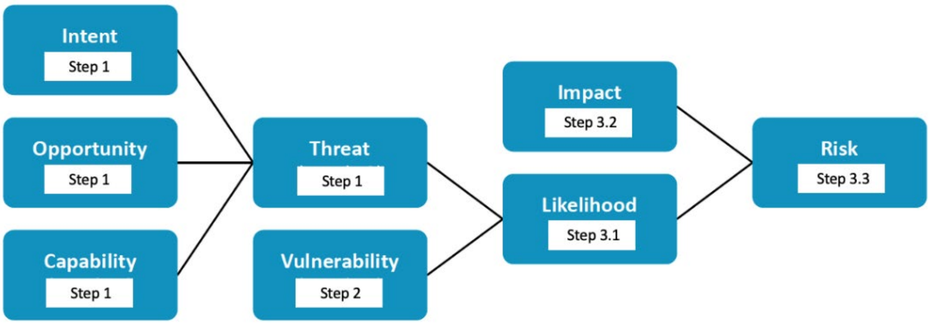

Figure 39: Factors influencing risk, copied from BIMCO (2018) with adaptation of references to the steps.

The guidelines suggest to use the risk score matrix in Figure 40 in order to derive the risk from the impact and likelihood numbers.

The impact assessment should be done for every system. It requires knowledge of the system’s functionality, the data flows and the connections to other systems. Relevant documentation should be reviewed, and all relevant subject matter experts (incl. cyber security experts from the system manufacturers) should be involved. The company performing the risk assessment should consider to involve a third party with specific expertise in cyber-security risk assessment. This is especially needed if the company has not enough resources or limited knowledge only.

Likelihood (scale 1-5)					
5	5	10	18	20	25
4	4	8	12	16	20
3	3	6	9	12	18
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5

Impact (scale 1-5)

Risk score matrix (scale 1-25)

Risk score 1-5 = Low Risk
Risk score 6-10 = Medium Risk
Risk score 11-19 = High Risk
Risk score 20-25 = Extreme Risk

Figure 40: Proposed risk score matrix (BIMCO 2018)

Step 4: Develop protection and detection measures

Two approaches of protection measures should be combined:

> Defence in depth: Layers of protection and detection measures are stacked onto each other. This means that even if an attacker gets through one layer there is still another protection layer and even more below.

> Defence in breadth: Protection measures should prevent exploitation of the vulnerability of one system to attack another system.

The guidelines suggest a list of technical and procedural protections measures:

Technical measures:

> Limitation to and control of network ports, protocols and services
> Configuration of network devices such as firewalls, routers and switches
> Physical security
> Protection of satellite and radio communication
> Wireless access control
> Secure configuration of hardware and software
> Email and web browser protection
> Application software security (patch management)

Procedural measures:

> Training and awareness
> Restricted computer access for visitors
> Clear procedures for crew's personal devices
> Upgrades and software maintenance
> Anti-virus and anti-malware tool management
> Clear procedures for remote access
> Limited and careful granting of administrator privileges
> Multi/factor authentication (MFA) and passwords
> Clear procedures for use of physical and removable media controls
> Clear procedures for equipment disposal including data destruction

In order to detect intrusions and infections, thresholds for network operations and data flows should be defined and automatically monitored. As a precondition for the definition of thresholds a base line for the operations and flows must be defined as a reference. In addition, personnel with clear roles and responsibilities are needed who are able to understand security alerts.

Step 5: **Establish response plans**
Response plans should be established and should be available in a printed form. When designing these plans, it should be carefully considered that they are consistent with other existing emergency plans. The guideline provides a non-exhaustive list for cyber incidents for which response plans should be defined:

> "loss of availability of electronic navigational equipment or loss of integrity of navigation related data",
> „loss of availability or integrity of external data sources, including but not limited to GNSS",
> „loss of essential connectivity with the shore, including but not limited to the availability of Global Maritime Distress and Safety System (GMDSS) communications",
> „loss of availability of industrial control systems, including propulsion, auxiliary systems and other critical systems, as well as loss of integrity of data management and control",
> „the event of a ransomware or denial of service incident".

A response plan should include disconnecting systems from shore network connections. This is possible for systems that are not "strictly necessary for operating the ship safely". Such a disconnection can be necessary to stop spreading of malware and to prevent attacks on safety critical systems.

Step 6: Respond to and recover from cyber security incidents
The response plans should be updated regularly based on lessons learned. When a cyber incident occurs the response team should find out, how the incident occurred, which systems are affected and how, which commercial and operational data is affected and if threats to further systems remain. The affected systems should be disconnected from the network or should be quarantined. The guideline suggests further steps:

> "Check the firewall rules have not changed."
> „Ensure that anti-virus and anti-malware definitions are up to date.
> „Take a full disk image of any impacted systems."
> „Consider taking memory dumps (RAM image)" for forensics purposes.

It is also important that after the incident adequate actions are performed. The systems and data should be recovered, and the incident should be investigated to update the protection measures to prevent the incident next time. Companies should also consider insuring themselves to cover for property damage and to cover for liability.

6 Certification of RCC

6.1 MASS and RCC in the certification process

To be able to define the certification of an RCC, the entire MASS system must be considered. The following guiding principles are intended to classify the RCC and, based on this, to define the certification of the RCC.

Classification of MASS and RCC

This study refers to remote-controlled MASS. It is assumed that there are no more operators on board, but that the MASS is managed and controlled from an RCC. However, it can be assumed that with the introduction of automated ships, there will be transitional designs that will last for several years. In addition, many innovations are to be expected, which will further develop the MASS system. From this it can be deduced that there will be mixed designs in the degree of automation and that there will still be people on board for certain tasks.

The certification cannot yet apply internationally agreed standards. For this reason, national rules will be necessary to be able to test and certify all the MASS systems to ensure safe maritime traffic.

The MASS, defined as the vessel at sea, is the central starting point. An RCC is an "outsourcing" of the control function, and must be aligned with the requirements of the MASS.

MASS and RCC are to be understood as one system. The MASS are controlled remotely, and remote control can be realized by different levels of autonomy depending on the subsystem.

A MASS may fly a flag according to UNCLOS [5] . It is thus a prolonged territory in which the legislation of the respective flag state applies.

An RCC cannot fly a flag like a ship or MASS. It is subject to the jurisdiction of the state in which it is located.

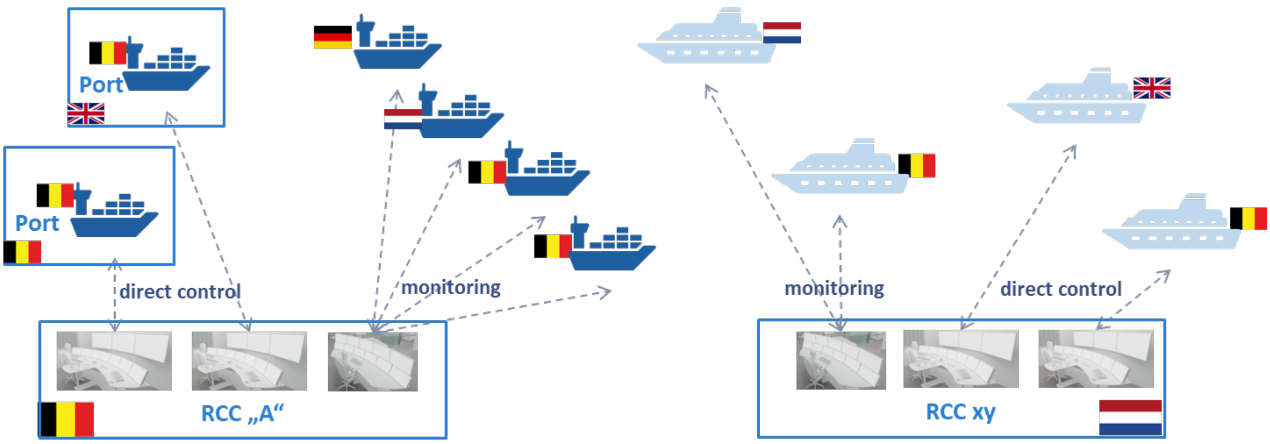

Figure 41: System of a fleet of MASS and it's RCC (shown flags are examples) (HSB/IfMS)

The MASS defines the requirements

A MASS specifies the requirements for an RCC. The technologies are the drivers of the necessary technical, organizational and personnel infrastructure.

[5] UNCLOS - United Nations Convention on the Law of the Sea

An RCC will be aligned with ship technologies. Even if there are many of identical processes, the technical requirements of MASS must be implemented in a differentiated manner in the RCC. For example, vessels that use containers (use case A) have different requirements than vessels that carry out dredging work (use case B). In container transport, the call of different ports and handling of cargoes (reefers, IMDGs) must be taken into account, while a dredger can use special positioning systems, is equipped with very specific technologies to carry out the mission, and usually docks in the same port. Furthermore, propulsion concepts can be very different, which will not always be completely feasible in one RCC. This tends to mean that there will be specialized RCCs focused on performing specific transportation tasks or missions.

A MASS cannot switch optional between different RCCs. The MASS and the RCC are to be seen as one system, together with the people who operate them. A change from one RCC to another RCC is only possible if the MASS system is considering all RCCs that are technically and organizationally compatible and, if necessary, take over the control of a MASS.

As systems and interfaces become more standardized, complexity will decrease and make it easier to switch between different RCCs. This will be a process over a several years.

Approval and certification of the establishment of an RCC

The owner or manager of MASS is responsible for obtaining approval and certification.

The MASS vessel must be built in accordance with the applicable international rules. Additional requirements may be required by the flag State. Classification societies will set MASS standards and adopt them.

An RCC is initially subject to the rules of the state in which it is established.

Since the MASS system places the requirements on an RCC, bilateral agreements between the RCC operator and the MASS manager are necessary. These will specify the requirements to be implemented.

The approval and certification take place for each individual MASS in the context of the RCC. The tests and acceptances must be carried out separately for each MASS. As standardization progresses, the corresponding systems can be considered and simplify acceptances.

Changes to the technical and organizational system concerning approved elements must be requested and newly authorized.

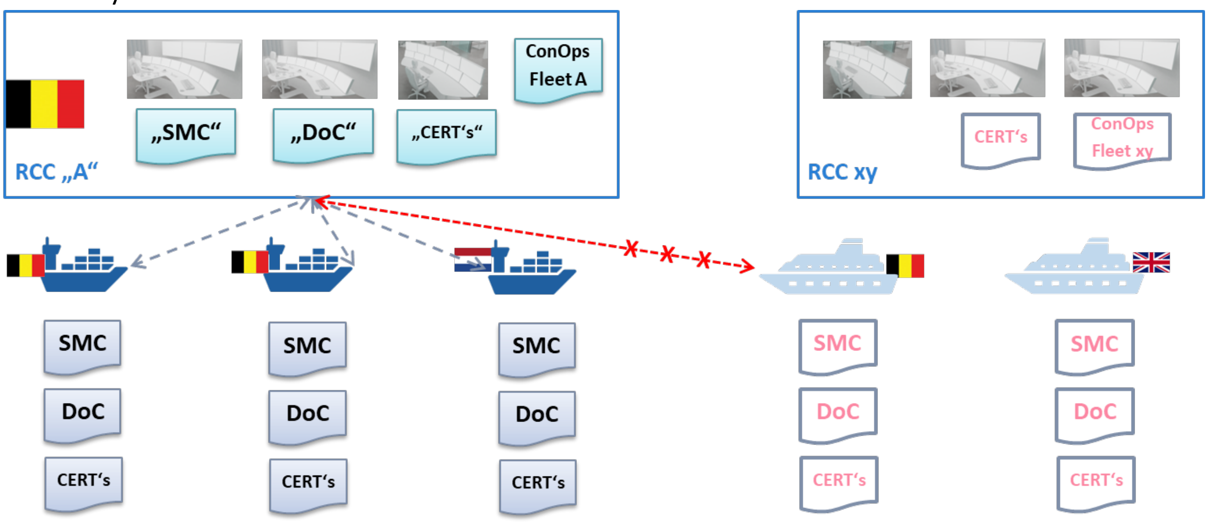

Figure 42: Certification for a fleet of MASS plus one RCC (flags are examples) (HSB/IfMS)

Approval of operations

Agreements are necessary to ensure permission to sail on national waters with MASS.

The coastal states that expect MASS traffic must define their framework conditions for the passage or call of territorial waters.

Flag States of MASS must enter into agreements with the coastal and port states that MASS may sail these waters under their flag. These arrangements shall include the states in which the RCCs are located. In the same course as the permission to sail, the legal relationship to the liability of the ship's command (there is no captain on board) is to be agreed between states and in principle.

MASS managers must apply to the flag state for permission to operate the MASS system. The flag state shall check whether there are agreements to navigate the waters of other coastal states and whether the relevant RCCs are approved by their states. The state then issues an operating license. The RCC state grants prior the authorization to the RCC operator to maintain a MASS in other territorial waters on the basis of intergovernmental agreements.

Due to the tripartite agreements on navigating waters and the regulation of the liability of the ship's command between MASS flag states, RCC states and coasts and port states, it can be ruled out that RCCs are used in untrustworthy states.

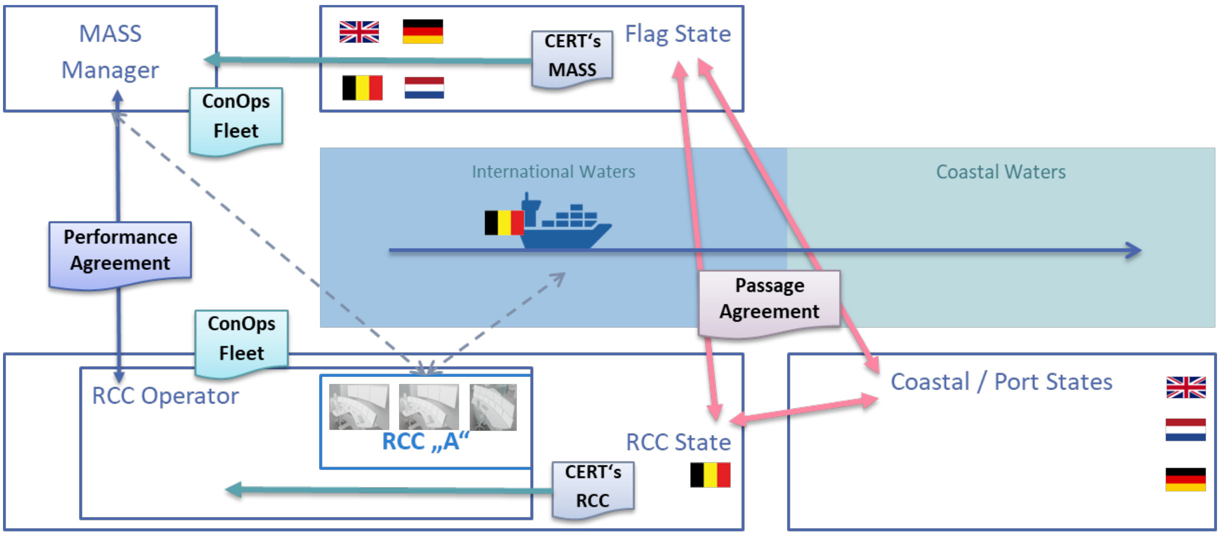

Figure 43: Correlation of MASS, RCC and Administrations (flags are examples (HSB/IfMS)

6.2 Scope of certificates for an RCC

The certification of a remote-control center must consider the entire system of a MASS. In this study, the full ship system is not considered, only the RCC. The MASS will require several additional documents, e.g., concerning environmental issues, registration or ship construction. In the next chapters certificates and documents are listed which are expected to be issued for the operation of an RCC.
The list covers certificates from different issuing bodies as well as documents which need approvals.

- Certificates of flag state
- Certificate by Recognized Organizations
- Certificates by Third Parties

+ Documents and Plans which needs checks and endorsements
+ Service reports of approved suppliers
+ Certificates and documents concerning labor and qualification

The list is a proposal which is to be discussed in detail.

To be able to approve an RCC, the overall system must be considered. To describe this, a Concept of Operations (ConOps) is recommended. The content must describe the entire system of MASS and RCC and it's operational envelope.
The RCC is strongly interlocked and forms a coupled system with the ship that is underway at sea. Control of a remote-controlled vessel may be shifted ashore, but this control directly affects maritime safety. From this point of view, an RCC is subject to the same rules as a seagoing vessel, the RCC is part of the overall "remote-controlled ship" system.
Against the background of a necessary system verification, various certificates for an RCC are conceivable, which require a corresponding basis for examination. Interim or exemption certificates are not considered in this study.
The state of the RCC shall issue a handling instruction or guideline with national requirements to establish an RCC. This will also determine how the RCC system is to be checked, and which certificates are to be issued. This would be an interim document until international legislation is in force.

6.3 Concept of Operations (ConOps)

The ConOps shall describe the system in a holistic way. The major focus is on the safety and best integration of the RCC-Ship-System into the entire conventional traffic.
There will be no "unique and universal" concept which suits every use case. Shipping companies will develop their own business cases with their own organizations. These must be integrated into the regulatory framework.

Table 28: Proposal for the content of a "Concept of Operations" (HSB/IfMS: own table)

Chapters	Concept of Operations Table of Content
Purpose	Business / application case
	Objectives of the automated shipping system
	Scope of system
Use case	Controlled ships or MASS, type, fundamental particulars
	Fleet size and schedules
	Description of operations (stages of the voyage, cargo operations/mission)
	Interfaces to all other systems
	Players and stakeholders involved
	Responsibilities for the system
Operational area	Geographic area of operations, ports and berths
	Traffic systems and traffic density
	Services (e.g. automated services, port, pilots, VTS, …) in the area
	Communication systems and interfaces
Environmental conditions	Description of the environmental conditions
	Environmental challenges (wind, swell/waves, current/tide, bathymetry)

Chapters	**Concept of Operations Table of Content**
MASS	Description of design
	Specification of elements related to MASS control and safety
RCC	Description of location
	Specification of design of RCC and workstations
RCC and MASS operation and control system	System architecture and its subsystems and elements
	Degrees of automation and control, for each critical subsystem
	Processes and functions for the required operations
	Critical equipment with approvals
	Communication lines and data flow (MASS - RCC; MASS – other ships, MASS – Maritime Services)
	Availability and reliability of all systems / subsystems
Modes of operation	Normal procedures
	Non-normal procedures
Persons on board	Embarkation of persons and purpose of persons on board
	Passengers on board
	Evacuation concept (medical, abandon)
Humans' integration	Humans'-in-the-loop involvement
	Conditions and situations with high demand for human attention
	Division of responsibilities between humans and automation
	Principles for handover of (partial) control between human and automation
	Organisation for situations with high demand
	Manning of the RCC (by capacities/roles/functions, by time, by situation)
Safety and security	Hazards identification (technology, organisation, operations, environment, …)
	Test scenarios
	Risk assessment for the identified hazards (e.g. concerning system availability and reliability, collisions and groundings, cyber risks, …)
	Implemented risk mitigating measures
	Contingency plans
Regulatory compliance	Approvals and certificates required
Appendices	RCC / MASS Risk Assessment
	RCC / MASS Safety Management System
	RCC / MASS Security Plan
	RCC / MASS System Architecture (with list of all (approved) equipment, used hardware and software)
	Ship / MASS System Architecture (with list of all (approved) equipment, used hardware and software)
	Proposed test procedures (test objects, limitations, scenarios for testing)

The content of the ConOps is to be discussed and decided. The criteria and limitations for evaluation have to be determined. For example, the risk of the system concerning collisions and grounding must be less than one per hundred years.

6.4 Certificates by the RCC Flag State

RCC Minimum Safe Manning
(according to SOLAS, Resolution A.1047(27) and STCW; comparable to *Minimum Safe Manning* of a ship).
Because an RCC can operate several ships by less operators the approval has to consider the different conditions or situations which may arise in operation. As basis the Concept of Operations (ConOps) shall be used. The operators of a MASS or a fleet of MASS are directly involved in the ship traffic with all requirements and implications concerning safety at sea. It is assumed that the operators will have a comparable status as seafarers, although they are working ashore. The principles of minimum safe manning, outlined in resolution A.1047(27) are to consider.

RCC Safety Equipment Certificate
(according to SOLAS and comparable to *Cargo Ship Safety Equipment Certificate (+ Form E)*).
This certificate certifies that the RCC can use the safety devices on board the remotely operated vessel and that it has the appropriate equipment available to operate and use the safety devices by the RCC. In terms of content, all controlled safety devices on the remote-controlled ship and in the RCC shall be considered, such as:
> Life-saving appliances, and
> Navigational systems and equipment.
A record of equipment, comparable to Form E, must be established.

RCC Safety Radio Certificate
(according to SOLAS and comparable to *Cargo Ship Safety Radio Certificate (+ Form R)*)
This certificate certifies that the RCC can operate all radio communication devices of the RCC and on board the remotely operated vessel. The appropriate equipment must be available to be operated and used without any delay. In terms of content, all controlled and operated radio communication devices on the remote-controlled ship and in the RCC shall be considered, such as:
> DSC / GMDSS systems,
> Satellite communication systems,
> SAR systems,
> Specific communication systems for remote control.
A record of equipment, comparable to Form R, must be established.

Document Of Compliance (DoC)
(according to ISM Code)
The RCC operates like an outsourced function of the ship. It is assumed that the ISM Code is to be considered accordingly. For that a DoC is necessary for each RCC. This confirms that the requirements of the ISM Code are met.
In the DoC the part of the RCC is to be considered. It should be based on the ConOps of the MASS or the fleet of MASS. In the ConOps the interfaces between the safety systems of the MASS and the RCC are to determine. The DoC can cover all ConOps together which are operated in the RCC.

Safety Management Certificate (SMC)
(according to SOLAS)
The SMC covers the entire safety system of the RCC, the operations of the remote-controlled MASS must be considered. The certificates states that the RCC and (if exists) the shipboard management

operate in accordance with an approved **Safety Management System (SMS)**. The SMS contains the definition of the safety management as well as the emergency contingency plans. Anyway, it is important that the safety systems must be seen in a holistic way.
A Cyber Security Plan is essential for a remote-controlled system, and must be a part of the SMS, too.
The SMS also can be verified and issued by a Recognised Organisation

RCC Security Certificate
(according to SOLAS and ISPS, comparable to *International Ship Security Certificate (ISSC)*)
This certificate confirms the verification that the RCC complies with the provisions of SOLAS and ISPS. Because the RCC is an essential part of the remote-controlled ship system the maritime regulations must be considered. Additional shore-based and RCC-specific measures are to integrate in the RCC Security Plan.
The Security Certificate also can be verified and issued by a Recognised Organisation.

Continuous Synopsis Record (CSR)
(according to SOLAS)
In case the remote-controlled ship needs a CSR, the RCC also needs to such a record certificate. The CSR provides a record of the history of the RCC and the remote-controlled system (interface to the MASS).

In addition to the above-mentioned certificates, consideration should be given to the need to demonstrate **insurance cover for environmental damage** by remote-controlled systems. A certificate of insurance or other financial security in respect of civil liability for damages caused by automation systems would be possible for this.
(comparable to *Certificate of insurance or other financial security in respect of civil liability for bunker oil pollution damage / for the removal of wrecks*).

6.5 Certificates by Recognized Organisations and Third Parties

RCC Safety Design Certificate
(according to SOLAS, comparable to *Cargo Ship Safety Construction Certificate*)
The design of the RCC needs a verification and certification by an RO. It is to certify that the design, which includes the used hardware and software for navigation, communication, operating and emergency operations satisfies the design requirements.

RCC Human Factors Concept Approval
In the RCC planning stage the concept of interfaces between humans and automation is to be authorised. The approval is based on a ConOps and the description by the RCC designer, how the RCC will be organized (roles, safe manning, work positions, software applications & displays & controls, room layout, operational procedures...). Also, a demonstration how the future RCC will handle normal situations and abnormal situations must be presented. The RCC designer must propose its own list and descriptions of such abnormal situations, based on the specificities of the ConOps, and the approving authorities must assess the validity and completeness of that list. The RCC designer must demonstrate that the proposed RCC design (roles, safe manning, …) will be able to deal with the incidental scenarios. In particular, it has to be argued how the high-level requirements associated with the high-level tasks relevant for the planned RCC will be fulfilled. Model-based workload evaluations and full-scope

simulations must be performed at that stage, for the various stakeholders involved in the management of these scenarios.

RCC Human-Systems Integration Certificate (Human Factors Certificate)
In the commissioning stage, when the RCC is built up, an HLT (High-Level Tasks) testing and assessment must be performed It is based on various normal and abnormal scenarios (e.g. loss of communication with the ship, simulated cyber-attacks, engine failure, on board fire...) and how are dealt with these in practice. In particular, it has to be checked in detail whether the high-level requirements associated with the high-level tasks are fulfilled.

MED (Maritime Equipment Directive), Declaration of Conformity (Directive 2014/90/EU)
The RCC uses equipment that serves the safety of the controlled ships and thus the entire ship traffic. The equipment of the RCC must correspond to the marine equipment and the requirements of the remote control. The equipment therefore requires verification of an RO and conformity must be confirmed. The affected equipment is listed in the MED Directive and can be projected onto the RCC. The specific requirements for remote control should be supplemented unless they fall under the existing chapters.

RCC Radio License
(according to SOLAS and ITU regulations, comparable to *Ship's Radio License*)
An RCC will be a radio station, involved in the international ship traffic. It needs to be registered and to be assigned to identification numbers.

6.6 Documents and plans with checks and endorsements

RCC Security Plan
(according to SOLAS and ISPS; comparable to *Ship Security Plan*)
The entire system of a vessel operated requires a plan to protect against external dangers. This plan must identify measures for the different security levels. Not only the ship but also the RCC must be protected to ensure safe operation of the ship. This plan must be verified, and records of security-relevant activities must be established.

RCC Musterlist with emergency instructions
(according to SOLAS, comparable to *Ship Musterlist with emergency instructions*)
An RCC needs an emergency organization which is adequate to the emergency organisation on a vessel. The RCC will operate emergencies on board of a remote-controlled ship. Contingency plans are to develop and to implement. An RCC-Musterlist is required, it is to update and to communicate before starting a voyage.

RCC Log Book
(according to SOLAS, comparable to records for *deck, engine, …*)
The RCC must keep a logbook in which the navigational activities, incidents, status of the RCC and ship, test procedures and safety trainings and drills are tracked.

A remote-controlled ship will keep an electronic logbook for remote control, deck and engine, which records the ship-related data and statuses.
There will also be other subledgers, such as for MARPOL requirements (oil record book) or the radio logbook.
The activities and statuses of the RCC are recorded in the RCC logbook. These include, for example, the sailed degree of autonomy and its changes, the manning and its changes and adaptations, the availability of the control systems and the degrees of control of the individual components. These contents shall be defined.

Plans and Documentations
All safety-relevant plans and documentation must be available in the RCC to have them at hand if necessary. Without explaining them in detail, they are listed below:
For the controlled vessels:

- Emergency towing procedure
- Construction drawings
- Stability information
- Damage control plans and drawings
- Manoeuvring booklet
- Maintenance plans for safety equipment
- Maintenance plans for critical equipment
- Fire control plan and safety arrangement plan
- Ship-specific plans and procedures for recovery of persons out of the water
- Operational manual for access of ship by helicopter or boat
- Cargo information and stowage plans
- Cargo securing manual
- Material Safety Data Sheets (MSDS) for dangerous cargo

For the RCC

- Nautical charts and nautical publications
- Compulsory publications (e.g. IAMSAR Vol. 3, Code of Signals, SOLAS, MARPOL, …)
- Technical documentation and design specifications
- Maintenance plans for critical equipment
- Fire control plan and safety arrangement plan of the ship and the RCC
- Training and drills records for the operating team
- Safety training manuals and emergencies operation booklets

The proposed documentations and plans are to discuss and to determine.

6.7 Service reports by approved suppliers

For all critical equipment which is related to navigation, communication, propulsion, safety and security, and other critical equipment a documentation is required. This shall cover documents, records and reports, as

i. certificates of compliance,
ii. test reports,
iii. service and maintenance records

6.8 Certificates and documents labour and qualification related

Certificates of Competence and Proficiency for RCC Operators
(comparable to STCW-Certificates of Competence and Proficiency for Seafarers)
Operators of remote-controlled ships will need competences to be allowed to take the responsibility and control of such vessels. The operators must meet the requirements for the service, age, medical fitness, training, qualification and examinations.
The certificates of competences and proficiency must be endorsed in case they are issued by another flag state.
The results of the EMSA study "Competences for MASS Operators in Remote Control Centres" are to consider.

Records of daily hours of rest
(according to STCW, comparable to seafarers Hours of Rest)
The special requirements for on-duty times for operators shall be defined. These will not be the same as required by STCW and MLC, as the specifics of the RCC must be considered. Since the work is carried out ashore, the rules for seafarers cannot simply be transferred.
A corresponding procedural instruction or guideline must be drawn up. The local rules on working hours must be considered. Working hours with breaks and rest periods shall be recorded accordingly.

Records of RCC Operator Trainings
(according to SOLAS, comparable to ship crew training records)
To respond efficiently to emergencies and functions, RCC operators must carry out appropriate training and drills. A training scheme and schedule must be drawn up for these. The trainings and drills must be logged.

It is to note that the regulations of the Maritime Labour Convention cannot be applied to a shore-based organisation. An RCC is subject to the labour law of the country of location.

Appendix A – RCC's State of the Art

Appendix B – Ergonomic standards applicable to RCC

List of Abbreviations

ALARP	As Low As Reasonable Practicable
C/O	Chief Officer (here: responsible for cargo and safety)
CoC	Certificate of Competence
CON	Conduct of Navigation
CoP	Certificate of Proficiency
CPP	Controllable Pitch Propeller
DSC	Digital Selective Call
ENG	Engineer (here: the engineer controlling a vessel)
ERT	Emergency Response Team
ERC	Emergency Response Center
FAT	Factory Acceptance Test
FOC	Fleet Operation Center
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
HLT	High Level Tasks
HMI	Human-Machine-Interface
HMT	Humatects
HSB	Hochschule Bremen (University of Applied Sciences Bremen)
IfMS	Institute for Maritime Simulation (HSB)
ISM	International Safety Management Code
ISPS	International Ship and Port Facility Security Code
ITU	International Telecommunications Union
MASS	Maritime Autonomous Surface Ship
MSC	Maritime Safety Committee at IMO
OOW	Officer Of Watch (having the CON)
PP	Passage Plan
RCC	Remote Control Center
RO	Recognized Organisation
RPN	Risk Priority Number
SAR	Search And Rescue
SAT	Site Acceptance Test
SMS	Safety Management System
SOLAS	International Convention for the Safety Of Life At Sea
VTS	Vessel Traffic Service

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