Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Ocean Operations and Civil Engineering

Zheng Wei

Hardware Design for Simulation and Remote Control Centre

NTNU Remote Control Centre for Autonomous Ship Support Project

Master's thesis in Naval Architecture
Supervisor: Karl Henning Halse, Pierre Major
June 2020

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OSC
OFFSHORE SIMULATOR CENTRE

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Abstract

NTNU Aalesund is now building a centre to test technology, methodology, and procedure for remote control of various functions on ships at NMK II. This thesis is a contribution to «OSC – NTNU forskningslab» project, and that is an early stage of the Autonomous Remote Control (AuReCo) project. Remote ship operation is the first step in autonomous ship research. Previous works are based on remote monitoring, did not provide a solution for high quality visual and control system based on simulation for a remote control centre. By analyzing the target vessel Gunnerus, a remote control center, including navigation bridge simulator and generic stations simulator, was developed in this thesis. The system uses OSC simulation software and has an interface for implementing ship hydrodynamic analysis software like ShipX and physics engines like AGX and Fhsim, provide the ability to be used as a simulation-based ship remote control system. A visual system was designed for monitoring and reporting the vessel states at the onshore station, and a control system was designed to send control commands. The ability of the centre and its value has been shown in the final test. As a result, the centre provides the ability for remote control operation for AuReCo project, and also shows its value for ship designers, shipmasters, and ship owners, which could contribute to the entire industry.

NTNU Ålesund bygger nå et senter for å teste teknologi, metodikk og prosedyre for fjernkontroll av forskjellige funksjoner på skip ved NMK II. Denne oppgaven er et bidrag i «OSC - NTNU forskningslab» prosjekt, og det er et tidlig fase av Autonomous Remote Control (AuReCo) prosjektet. Fjernstyring av skip er det første trinnet i autonom skipskontroll forskning. Tidligere arbeid er basert på fjernovervåking, ga ikke en løsning for visuelt og kontrollsystem av høy kvalitet basert på simulering for et fjernstyringssenter. Ved å analysere målfartøyet Gunnerus, ble det utviklet et fjernkontrollsenter, inkludert navigasjonsbrosimulator og generisk stasjonssimulator, i denne oppgaven. Systemet bruker OSC-simuleringsprogramvare og har et grensesnitt for implementering av skipets hydrodynamiske analyseprogramvare som ShipX og fysikkmotorer som AGX og Fhsim, og gir muligheten til å bli brukt som et simuleringsbasert skipsfjernkontrollsystem. Et visuelt system ble designet for å overvåke og rapportere fartøyets tilstander på landstasjonen, og et kontrollsystem ble designet for å sende kontrollkommandoer. Evne til sentrum og dets verdi er vist i den endelige testen. Som et resultat gir senteret muligheten for fjernkontrolldrift for AuReCo-prosjektet, og viser også verdien for skipsdesignere, skipsførere og skipseiere, noe som kan bidra til hele bransjen.

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Contents

List of figures v
Acronyms vi
1 Introduction 7
1.1 Project background 7
1.2 Problem formulation 8
1.3 Objectives 9
1.4 Thesis outline 12
2 Background and theoretical basis 13
2.1 What are the key technologies in the digital shift? 14
2.1.1 Digital twin 14
2.1.2 Technology for energy-efficient ships and operations 14
2.1.3 Automation of work processes - yard and port 14
2.1.4 Technology and services for system integration 15
2.2 How can we relate to developments? 15
2.3 State of the art 15
2.3.1 Research of the remote control center 16
2.3.2 Research of autonomous vessel and its benefits 17
2.3.3 What we can improve in this project and the challenges 20
2.4 The advantage of OSC and purpose of SRCC research 22
2.4.1 Features of OSC simulators 22
2.4.2 The purpose for research of SRCC 25
3 Methods 29
3.1 Method description 29
3.1.1 Analyze 30
3.1.2 Design 30
3.1.3 Test of the SRCC 31
3.2 Design loop 31
4 Analyze 32
4.1 Target vessel bridge house analysis 32
4.1.1 Internal Visibility 32
4.1.2 External Visibility 35
4.2 Target vessel console and workspace analysis 37
4.3 Analysis of the site 39
5 Design 40
5.1 Visual system design 40

5.1.1 Size and shape 41
5.1.2 Projection screen 43
5.1.3 Projector pre set up 44
5.2 Control system design(console, controllers, chair) 46
5.2.1 Navigation bridge dome control system 46
5.2.2 Generic operation station dome control system....49
5.3 The final visual system set up 52
5.4 Data information wall design....53
5.5 Site arrangement 53
5.6 Design alternatives....55
5.6.1 Dome 55
5.6.2 Bridge house 55
6 Test cases of the SRCC....56
6.1 Prove of concept 56
6.1.1 Zigzag comparison test....58
6.1.2 Test case with the deck crane....61
6.1.3 Discussion of the Gunnerus digital twin test 62
6.1.4 Future works 62
6.2 Using the SRCC for ship designers 62
6.2.1 Test tool for design ideas....62
6.2.2 Test case – Validation with Virtual Sea Trials....64
6.3 Using the SRCC for shipmasters 65
6.3.1 Real-time observation 65
6.3.2 Live decision support....66
6.4 Using the SRCC for ship owners 67
6.4.1 Detect potential issue....68
6.4.2 Reduce transportation cost....68
6.4.3 Reduce human error and risk 68
7 Summary....69
7.1 List of Contributions....69
7.2 Work under safety culture by following the new guidelines 71
7.3 Fulfilled requirements while keeping flexibility....71
7.4 Built a site with value for the industry 71
8 References....72
Appendix....75

List of figures

Figure 1: Remote control centre for Autonomous Ship Support (Zhang 2019) 10
Figure 2: A data-driven scheme for onboard support of the remote control centre (Zhang 2019) 11
Figure 3: ROMAS project of DNV GL (DNV·GL 2019) 17
Figure 4: Remote operation/control centres(Image from Kongsberg website)..............18
Figure 5: Main control room of Yara Birkeland (Photo: Tore Stensvold) 18
Figure 6: Kongsberg Intelligent Asset Management Customer Centre (Delivered by OSC) 19
Figure 7: Kongsberg VR bridge (Designed by OSC) 19
Figure 8: : SRCC: the switch of the real-world and virtual world 21
Figure 9: OSC Systems Architecture (Major 2020) 22
Figure 10: ShipX (www.sintef.no/en/software/shipx/) 23
Figure 11: Wave model analysis in OSC Sandbox 23
Figure 12: Levels of autonomous - Sheridan's model (Sheridan 2002, Kari, et al. 2018) 25
Figure 13: Gunnerus 3D model..32
Figure 14: Example of Height of Upper Edge of Front Window concerning Eye Height 33
Figure 15: Model dimension in relation to eye height 33
Figure 16: Photo of the frame between front windows 34
Figure 17: View of Sea Surface 35
Figure 18: Field of View Around Vessel 35
Figure 19: Model showing Main Steering Position Field of View 36
Figure 20: Photo of the console on Gunnerus bridge 37
Figure 21: Console Configuration and Dimensions for Standing Positions 38
Figure 22: Console Configuration and Dimensions for Sitting Positions 38
Figure 23: Sketch of navigation bridge dome 42
Figure 24: Sketch of the generic operation station dome 42
Figure 25: Visual zones for stations, pink area represents the blended zone in the middle 43
Figure 26: Balanced light intensity of the projectors...45
Figure 27: Balanced low and high light intensity of the projectors..............................45
Figure 28: Test build up in Autodesk Inventor 47
Figure 29: Finished operator chair in navigation bridge dome....................................48
Figure 30: Compact bridge console 48
Figure 31: Generic operation station dome chairs 49
Figure 32: Console concept top view with operator reach range 50
Figure 33: Concept 3D render 50
Figure 34: Center console controller layout 51
Figure 35: Test build in Inventor 51
Figure 36: Top view of navigation bridge dome with compact console installed............52
Figure 37: Top view of the generic operation station dome with two operator chairs installed 52
Figure 38: Overview of the site's digital twin. 53
Figure 39: Debriefing table 54
Figure 40: 360 views of the site 54
Figure 41: 4m Dome with more projection area...55
Figure 42: Full-size bridge with 360 views 55
Figure 43: Data transition phases of SRCC..56

Figure 44: Simulation system.....57
Figure 45: Experiment description of Gunnerus (Li 2019) 58
Figure 46: Test of SRCC 59
Figure 47: Graph of the measured and simulated test result 60
Figure 48: Video records of real and simulated crane operation 61
Figure 49: Add deck crane using FMI 63
Figure 50: VST Virtual Trials' Data (Major, Zghyer, et al. 2020).....64
Figure 51: Digital twin of subsea installation operation 65
Figure 52: Prediction data analyzing 66
Figure 53: Ghost objects in a simulation.....67
Figure 54: Engine control from SRCC (ROMAS project).....67

Acronyms

AMO	Centre for autonomous marine operations and systems
AuReCo	Remote Control Centre for Autonomous Ship Support
FAFO	The Fafo Research Foundation
FOV	Filed of view
IO	Input/Output
SRCC	Remote Control Centre
VEP	Virtual eyepoint
VHF	Very High Frequency, radio bands
VP	Virtual prototype
VST	Virtual Sea Trials

1 Introduction

The ability to test the implications of what happens when an offshore or maritime project is carried out is important for making the right planning decisions: to save time and lives and cut costs. The importance of decisions lies in the search and quantification of various solutions compared with performance. The simulations often provide a chance to see the future planned in real-time and provide a straightforward summary of the findings.

For decades, ship's bridge simulators have been used in the maritime environment for both engineering, training, and research. The authenticity of a simulator of a ship bridge has a significant effect on the use of a futuristic world for training, exercise, and planning. Technology enables simulation production to go beyond real life. Essentially, they are simulated crafts with mock-up bridges, fitted with real consoles, with handles that move in actual time in a virtual world that replicates future reality. (Digital21 2018)

This thesis describes the methods employed to create the hardware and centre layout for "Forskning Lab", the NTNU Ålesund Research lab, which will be used as a centre to test technology, methodology, and procedure for remote control of various functions on ships. This thesis is a contribution to «OSC – NTNU forskningslab» project, and that is an early stage of the Autonomous Remote Control (AuReCo) project.

1.1 Project background

The Remote Control Centre for Autonomous Ship Support (AuReCo) project aims to establish a simulation-based remote control centre(SRCC) for onboard support of autonomous ships, which is closely relevant to the thematic area of "autonomous and remote-controlled vessels" in the call for proposals. In particular, efforts will be put on the sub-area "autonomy and remote control technology" by analyzing historical/real-time ship data and modeling sophisticated planner, predictor, and controller, thereby establishing a remote supporting platform. The system will be developed to serve for ships that are either autonomous or remote-controlled for safety and reliability enhancement. (Zhang 2019)

The digital twin, fueled by an integrated data loop, will be critical to the advancement of remote monitoring, remote control, and autonomy in shipping. Before any ship sails by itself, ship owners, ship designers have to make sure of its behavior in any condition. A vessel is a quite expensive asset that taking any kind of risk on them when it is in the water is unacceptable. Hence, we should use the simulators to make sure that technology and product are safe enough to be used on a vessel. To be able to control a digital twin, which duplicates both the environment and status of the real vessel in real-time, design a proper simulator is the first step and the foundation. (Jayarathne, et al. 2014)

The establishing of the first remote control centre for onboard support of autonomous ships will be concentrated on with focusing on human factor issues. The proposal is associated with and supported by NTNU AMOS.

1.2 Problem formulation

To date, the industrial internet of things is of high interest for shipbuilding companies and equipment suppliers. One of the most attractive aspects is the concept of digital twins, which refers to a digital replica of physical assets, processes, and systems that can be used for realizing ship autonomy to some extent. In general, digital twins maintain a digital model integrating artificial intelligence, machine learning, and model analytics, and update with the change of its physical counterpart. They are ideal to be applied to increase the level of autonomy of ships from the perspective of diagnosis, early warning, dynamic optimization, and prediction.

The capability for remote human interaction and control has to be enabled for situations where the ship's autonomy cannot resolve or is not allowed to handle by itself. Relaying the data gathered by ship’s sensors to a remote operator may require the transfer of a significant amount of data. Due to the practical limitations on e.g., satellite communications at the open sea, the same amount of bandwidth may not be available at all times. Methods for reducing the amount of sensor data only to what is absolutely needed for the human operator to perceive the environment of the ship needs to be considered. Also, issues such as data security and link reliability should be addressed, and the possibilities of using multiple alternative communication networks depending on availability and performance needs should be examined.

Data visualization, especially environmental mapping, is another important element in the SRCC, as it is the fundamentals for path planning, obstacle avoidance, and localization of the autonomous ship. There are multiple ways the mapping process can be performed and what kind of a presentation of the world is created, depending on the application, where the maps are needed, and what sensors are used for perceiving the environment. The two most common approaches for presenting the world are topological and metric maps. Topological approaches describe the connectivity of spatial locations in the environment, whereas metric maps describe the world through a geometric presentation. (Rødseth 2014)

Finding the optimum way to combine the different sensors technology in a range of operating and climatic conditions will be the subject of a series of tests at sea. The need is to develop a set of advanced supporting tools using machine learning and optimization methods for multifaceted enhancements in vessel performance and operation. The basis for ship state estimators is a mathematical model representing the system to be observed, and a set of sensor signals that updates the model in real-time. Today, closed-loop systems based on state estimators are found in all modern offshore vessels. The next step for developing support tools is to include the operations and predict information to the operation management, which is relevant for the actual stage of the operation. (Wang, Yang and Chen 2011) This will provide information about, e.g., objects being transferred in the near future and positioning of units on the seabed.

1.3 Objectives

NTNU Aalesund a.k.a. Campus Aalesund wants to position itself as a leader in digitalization, simulation, and visualization, and become the capital of simulation. Gunnerus is a small research vessel owned by NTNU and is the best option to develop research and test for digital twins.

The digital agenda is one of the pillars of the European Strategy for Growth, which proposes to better exploit the potential of Information and Communication Technologies (ICTs) in order to foster innovation, economic growth, and progress. It lists "Ship Intelligent" as one of the main areas through which to achieve growth. In the marine system and transport, digitalization can significantly improve the design, operation, and management through more accurate information on operational and infrastructure conditions and on the location of vehicles and/or system behavior models. Better access to and sharing of digital data (traffic, travel, vehicle, cargo, etc.) for both public and private stakeholders along the supply chain can foster seamless information flows and open up a wide range of new business opportunities. (Reegård and Rogstad 2012)

In order to test and analyze digital twins, a customized simulation centre with proper facilities is needed to duplicate the environment on the vessel to make it possible, in the future, it will also have the potential to be able to do remote monitoring and control operation from onshore.

At NTNU, Centre for autonomous marine operations and systems (AMOS) work between the disciplines to create a world-leading center for autonomous marine operations and control systems. NTNU AMOS contributes to fundamental and interdisciplinary knowledge in marine hydrodynamics, ocean constructions, and control theory. The research results are being used to develop intelligent ships and ocean structures, autonomous unmanned vehicles (underwater, on the surface, and in the air) and robots for high-precision and safety-critical operations in extreme environments. According to research at AMOS, there are two major concerns/risks regarding ship autonomy. One is "Cybersecurity", and the other is "Human factors/ human in the control loop". So far, NTNU AMOS is organized in 9 research projects. Six projects focus on the topic of ship intelligence.

A novel and flexible approach is needed, so the training can be performed for various vessels and procedures, planning, and virtual prototyping can be simulated, and remote operations can be monitored in the research lab.

The primary objective of this project is to develop such the first remote control centre based on the digital twin of autonomous ship operations, performance prediction, system early warning, etc. as shown in Figure 1. It will take advantage of all digital information available for an asset including system and data information model, 3D visualization models, mathematical models, dependability models, condition and performance indicators and data analytics, to provide onboard support, such as visualizing complex surroundings and illustrating future prediction of the situation for either achieving autonomy or remote control. This project is to develop a new integrated architecture for planning and execution of real-time support to autonomous or semi-autonomous ship operations, with corresponding risk evaluation tools that take human factors, focusing on situational awareness, into consideration. This will serve the industry for improving operational effectiveness and safety through the use of simulator facilities.

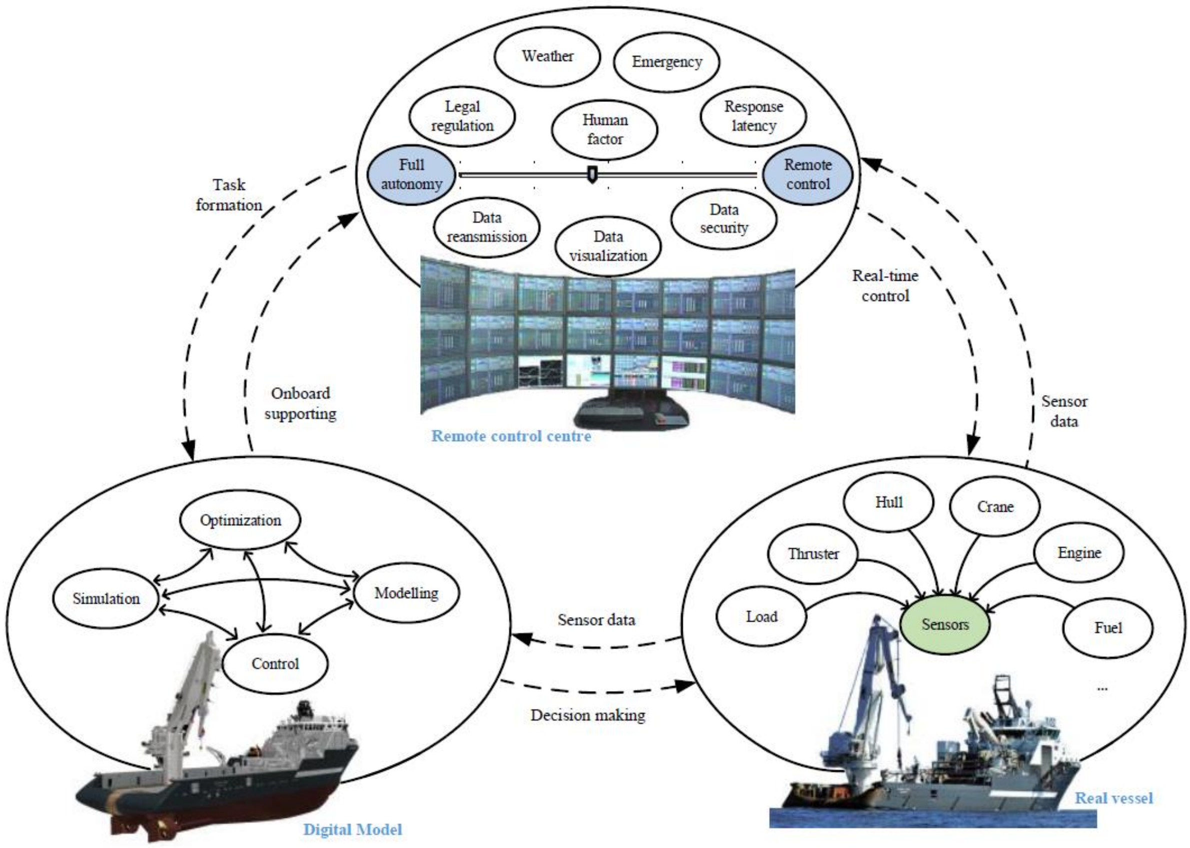


Figure 1: Remote control centre for Autonomous Ship Support (Zhang 2019)

Figure 2 illustrates a possible scheme of the support system based on the digital twin. The data transmission and visualization are responsible for storing/transferring ship data and visualizing it in the remote control centre. The data sensitivity analysis module takes the vessel's status, the operational commands, and the environmental data as input and the designated metric, e.g., ship position, as output, to quantify how much the input contributes to the output. The result can benefit both the optimizing and the prediction phase.

For example, if the ocean current accounts for one of the main factors for maneuvering, this element will be considered in the path optimizer or the motion predictor as a cost function or an input of the predictive model. Dynamic optimization refers to the state of the ship and the mission being executed. It considers physical constraints and generates optimized references. The result can either serve for control with human interaction or formulates the references as prior knowledge for prediction of future operation—as far as the followed control strategy couples with the optimization module. Similar couplings exist between the prediction module and the control module, as they are, in essence, a completely closed-loop system.

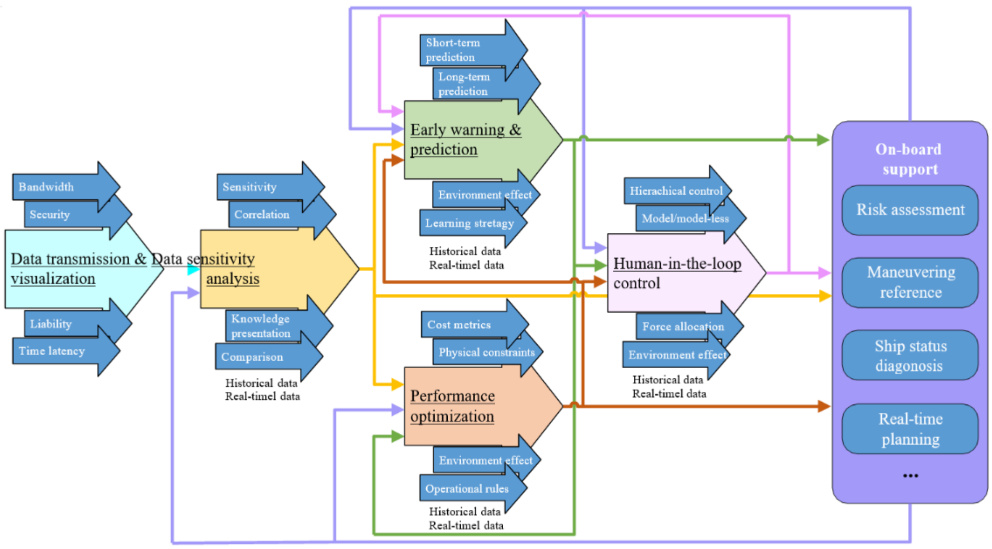


Figure 2: A data-driven scheme for onboard support of the remote control centre (Zhang 2019)

NTNU Aalesund is now building a centre to test technology, methodology, and procedure for remote control of various functions on ships at NKM II. In order to be able to research different targets/stations in normal offshore operation: vessel, crane, winch, etc., the research arena needs to include all work stations on a ship or in a control centre for autonomous or semi-autonomous control.

As the designer of this project, the following list of stations will be included in my design work:

- Navigation bridge
- Operation station (aft bridge)
- Engine room
- Crane, WROVs, Winch
- Operation manager (onshore and offshore)

Other than the stations, some more design objectives that need to be achieved are:

- All interfaces need to be real interfaces commonly used in the industry.
- All work stations need to be flexible.
- Single controls can be replaced for customized set-up, and workplaces can be modularized.

- A minimum of interfaces to simplify the test of equipment of different makes.
- All working packages need to be implemented in the remote control centre at NMK II.

In my work, the full hardware package for the simulation center will be designed – including 2D drawings and 3D models based on the real vessel, as a part of the project to build up the centre. The control system will also be integrated and used for simulation and analysis of human operations in SRCC.

1.4 Thesis outline

Chapter 1 – Introduction

This chapter introduces the problem, providing motivation, specifying the goals of the thesis.

Chapter 2 – Background

This chapter presents the trend of technology development in the maritime industry, introduces state of the art in remote control center research, related work, and concepts used in the thesis. List the challenges and solutions of this thesis.

Chapter 3 – Method

This chapter describes the method and software that will be used in the thesis. Following the design guidelines, a design loop of my work will be presented for the project.

Chapter 4 – Analyze

This chapter analyzes the site and target vessel for the project through the guidelines and finalizes the requirements for my design.

Chapter 5 – Design

This chapter shows my design process for all hardware. The process has been divided into mainly two parts: visual and control systems. Based on my analysis, the hardware design will be developed from the draft to the final version. The visual and control system develops along with the hardware in form. In the end, all hardware will be gathered into a 3D digital twin of the site. The site layout will be tested in the virtual world.

Chapter 6 – Test of the SRCC

This chapter shows some test cases of the SRCC. A method to prove the remote control concept will be introduced. A simulation test will be applied by me to prove the concept and to evaluate the performance of the simulator in SRCC. Other test cases and the potential way of using the SRCC will be written to show it's value for ship designers, shipmasters, and ship owners.

Chapter 7 – Summary

This chapter contains a summary of my work and its results, discussed the contribution of this thesis. It also describes some issues during the design process and experience for future work.

2 Background and theoretical basis

The Norwegian maritime cluster is almost complete and covers the entire value chain. At Norwegian shipyards, primarily specialized and relatively small vessels are built for Norwegian shipowners related to activities in offshore oil and gas, offshore wind, aquaculture, as well as various ferries and passenger boats. Norwegian shipowners are leaders in offshore, transport of LNG, chemical transport, as well as RoRo (roll-on-roll-off). They were well supported by an internationally leading cluster of equipment and services suppliers. Significant progress is also being made nationally on the development of battery-electric vessels, and there is an ambition that by 2021, 60 ferries will be electric. There is also considerable activity related to the development of autonomy and where Norwegian players contribute to international development, both in transport systems, technology, services, and regulations.

For Norway as a nation, the maritime industry is essential for the economy, and overall for 2018, the industry contributed 142 billion in value creation, corresponding to 8% of GDP (excluding oil operators). Employment for the same year was 85,000, and exported values were equivalent to NOK 217 billion. In short, the period following the correction in the petroleum industry in 2014, and until today, has been very challenging for the part of the maritime industry that is most exposed to offshore petroleum activities. For the period 2015 to 2018, offshore shipping companies and rigs saw a 25% and 26% reduction in employment, respectively, and a significant reduction in value creation and turnover of about 40%. This decline has also had a significant impact on the supplier industry, especially for suppliers of equipment and technological services. (Kvamstad-Lervold, Holte and Johansen 2019)

Sunnmøre, Norway's maritime industry, has a long tradition of constructing specialized vessels for platform supply, anchor handling, and underwater operations. The area has a cluster of companies developing solutions for the oil industry's demanding needs. Digitization is in the maritime industry today, as well as the likely development path in the future.

There is a trend to consider developing more advanced vessels that have intelligence and are capable of executing different levels of autonomy for maritime operations. The term levels of autonomy are often used to describe what degree the plant can act on its own. Autonomy can scale from a machine being completely controlled by humans, i.e., teleoperated, to the machine being fully autonomous and without any interaction from the human. Fully autonomous may not be applicable to the entire maritime operation but are most useful when applied to subtasks of the operation. For example, ship navigation in the open sea can be nearly autonomous, whereas, for some part of the voyage like passing narrow water, it will require close supervision and decision making, or even full teleoperation. (Junior, et al. 2009)

As the technologies, especially sensor technologies for perception and communication has been developed, the prospect of the so-called autonomous ship will become a reality. Multiple sensors, including not only the internal status of machinery, propulsion system, engines, but also camera, lidar, radar, sonar, and GPS/INS external sensors for operation and navigation, could be integrated into the ship. On the one hand, in the light of sensor information, the ship is able to make a decision in an optimum way to combine operational reliability and cost-efficiency. The benefit is obvious that human errors will be reduced, as well as the cost. Yet, on the other hand, it is challenging to include environment sensing, autonomous navigation, and unmanned ship maneuvering under different environments like an open sea with different waves or weather conditions. Moreover, new types of risks, such as communication with other human-controlled vessels, the interpretation of international maritime rules and regulations, and other safety and security issues, will arise. Therefore, developing autonomous ships cannot accomplish at one stroke but should take the human factor into account and improve in a gradual and iterative process.

2.1 What are the key technologies in the digital shift?

The new enabling technology is an essential driver for understanding the changes that will occur in the maritime industry over the next few years. Digital21 has described critical enabling technologies in a separate note. Here, a distinction is made between fundamental and system technologies. The fundamental technologies are described as relatively essential in the sense that they are used as building blocks for system technologies. For example, artificial intelligence and algorithms are fundamental technology put together to create autonomous systems (system technology). Common to both groups is that they are generic - they are used across traditional industries and sectors. (Jakobsen, Basso and Mellbye 2018)

2.1.1 Digital twin

Development of technology and standards for digital twin ships and logistics can be used both in the design phase, in the construction phase of shipyards, and in the operational phase (shipowners). The same digital twin can also be used for further research and improvement of processes.

2.1.2 Technology for energy-efficient ships and operations

The data analysis for future maintenance planning, use “augmented reality” and VR for training on energy-efficient navigation and linking data sources for optimized routes and fleet composition, will allow skilled engineers to be in charge of a fleet of vessels from shore-based centres instead of dispatching machinist on every vessel.

2.1.3 Automation of work processes - yard and port

By introducing, for example, robotics and VR into shipyards, work processes can be automated and operations streamlined. Data analytics, AI, VR can give shipowners a whole new opportunity to monitor and make the right decisions for maritime operations because multiple data sources can be linked together. Systems become better able to handle large amounts and complex combinations of data. Automating ship reporting and port operations is another great opportunity, as this is also one of the most significant barriers to competitive maritime transport today. (Munin n.d.)

2.1.4 Technology and services for system integration

This is interesting as the competing industry in other nations may seem to focus on the ship itself as a system, while the Norwegian industry can take advantage of the natural benefits of developing systems and services that connect customers and suppliers more closely. Here, blockchain technology can also play a role in a new way of managing contracts between players.

2.2 How can we relate to developments?

The main difference between autonomy and digitalization is that autonomy has the potential to lead to radical changes in the value chain and business models, while digitalization provides a significant but more incremental change. There is more talk of process improvements that can, for example, equal energy savings as new energy systems, improvements in hulls, etc. What is interesting in this context is that this is the technology that can be installed on ships without rebuilding. This is interesting as we know that many of the ships being built today will be in operation even in 2050 when the IMO has a goal that emissions from shipping should be halved. (NOU 2018:2)

Digital21 defines digital technologies in fundamental and system technology. The fundamental technologies make it possible to digitize, for example, big data analysis, AI and machine learning. System technologies employ both fundamental technology and other areas of expertise, such as drones and digital twins. Digital technologies tend to intervene in the industry at various stages. They first emerge as an innovation, and then they move into a period where we have an excessive belief in what technology can do for us, to a period when realism is pouring in on us until eventually, we move into a productive phase. (Andersen, Bjørnset and Rogstad 2019)

2.3 State of the art

The recent years have seen an increasing interest in developing and employing digital twins, big data, and cloud computing in marine industrial systems. Digitalization has become a key aspect of making the maritime and offshore industries more efficient and fit for future operations. Regarding autonomous ship, instead of realizing onboard autonomy, efforts may be put to set up a digital twin that generates a range of digital models of a vessel and its equipment for new ways of managing a vessel's safety and performance via remote control. The digital twin tracks information on all parameters to define how each individual module and sub-modules behaves over its entire useful life, including the initial design and further refinement, manufacturing related deviations, modifications, uncertainties, updates as well as sensor data from onboard systems, maintenance history, and all available historical data obtained using data mining. The digital twin also follows its corresponding real-life twin through its life cycle, thereby making the control and monitoring from a remote control centre become possible.

Industrial demand shows although at present there are global location and traffic management systems such as the GPS system and the traffic separation system for ship status monitoring, ship owners are eager to have their own control centre used for condition-based monitoring or traffic control for regular vessel maintenance, task dynamics distribution. When humans are in the loop, the control complexity will be increased. It is widely agreed that the human element is the dominant source of error in demanding marine operations. It is a matter of priority to look into the human element in order to ensure safety and efficiency during remote control of autonomous ship operations. Mitigating risk due to the human element is of vital importance. (Basso and Jakobsen 2019)

2.3.1 Research of the remote control center

From the year 2017, Rolls-Royce Marine (now Kongsberg Marine), Wärtsilä, and Navtor have been showcasing innovations for remote control of various types of workboats.

Rolls-Royce Marine partnered with Danish tug owner Svitzer and the Lloyd's Register class society to establish a system for operating a harbor tug from a remote control room. On 16 November 2017, in Copenhagen, Denmark, a tug master has successfully operated the 2016-built Svitzer Hermod harbor tug from a shore-based operations center in Svitzer's offices.

In August 2017, a platform supply vessel in the North Sea was the focus of a demonstration by Wärtsilä Marine Solutions of its involvement in smart marine ecosystems. GulfMark Offshore's Highland Chieftain, which equipped a Wärtsilä Nacos Platinum package for navigation, automation, and DP, was controlled from a center in San Diego, California, USA.

In the same year, Navtor cooperated with Cyber-Physical Systems Engineering (CPSE) Labs and tested the concept of a shore-based bridge, which was thought of as a critical step on the path to autonomous shipping.

From then, more and more research has been dedicated to this area. A lot of remote control centers have been built along with the development of autonomous technology, not just in the Marine industry but also in the offshore industry for the unmanned platform. (Walker 2019)

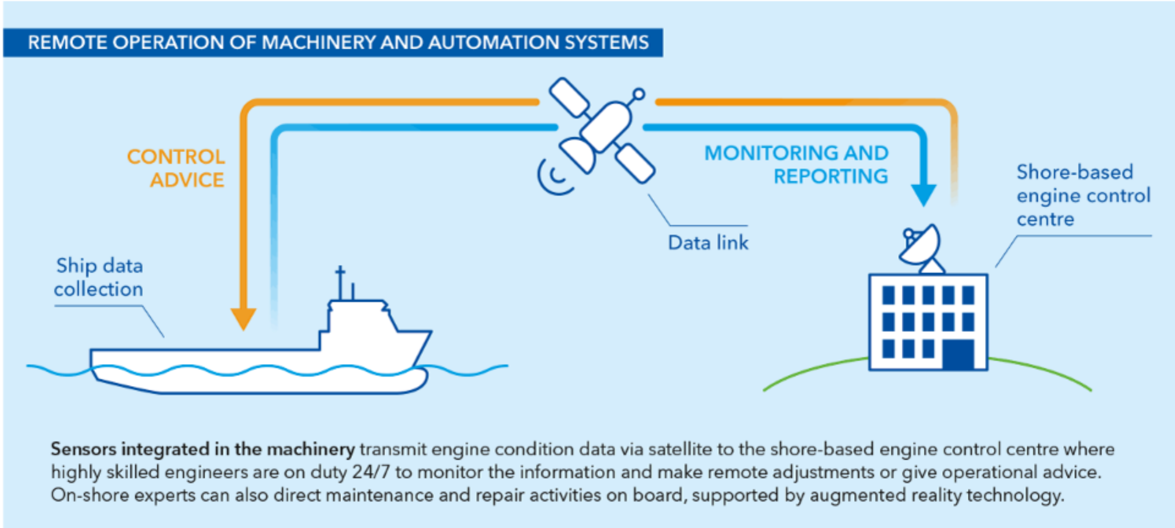


Figure 3: ROMAS project of DNV GL (DNV·GL 2019)

The project Remote Operation of Machinery and Automation System (ROMAS) by DNV GL has also commenced in 2017. As Figure 3 shows, the idea is to move the ECR (Engine Control Room) from ship to an onshore control center. In this way, a competent engineer could operate a fleet of vessels' machinery systems.

2.3.2 Research of autonomous vessel and its benefits

In transit of cargo, cargo ships are generally a much slower choice than cargo aircraft or even vehicles, but they typically represent a much lower environmental and operational cost alternative. Therefore, the shipping industry is still seeking ways to reduce operational expenses. The industry needs to make transportation as cheap as possible to keep the export demand growing. Reducing transportation costs would enable economically viable exports of new products around the globe, opening new market opportunities. (Andersen, Bjørnset and Rogstad 2019)

Automated vessels can give the advantage of reducing/eliminating the cost of the crew members' salaries. This is more important for smaller size vessels, where the cost of crew represents a larger part of total costs, but less important on larger vessels. The other potential cost reductions for large ships go beyond pure cutbacks in personnel costs. The crafts could sail at a much lower speed, thereby reducing energy consumption, which has a positive financial and environmental, operational impact. (Massterly 2018)

Among all the autonomous ship projects, Yara Birkeland will be the world's first zero-emission, autonomous container feeder. It is a 120 TEU open-top container ship that is under construction and due to be launched in 2020 (at the earliest). Following trials with a small crew on board, it is scheduled to operate autonomously, beginning in 2020. At the time of project initiation, the Yara Birkeland project was designed to create the first fully autonomous logistics concept in the world (from industrial site operations, port operations, and vessel operations). In 2019, the Yara Birkeland was a finalist in the competition for the annual Nor-Shipping Next Generation Ship Award. (Wikipedia n.d.)

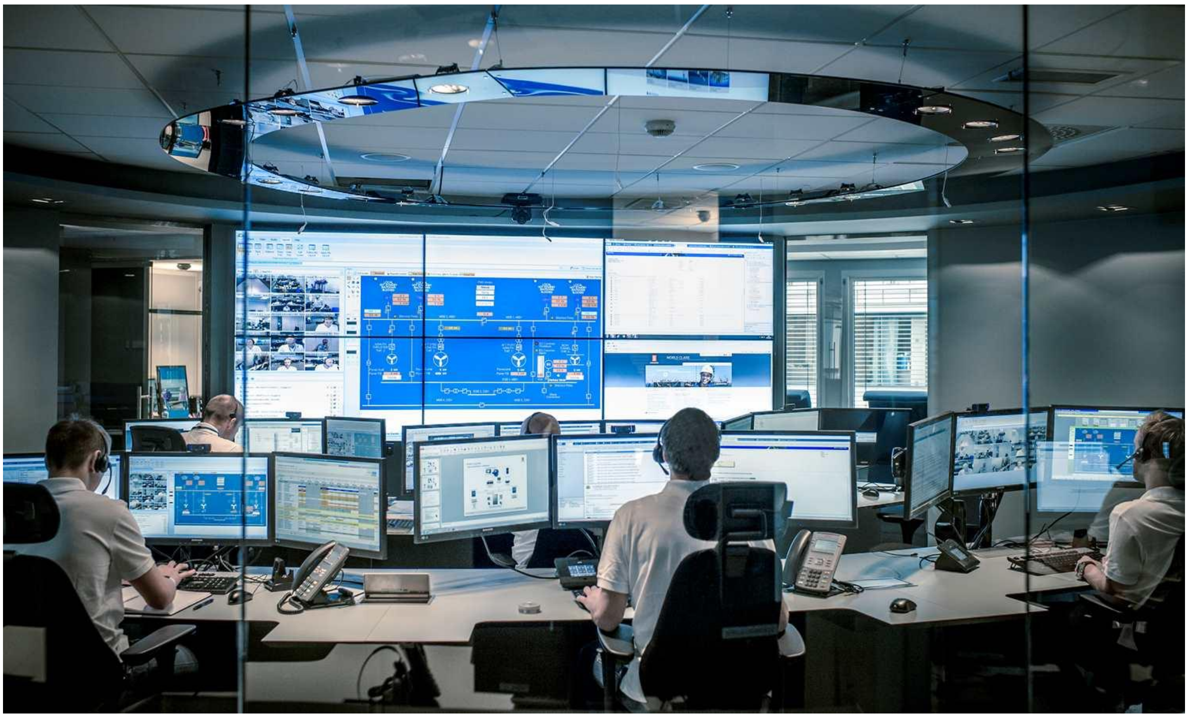


Figure 4: Remote operation/control centres(Image from Kongsberg website)

Three centers with different operational profiles are equipped to handle all aspects of the operation and ensure safety, as in Figure 4. Such centers will provide emergency and exception response, crisis regulation, operational tracking, decision assistance, autonomous ship, and surroundings observation and all other safety aspects. A logistical operation interface to Yara will be implemented at the Herøya operations centre. (Stensvold 2020)

Figure 5: Main control room of Yara Birkeland (Photo: Tore Stensvold)

Most of the centers are currently equipped with only a few flat-screens to monitoring data of the vessel, as we can see in Figure 5. However, the trend to use big size projection screens or dome is becoming more and more popular, for example, the Kongsberg intelligent asset management customer centre (Figure 6) and Kongsberg VR bridge (Figure 7). Both of them were developed with my design work involved and been using as a showcase for the leading technology in their area.

Figure 6: Kongsberg Intelligent Asset Management Customer Centre (Delivered by OSC)

Figure 7: Kongsberg VR bridge (Designed by OSC)

2.3.3 What we can improve in this project and the challenges

Although many remote control centers are now in testing or use for researching purpose, barely of them are simulation-based and has advanced visuals, which could provide next to a real offshore environment in the control center and replicate the real-time status of the vessel at the same time.

As we know from the mentioned projects, and the image and video sources we found from the internet, comparing the fast development of software, which could take in real-time data of vessel sensors and generate the environment in the simulator, the hardware is "hard" to provide the true feeling of operating the same vessel in real-time by sitting in front of some keyboards plus a video wall and just imaging that you are on the bridge.

There are not many suppliers in the world that can deliver full-scale simulators with beautiful visual, industrial standard control unit and software with real physics embedded. Most of the simulators currently on the market are made by flat screens. It is very efficient way of showing a large scale field of view (FOV) as we use in the simulator. Using large size monitors combined by a frame, connect to one or multi-server to receive a video signal, then extend the source video to the monitors. (Varela and Soares 2017)

However, because of the bezel and the size of the monitors, the visual in front of operators is not a continued image but separated into many smaller pieces, which may distract the operator, like always remind you that you are in a simulator instead of providing an immersive experience. Also, the control units are not even close to a vessel operating environment, e.g., the main control room of Yara Birkeland. The only available control unit we can see are keyboards and mouse, plus VHF or phone. Does the SRCC need to have a similar environment as on the vessel? According to DNV-GL rules, the SRCC has the purpose of facilitating remote control and supervision of vessel functions. The objective of the rule is to ensure that the remote control and supervision, in combination with automation systems, will provide a level of safety equivalent or better compared to the functions being conventionally controlled and supervised from onboard the vessel. (DNVGL-CG-0264 2018)

What I would like to achieve for my work in this project is to provide a seamless FOV inside simulation dome, which provides a strong immersive experience for the operator, while having industrial standard control units for all stations and prove the concept of remote control operation. Furthermore, by integrating the advanced simulation software and platform, the site will be not only a center for remote control testing but also an environment for future ship design and system researches like virtual prototypes and digital twins. It has the possibility to be used in many different ways than just a command centre, which will have great value for the maritime industry.

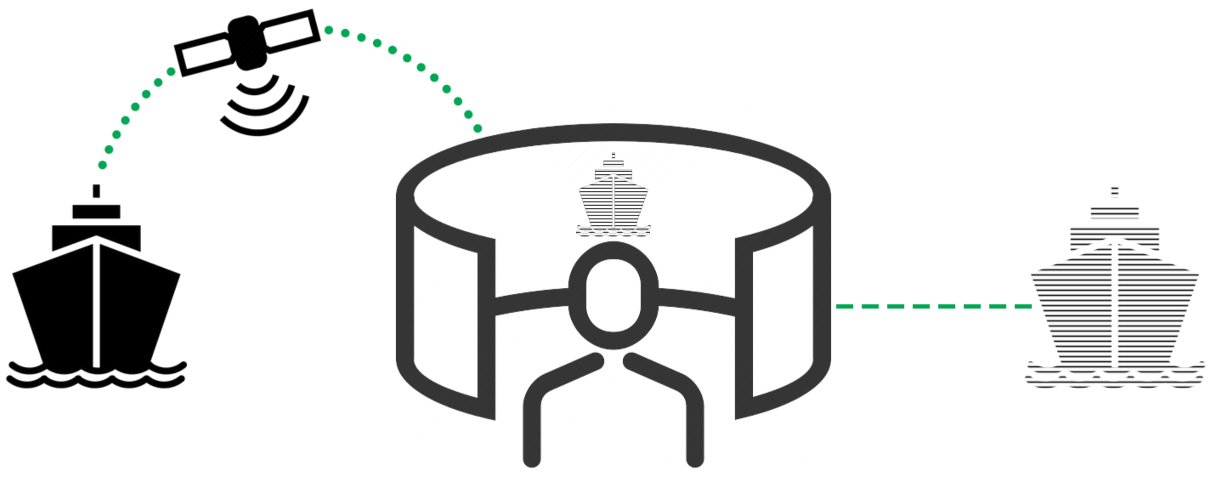


Figure 8: : SRCC: the switch of the real-world and virtual world

The SRCC is a switch between the real-world and the virtual world. In remote control operation, it is a media for onshore operators taking over the operation offshore, but if we take away the signal transitions in the process, the SRCC is a great tool for testing and research of virtual prototypes and digital twins in the simulator. It provides an environment to be used for testing the new concept of ship design, system design, system analysis, and validation of models, even human factor research. That shows the value of the site beyond a remote control centre.

There are also many constraints for achieving these goals, depends on the site condition and the projects' budgets it is not possible to have full-scale bridge duplication in the building. A unique design for the visual system need to be developed, and it needs to provide enough FOV inside the constrain of the building size. Instead of a full-scale station, a multi dome solution will be dedicated to different stations. The dome will be designed as one product family, keep a similar look and feel but fulfill their own purpose. As many elements as possible could be reused to save the cost of production.

And from a sustainable development perspective, once a site been built as an exact duplicate of one station, for example, a vessel bridge, it is very hard to be transformed for other use. So, for the project, since it requires flexibility to the stations, what we really need to achieve in the design is inside the DNV-GL classification rules, use software panel to replace real physics controls as much as possible, and blur the line between different control stations, combine the similar ones, for example, a crane control station and a winch control station. In this way, we could keep the hardware evolving alone with the software all the time, so as a result, we will have an SRCC fulfill for current and future use. (Benedict, et al. 2014)

By implementing an advanced simulation platform, the SRCC could show its value than other normal RCCs.

2.4 The advantage of OSC and purpose of SRCC research

OSC has spent the last 15 years developing some of the world's most advanced simulation solutions for the offshore industry. All OSC solutions are based on one common core software platform. Within this, OSC has spent years developing a virtual world with all parameters based on real-world details, therefore adding content is very fast and behaves with real physics. Basing all core products on the same software platform gives incredible versatility and the opportunity for fast development virtual prototyping. This puts OSC in a unique position of being able to use the same simulators for training and verification of complex, custom operations, as users know that the behavior experienced in the simulator is very close as it will be seen in the real offshore operation.

2.4.1 Features of OSC simulators

2.4.1.1 **Advanced integration of maritime and offshore equipment**

The key competence is to integrate offshore and maritime hardware to simulation to reach a high level of fidelity such that trainee or research subjects (marine officers, marine, and offshore engineers) have a low level of familiarization. This requires careful planning of hardware and integration with software.

2.4.1.2 **Ship hydrodynamics**

OSC software can connect the client application and physics model through the core. Ship hydrodynamics analysis tools like Shipx and physics engine as Agx and Fhsim have already been used in the OSC system. The following Figure 9 made by Pierre Major (Head of Research in OSC) shows OSC Systems Architecture.

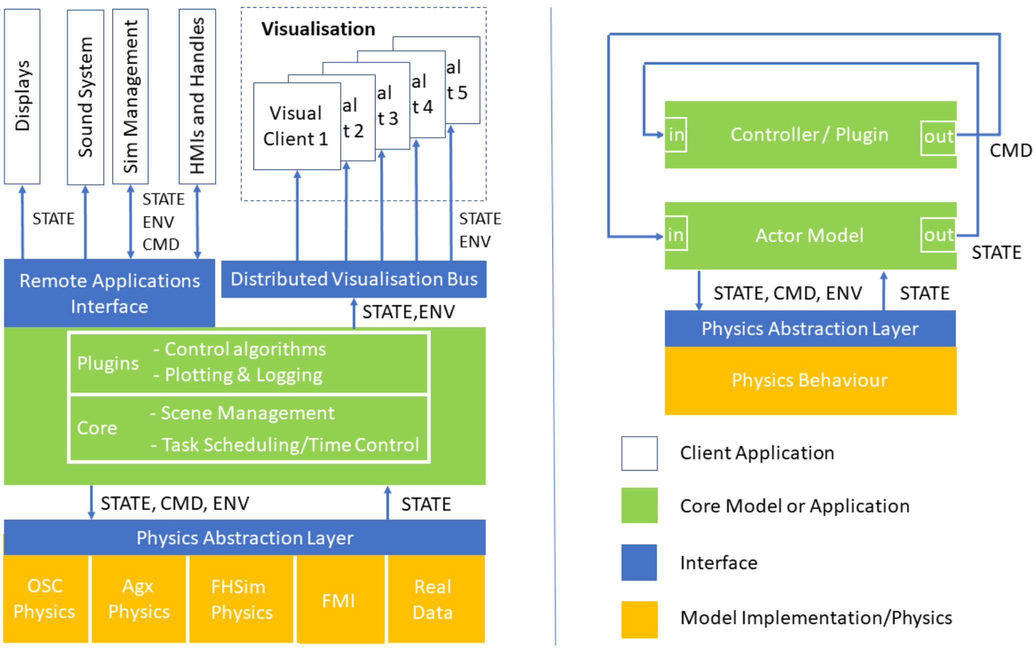


Figure 9: OSC Systems Architecture (Major 2020)

The basic idea behind ShipX (Figure 10) is to make a platform that integrates all kinds of hydrodynamic analysis into an integrated design tool. (www.sintef.no/en/software/shipx/ 2020) One of the functions is the calculation of ship motions and global loads. Based on the hydrodynamic model of the vessel hull and real-time data from vessel sensors, Sandbox could analyze and calculate the vessel's motion in the wave, update the state of the digital twin in the simulator.

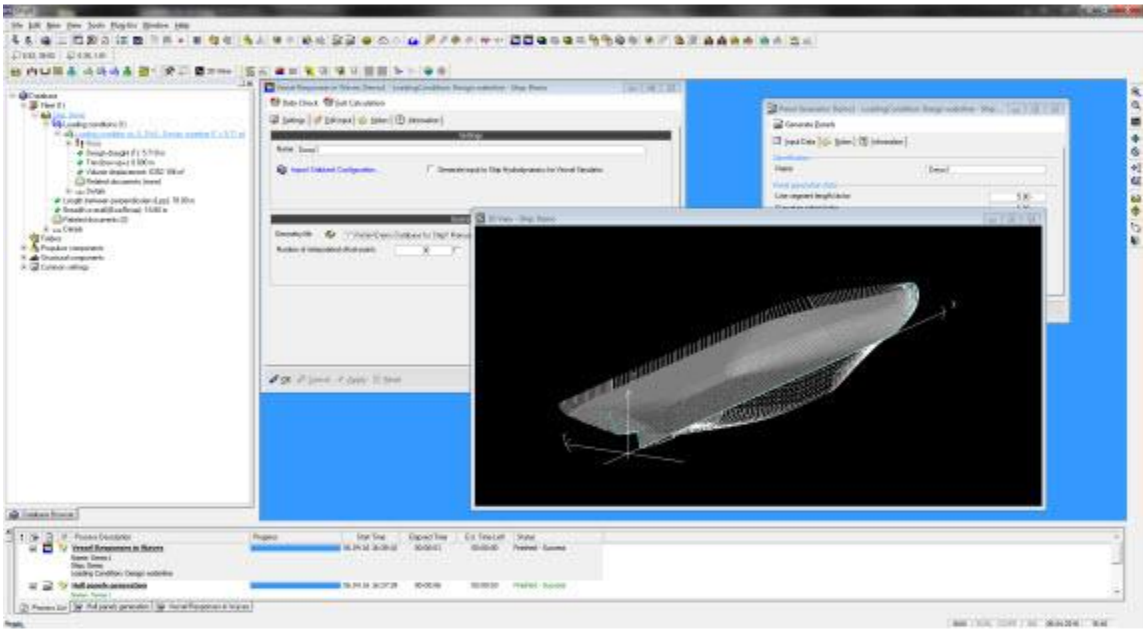


Figure 10: ShipX (www.sintef.no/en/software/shipx/)

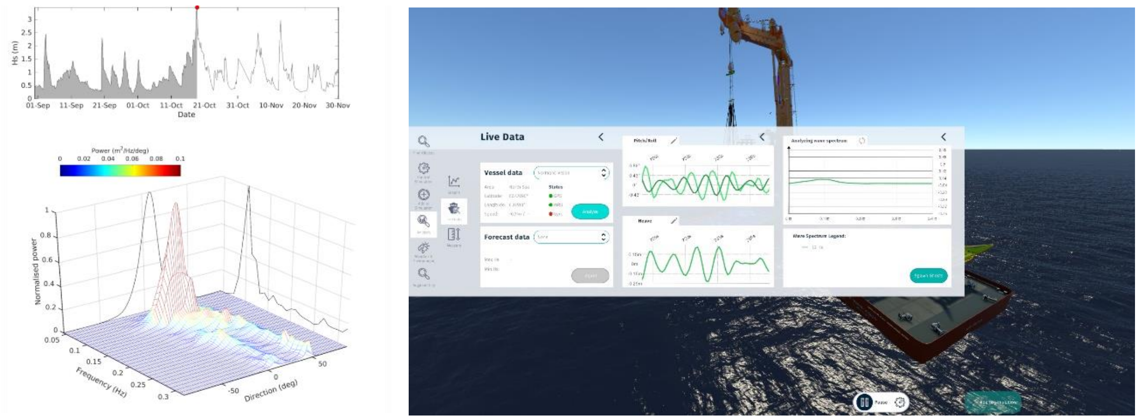


Figure 11: Wave model analysis in OSC Sandbox

In OSC product Sandbox, data gathered from the vessel sensor will be analyzed to research its movement. (Figure 11) The data transferred from the time domain to the frequency domain and gets the current spectrum then generates the wave model in a virtual environment in the software. It is even possible to define different wave spectrum and combine with the weather forecast to get estimate sea state in a future period.

For a general simulation process, Sandbox takes the source files of hydrodynamic analysis of the vessel from ShipX, feeds into FhSim (the physics engine for wave model in Sandbox), and get ready for calculation. The control system from SRCC sends commands to the core of Sandbox through an input/output(IO), then in the physics abstraction layer, FHSim calculates for the wave response of the vessel while Agx and OSC physics calculate the physics responses for the other objects in the scene. After calculation, the status of objects been updated in the core of Sandbox. The core then sends feedback to the visual clients to update the state of the projected image.

By recording the log from simulation, the wave force response and vessel motion could be shown in the report, and it will allow a better comparison between the estimated sea state, calculated ship motions from ShipX and the result files of the virtual sea trial. It shows the value of it being a tool for the research.

2.4.1.3 **Physics and collision**

OSC physics run analysis in real-time, based on the assigned materials' properties of the objects, weight, and COG. This ensures that collisions respond correctly, including friction coefficient between objects.

All permutations of flexible coupling (wire, chain, hose, rope, etc.) resolutions are dynamically altered to ensure optimal simulator performance while maintaining accuracy. In practice, this means that long stretches of anchor chain, for example, have a high segment length as they are not colliding with other objects or being flexed, whereas wire lying on deck has a short segment length to ensure accurate behavior.

Physical parameters, such as waves, wind, current speed, and direction, are set in the simulator to ensure that the behavior is as in reality. Alternatively, for extremely specific simulation, customers can apply their own Functional Mock-up Units (FMUs) for simulated systems such as hydraulics. This has the added benefit of the customer protecting their IP while having an extremely accurate simulation. OSC standard co-simulation time step is 20Hz.

2.4.1.4 **Virtual prototyping**

OSC has created a simulation environment that has most of the real-world factors to be used onshore or offshore and even in solutions with the interaction between surface and subsea/subsurface.

OSC has built up a wide knowledge of simulating environmental forces, such as wind and waves, through over ten years of working with offshore crews accustomed to the most challenging environments on the planet. This knowledge is applied in the environment OSC provides as standard in all simulation.

The instructor station can control and change parameters for wind shielding, atmospheric pressure, geolocation, and time of day and year wave aware, wind waves, water current shielding, lee effect, ocean transparency. (Sellberg and Lundin 2017)

2.4.1.5 **Augmented tools:**

Tools for augmenting simulation, add another dimension to project solutions and training. The ocean can be hidden in real-time simulation, giving a perfect view of the subsea environment and or lifting an object in a subsea lift. The environmental effects (wind, waves, currents, etc.) motions of vessels, movement of lift objects are all still live and calculated real-time, only with full visibility below the water surface.

2.4.1.6 **OSC Sandbox:**

A new tool that enables customers to build complex simulation scenarios by drag and drop 3D models into Sandbox. Simulation for verification can then be run and the risks of a solution, or operation, can be found within minutes.

Examples of functions:

- Insert new load objects
- Placement of load objects and rotation of objects
- Change weight and CoG
- Insert loose objects (shackles, tools, etc.)
- Vessel-/Rig layout (placement and orientation)
- Training scenario creation

2.4.2 The purpose for research of SRCC

In a simulator, people can observe and control remotely vessel while having advanced visuals of the real-time status of the environment. Real physics applies to the vessel's digital twin in the simulator, which could be used for the test and prediction of the future behavior of the real vessel. This is important when the humans are sitting onshore with a limited view of the offshore equipment. Engineers have little understanding of what is happening on-site before they are offshore, and simulators are the key to understanding that. Therefore, it is also the key to making semi-autonomous and autonomous systems.

1	Computer offers no assistance and human must do everything
2	Computer offers a complete set of action alternatives
3	Computer narrows the selection down to a few
4	Computer suggests a solution
5	Computer executes that suggestion if the human approves
6	Computer allows human some time to veto before automatic execution
7	Computer executes automatically, then necessarily informs human
8	Computer informs human after execution if only asked
9	Computer informs human after automatic acts only if it decides to
10	Computer decides everything and acts autonomously, ignoring the human

Figure 12: Levels of autonomous - Sheridan's model (Sheridan 2002, Kari, et al. 2018)

In remote ship operation, an objective is operated from a distant location such that there is no direct human sensory contact to it. According to Sheridan's model, there are ten levels of autonomy advice and help, while at the highest autonomous level, the system decides everything and override and replace human actions and decision making. The focus now will be on the lower level for the development of hardware. Step by step, this could lead us towards semi-autonomy, then full autonomy of a vessel in the future.

The primary purposes of dedicated research in remote control centers are as follows:

2.4.2.1 **Training nautical and naval architecture students**

Over the years, educational research has identified many factors that also seem vital to the growth of competencies and maritime organizational preparation. The work at OSC is based on the belief that relevant and realistic interactive simulation may be regarded as an essential contributor to safe and efficient marine operations as well as to successful improvement and innovation for the offshore community at large. Besides, communication, collaboration, and human interaction play an essential part in any training and simulation of critical operations, as well as in any modern development and innovation effort. (Varela and Soares 2015)

Knowledge, skills acquisition, and the development of appropriate attitudes need to be context-specific, reflecting ordinary context-dependent reference and usage. (Cohen, Brinkman and Neerincx 2015)Therefore, the OSC simulator systems – training environments - shall afford authentic performance.

Significant knowledge development happens in practice, through conscious and deliberate explanation as through the implicit sharing of knowledge and wisdom in the heat of the doing. However, when it comes to the doing, the implicit in this respect is only partially in the students' own doing, and only partially in fellow students' doing. The implicit in the doing that is implicit that might reveal the dynamics of competent performance, must be sought from competent practitioners dealing with authentic activities. In situated learning one is not told of a situation, one is immersed in it, and often exposed to a master who performs his skills and the learner acquire similar skills not only by the verbal comments from the master but by 'stealing moves.' (Murai, et al. 2010)

Therefore, the OSC simulator-based learning environments shall afford the development of knowledge as well as its sharing. The OSC training scenarios and course concepts are designed so that they offer experienced personnel rich opportunities to develop and display competent performance. In other words, they are also designed to offer the experts opportunities to display their expertise as well as become learners themselves by being able to practice and train on very demanding situations under novel conditions.

2.4.2.2 **Understanding how crew think onboard**

The implicit aspects are pivotal for the successful development of professional competence. It is argued that the implicit is not in the telling and writing, nor can it be deduced from telling or writing; it is only in the being and doing. It is in the being in terms of the physical surroundings in which the authentic activities may take place. (Hontvedt and Arnseth 2013)

Therefore, the OSC ship bridges are shaped and equipped as real ship bridges, even to a large extent reconfigurable to afford ship (type) specific training. Deck crews will find substantial resemblance of actual deck arrangements, selectable with equipment representing several suppliers and various technological solutions, with the ability to simulate/perform important tasks related to the operations taking place. Similarly, crane operators can, if requested, even climb into crane cockpit simulators and participate in joint operations or individual training. The virtual worlds of the OSC's systems are designed as rich environments with diverse, detailed, and high-quality visual scenes.

2.4.2.3 **Reduce cost and risks**

In reality, it is costly to book a boat to make human factors experiments considering crew, ship's rent, fuel cost, etc. Instead of that, a simulation center with similar hardware and set up will be an efficient way to do the experiments. A full functional simulation center could be easily set up and be modified to replicate different vessels and simulate environments for testing. (Jensen, et al. 2018)

Comparing time costs for the production of real hardware and a digital twin is also showing an enormous difference. Instead of waiting month or years for a real product to test, a digital twin could be build up within days to test, and even faster to do any modifications.

2.4.2.4 **Engineering proof of concept**

By doing experiments in the simulation center, people can make proof of concept for new control algorithms, new bridge hardware, and test if they can fit or not for the real vessel. (Yang and Feng 2014)

The ability to confirm or refute ideas related to ship and port design makes a simulator runs useful. Not only valuable for theory proof but also essential for further development and planning. Simulator runs can be used to train people, algorithms, and procedures, according to one interviewee. Experiments on simulators are essential to the advancement of the following disciplines. Algorithms can be tested and fitted by simulators. Artificial intelligence algorithms need data set for learning. Datasets show the algorithm on how things work under such conditions. For such algorithms, simulators can provide valuable learning datasets. Furthermore, the performance of the trained algorithm can be brought up in more simulations.

For the hardware, the performance can be verified in simulator experiments, and experienced users could be investigated to evaluate the easiness and user-friendliness of the piece. Simulators provide the place for risk-free ways of evaluating interactions. Gui elements such as controls, graphics, and bridge configuration are subject to simulator testing to determine the effect of the improvements on seafarer topic results. (Zghyer 2019)

2.4.2.5 **Shipowner's office of the future**

The new SRCC will be a showcase of the shipowner’s future office in the marine industry. Instead of having daily emails communication about what has happened, filling excel files every now and then, the shipowner could have a live feed with a co-captain onshore in charge of many vessels at the same time, which saves both cost and time, provides extreme efficiency and will be a revolution in the way which the industry stayed in for decades.

On the human factor side, simulators provide the opportunity to investigate group dynamics and interactions in a maritime operation setting. For research such as ethnicity, cultural differences, knowledge, and age differences, socio-cultural factors could be identified and examined. Simulator experiments also provide the possibility of observing the experts. It is an important data source for designers to learn how do experts use and interact with the machine. (Håvold, et al. 2015)

Simulators are the perfect environments for conducting many scenarios and case studies of all forms of mixed traffic, including autonomous vehicles, remotely controlled vessels, and conventionally regulated commercial shipping, like pleasure boats and fishing boats, when researching the safety and efficiency of individual levels of autonomy. The accumulated digital nautical miles provide the business with experience and knowledge to proceed safely. Simulators can also be the laboratories for testing the GNC algorithms.

2.4.2.6 **Environmental impact**

While having only 0.1% of the world’s population, Norway has a strong position within the marine and maritime industry. This is one of the few areas where Norway might play an important role in mitigating the mounting climate problem. This project has ambitions to contribute significantly towards this, focusing on developing cost-reducing technologies for the marine industry.

The results from AuReCo project may contribute to improving the safety of the personnel involved in the marine operations as well as ensuring that the operations are carried out with a minimum of environmental impact. Also, safe and efficient operations in sensitive environments will be crucial when Norway starts developing advanced maritime production or utilizing new transportation routes. Energy-efficient and environmentally friendly merchant ships, offshore vessels, and maritime operations will be prerequisites in the future.

3 Methods

In order to reproduce the environment of Gunnerus’ bridge, the design guidelines for a real vessel will be used for the simulator equipment and try to achieve as close as possible. However, considering the requirement from NTNU and the development of the simulator in the future, the design will also try to keep generic and flexibility as the main features.

The design flow will follow the overview of the principles of human interface design in **<<Guidance notes on ergonomic design of navigation bridges>>**. (ABS 2018) and class guidelines from DNVGL **<<DNVGL-CG-0264 Autonomous and remotely operated ships>> section 6 remote control centres.** (DNVGL-CG-0264 2018)

The following eight principles are presented in the file:

Principle 1 - Define the roles and responsibilities of bridge personnel

Principle 2 - Design for human limitations, capabilities, and expectations

Principle 3 - Arrange bridge devices, controls and displays to maximize access

Principle 4 - Design displays consistent with task requirements

Principle 5 - Design simple, direct and easy to use inputs and controls

Principle 6 - Design for productive performance and to reduce human error

Principle 7 - Provide job aids and training

Principle 8 - Perform testing.

For the design of a generic simulation solution of the vessel based on research target Gunnerus, principles **3, 4, 5, 6, and 8** will be the main focus.

3.1 Method description

In each step of my design loop, the following methods and software will be used:

1. Analyze
    a. Analysis of target vessel – Guidance notes on the ergonomic design of navigation bridges, Rhinoceros
    b. Site analysis – AutoCAD
2. Design
    a. Build up 3D model for visual system and alternative solutions – Rhinoceros, Even

    b. Build up 3D model for the control system and alternative solutions – Inventor
    c. Test setups in a 3D world which duplicate the site – Rhinoceros, Twinmotion
    d. Provide different solution packages – Twinmotion
3. Test of the SRCC
    a. Test operation in SRCC, prove the concept
    b. Evaluate the reliability and performance
    c. Show the value of SRCC for ship designers, shipmasters, and ship owners

3.1.1 Analyze

3.1.1.1 **Analysis of target vessel**

In this step, an intensive analysis of the 3D model Gunnerus' bridge house will be investigated along with photos and other materials of the vessel. Following the guidance notes, each detail part of the bridge house will be measured and recorded for a later stage when designing the visual and control system of the simulator.

3.1.1.2 **Analysis of site**

In this step, the site will be analyzed from its plan layout. Based on the requirement of NTNU, the site will be divided into different functional areas. An AutoCAD drawing will be provided for on-site renovation and installation work.

3.1.2 Design

3.1.2.1 **Build up 3D model for the visual system**

In this step, two simulation domes will be designed based on my analysis. 3D models will be built in Rhinoceros, and further visual system plan and testing will be processed in Even. The reason for using Rhinoceros is it suit for concept design, provides better performance in generating continuous polygons, and that is critical for testing a curved surface simulator in software. Even is a tool for geometry correction when applying the projection image to the dome, developed mainly by OSC former employee Martijn Kragtwijk, and being constantly improved by OSC engineer Geir Atle Storhaug. By using it, the light intensity could be balanced and adjusted to generate the blending area for a multi-projector solution, then find out the best combination for the product.

3.1.2.2 **Build up 3D model for the control system**

In this step, a control console will be designed based on the previous steps. Following the ergonomic design guidelines, a 3D model will be built in Inventor, and further control systems will be applied, too. The reason for using Inventor here is it suit for industrial production better than Rhinoceros.

3.1.2.3 **Test setups in a 3D world**

After the main hardware design finished, a virtual 3D site will be made, and all equipment will be integrated inside it. Instead of traditional 2D renderings, a virtual 3D world of the site provides a more immersive experience of the final product. 360 degrees view and walk through the site will help the team to decide the final solution.

3.1.2.4 **Provide different solution packages**

In the end, some more solutions, such as the different sizes of dome and console, a variety of control set up, etc. will be provided. It shows more possibilities of the site and will give the team more options to select based on their budget and plan of development.

3.1.3 Test of the SRCC

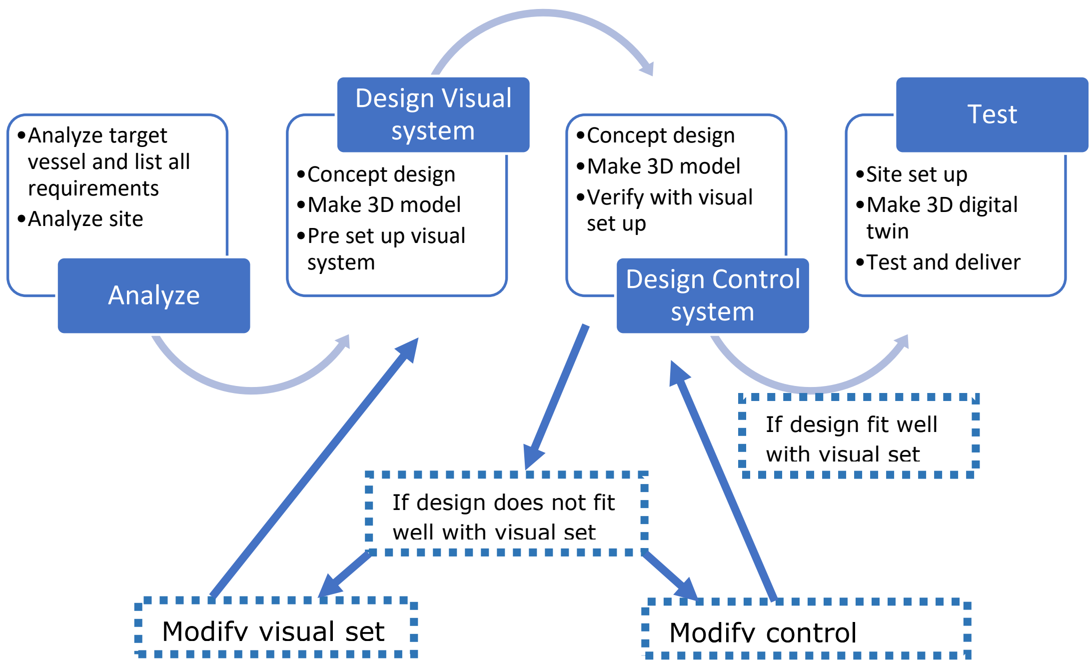
3.1.3.1 **Prove of concept**

Based on real data logs from Gunnerus, a virtual scene will be built to try to reproduce the initial state of operation, and the same operation will be performed in the SRCC. The simulated response of the vessel will be logged to compare with the measured responses log from the real world to evaluate the performance of simulator in SRCC. Then further discuss the concept for applying remote control in the next stage of the project.

3.1.3.2 **The value for the maritime industry**

Examples of test cases will show the value of SRCC for ship designers, shipmasters, and ship owners. What kind of benefits they could get from the SRCC, and how they could use its ability to drive the industry forward.

3.2 Design loop



4 Analyze

An intensive analysis of the vessel bridge will be performed in this chapter in order to clarify the design criteria for the SRCC in the next chapter. It is essential to have a clear mind of what should be achieved, so the design work could be done effectively. Due to the period of research work that does not meet the vessel's schedule in town, most of my analysis will be done based on the 3D model of the vessel, with photos taken on the bridge in advance.

4.1 Target vessel bridge house analysis

This section will analyze the research target Gunnerus, measure the dimension of its 3D model and compare with the photos of real vessel, and specify the dimension of the projection dome, FOV, etc. After the analysis, we will be able to generate a proper visual dome by following the design principles. Figure 13 shows the bridge parts model been separate from the vessel and ready to analyze.

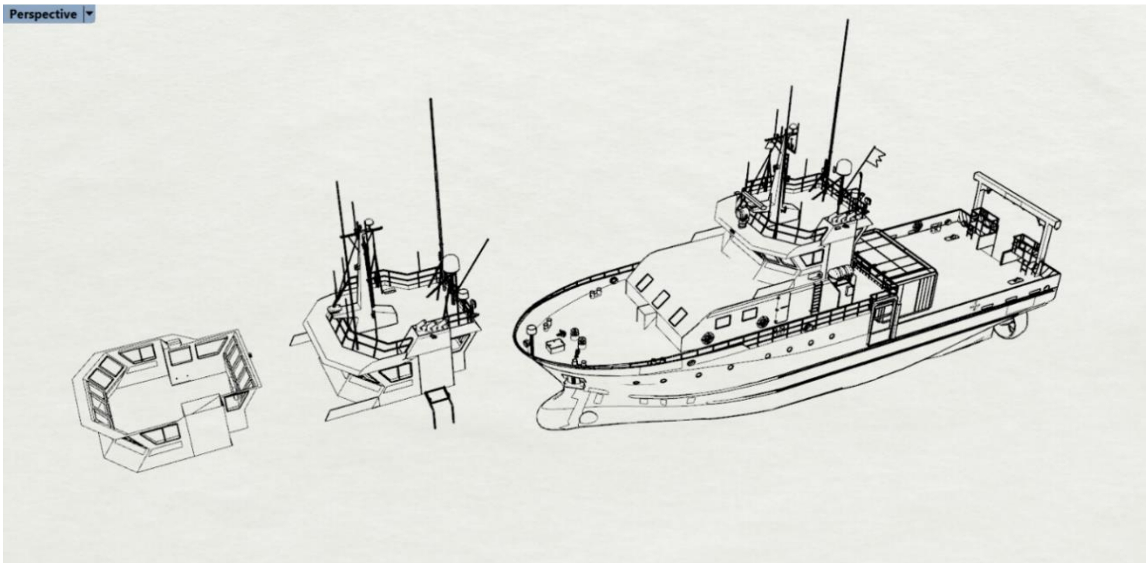


Figure 13: Gunnerus 3D model

4.1.1 Internal Visibility

4.1.1.1 **Height of Lower Edge of Front Windows**

Through the guidelines, the height of the lower edge of the front windows should allow a forward view over the bow, from which a person seated at the workstations can monitor, navigate, and maneuver. The height of the lower edge of front windows above the deck should be kept as low as possible. It should not, as far as practicable, be more than 1000 mm above the deck.

By checking the bridge model, the following dimensions are got

- The lower edge of the separate bottom front window is 0.79m from the deck
- The lower edge of the separate top front window is 1.34m from the deck

4.1.1.2 **Height of Upper Edge of Front Windows**

Through the guidelines, the height of the upper edge of the front windows should allow a forward view of the horizon for a person in a standing position with a standing eye height of 1800 mm at the navigating and maneuvering workstation. The minimum height of the upper edge of the front windows above the deck surface should be 2000 mm. The height of the upper edge of the front windows above the deck should be as high as practicable and at least allow a forward view of the horizon when the bow is 10° below its even keel position. Detail side view in Figure 14.

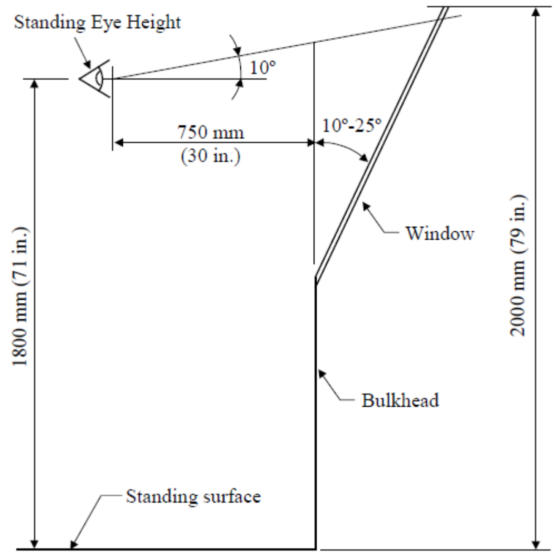


Figure 14: Example of Height of Upper Edge of Front Window concerning Eye Height

By checking the bridge model, the following dimension are got as in Figure 15

- The upper edge of the separate bottom front window is 0.79m from the deck
- The upper edge of the separate top front window is 1.34m from the deck

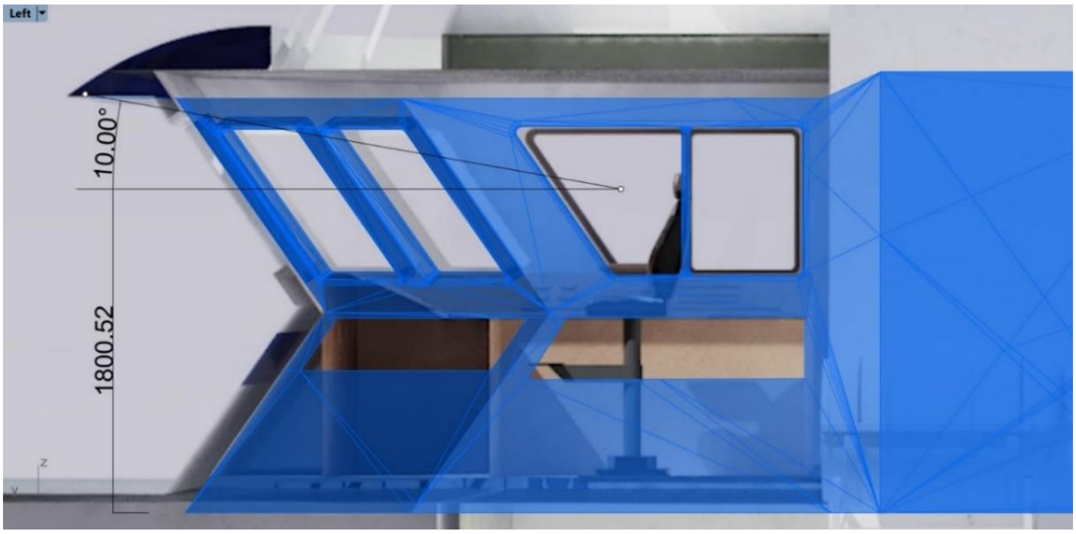


Figure 15: Model dimension in relation to eye height

4.1.1.3 **Window Framing**

Through the guidelines, the divisions/frames between windows should be kept to a minimum. No frames, including the centerline, should be installed immediately forward of any workstation. The frames between front windows should not exceed 150 mm.

By checking the bridge mode and photo taken from the bridge (Figure 16), the following information is got

- No frames in the centerline
- The frame between windows is about 200mm, which is over the guidelines suggested dimension and will be adjusted in the simulator design

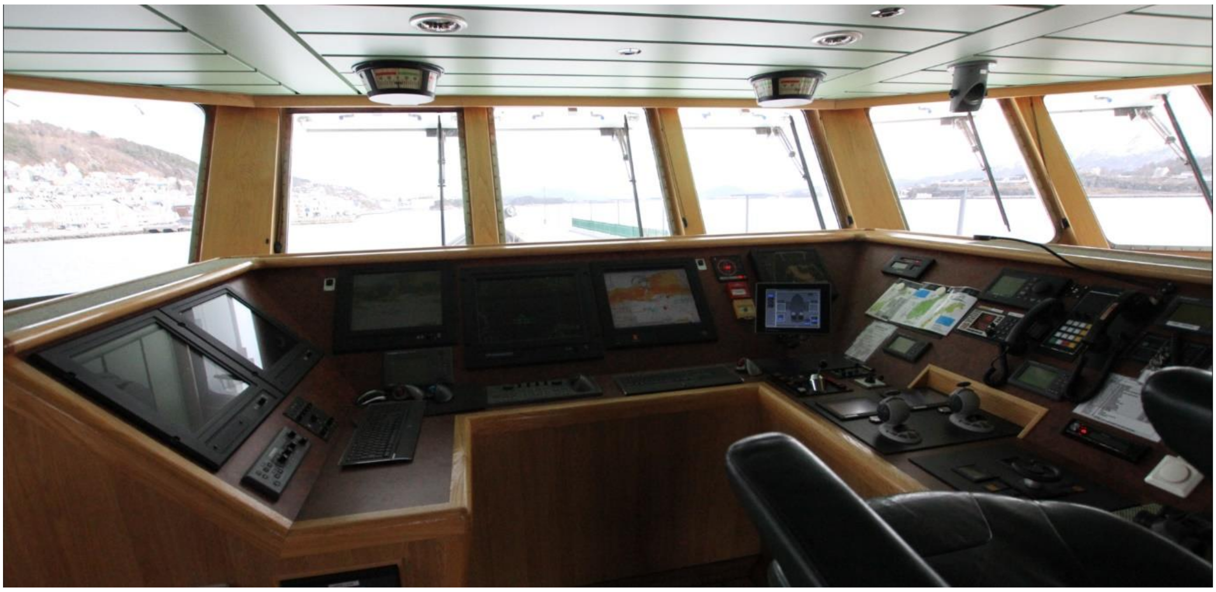


Figure 16: Photo of the frame between front windows

4.1.1.4 **Window Inclination**

Through the guidelines, to help avoid reflections, the bridge front windows should be inclined from the vertical plane, top forward, at an angle of not less than 10° and not more than 25°. The rear and side windows should be inclined from the vertical plane top outboard, at an angle of not less than 10° and not more than 25°. Exceptions can be made for windows in bridge wing doors.

By checking the bridge model, the following dimension are got as in the following figure

- Both forward and rear window's inclination are over the suggested dimension of the guidelines, which is about 35 degrees.

In the design of the simulator, different options will be suggested for the bridge hardware. An improved bridge house design might be included in the package.

4.1.2 External Visibility

4.1.2.1 **View of Sea Surface**

Through the guidelines, the view of the sea surface from the conning position should not be obscured by more than two-vessel lengths or 500 meters, whichever is less, forward of the bow to 10° on either side irrespective of the vessel's draft, trim and deck cargo. See the Figure below. The details side view shows in Figure 17

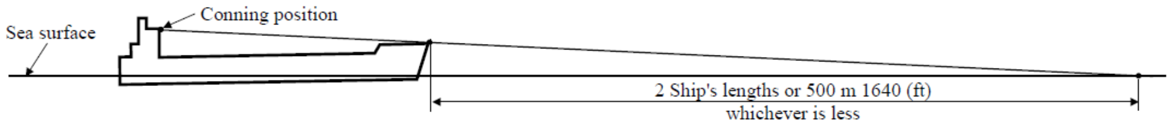


Figure 17: View of Sea Surface

By checking the bridge model, the following dimension are got

- The view of the sea surface at the bridge is from about 28m ahead of the vessel bow

4.1.2.2 **Field of View Around Vessel**

Through the guidelines, it should be possible to observe all objects necessary for navigation, such as ships and lighthouses, in any direction from inside the wheelhouse. There should be a field of view around the vessel of 360° for an observer moving within the wheelhouse. See Figure 18, "Field of View Around Vessel."

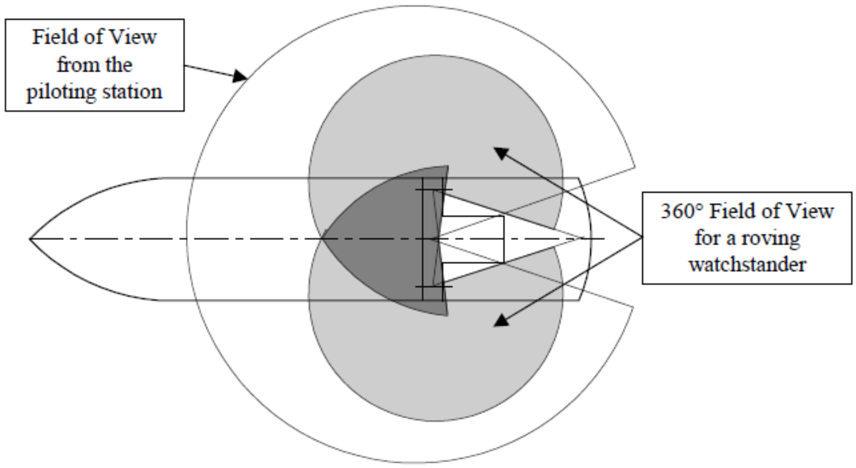


Figure 18: Field of View Around Vessel

By checking the bridge model and photo, it has been verified that the bridge has a 360° view for an observer moving within the wheelhouse. An optimized solution for this in the hardware design process will be tried by taking the site situation in concern.

4.1.2.3 **Navigating and Maneuvering Workstation Field of View**

From the guidelines, at the navigating and maneuvering workstation and the conning position, the navigator's field of view should be sufficient to allow compliance with the International Regulations for Preventing Collisions at Sea Guidelines.

By checking the bridge model and photo, it can be verified that the workstation's position has fulfilled the suggested dimension of the guidelines. This will be tried to achieve in the simulator.

4.1.2.4 **Bridge Wing Field of View**

Through the guidelines, from each bridge wing, the horizontal field of view should extend over an arc of at least 225°, that is, at least 45° on the opposite bow through right ahead and then from right ahead to the right astern through 180° on the same side of the vessel.

By checking the bridge model and photo, it can be verified that the wing field of view has fulfilled the suggested dimension of the guidelines. The site situation and requirements will be considered to archive it.

4.1.2.5 **Main Steering Position Field of View**

Through the guidelines, from the main steering position (i.e., a workstation for manual steering), the horizontal field of view should extend over an arc from direct forward to at least 60° on each side of the vessel.

By checking the bridge model (Figure 19) and photo, it can be verified that the wing field of view has fulfilled the suggested dimension of the guidelines. This will be the main focus during the design loop.

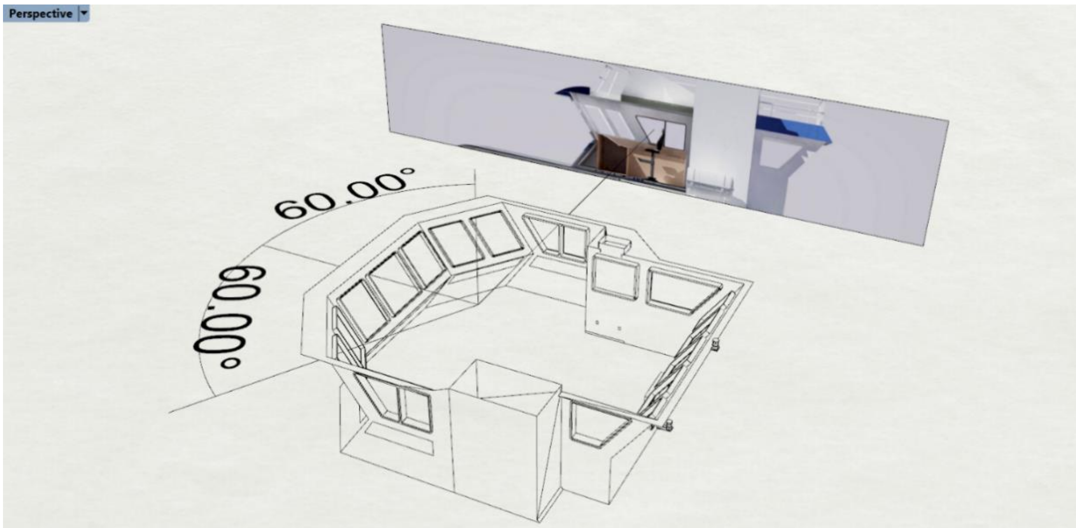


Figure 19: Model showing Main Steering Position Field of View

4.2 Target vessel console and workspace analysis

The objective of this section is to help design functional and efficient bridge components.

4.2.1.1 **Workstation Area Configuration**

Through the guidelines, the workstations designed and placed within an area spacious enough for not less than two crew members, but close enough for the workstations to be operated by one person.

4.2.1.2 **Single Watchstander Console**

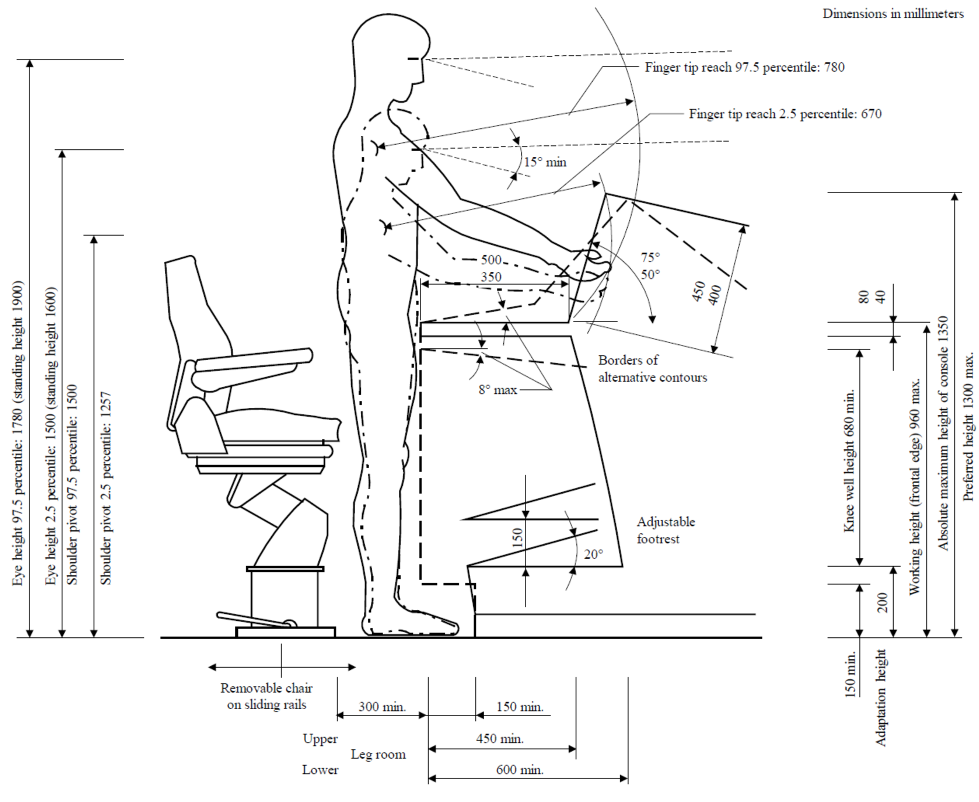
The console should be designed so that from the normal working position, the navigator can use all instruments and controls necessary for navigating and maneuvering. The width of consoles designed for single-person operation should not exceed 1600 mm.

The console on the Gunnerus bridge is for one operator. (Figure 20) The console will be designed based on this but also take consider of multi-operator option.

Figure 20: Photo of the console on Gunnerus bridge

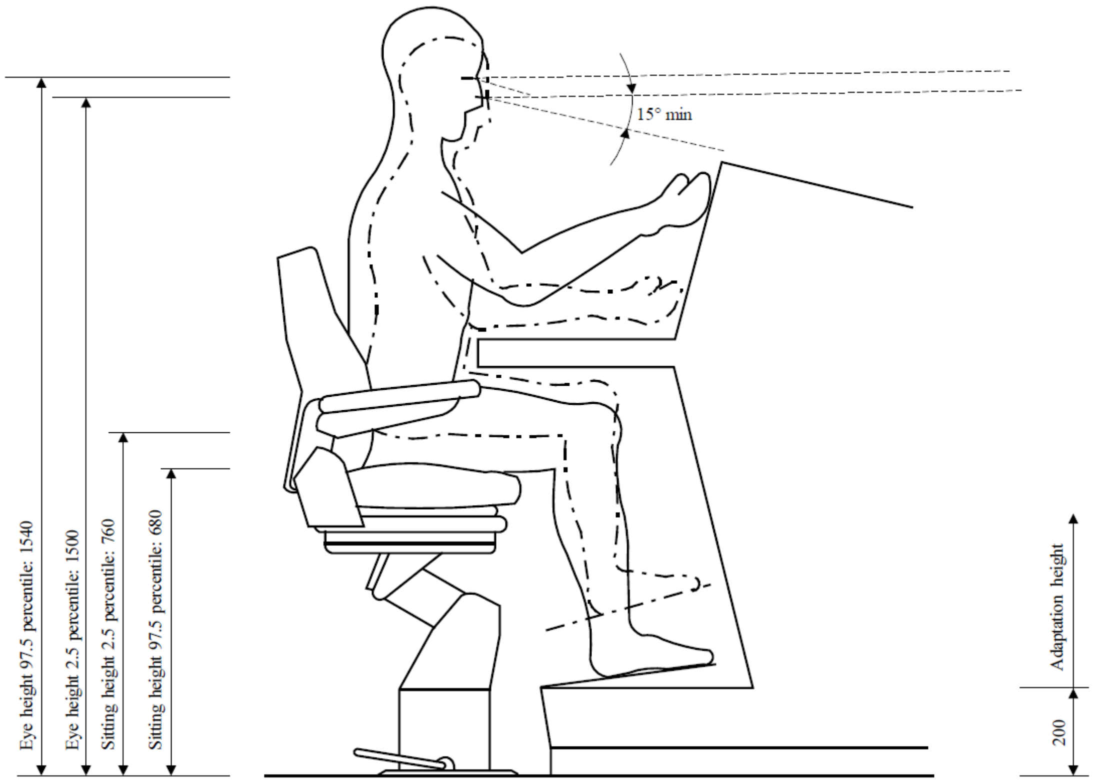
4.2.1.3 **Design of Consoles for both Seated and Standing Operation**

Through the guidelines, we know that the configuration and dimensions of consoles should be able to be used by crewmembers in both standing and sitting positions. The console profile meets the anthropometric value of the 97.5 percentile (male) and the 2.5 percentile (female) of bridge personnel. (Data in Figure 21 and Figure 22 are based on Northern European and North American anthropometrics). The console design will follow these criteria.



Note: The intention of this figure is only to demonstrate solutions based on ergonomic principles.

Figure 21: Console Configuration and Dimensions for Standing Positions



Notes:

1 The intention of this figure is only to demonstrate solutions based on ergonomic principles.

2 Preferred knee well width for sitting position is 600 mm, minimum 500 mm.

3 The height measurements of consoles for only a sitting position shall be reduced by the adaptation height of 200 mm.

Figure 22: Console Configuration and Dimensions for Sitting Positions

4.2.1.4 **Console Left-to-Right Viewing Angle**

The console should be designed so that from the normal working position, the total required left-to-right viewing angle should not exceed 190°. This angle should be reduced whenever possible through an appropriate control-display layout.

4.2.1.5 **Console Height**

The top of the consoles should not exceed a height of 1200 mm.

4.2.1.6 **Console Leg Room**

The upper legroom of the console should have a minimum of 450 mm in depth and the lower leg room a minimum of 600 mm in depth.

4.2.1.7 **Chair Design**

Chairs at workstations designed for a sitting position should be capable of rotating with the footrest being arrested, adjustable in height, and capable of being arrested on the floor. Chairs should be capable of being moved out of the operating area.

4.3 Analysis of the site

The site has been analyzed by checking AutoCAD drawings of structure layout, electrical diagram and ventilation system, etc. Measurements have also been taken at the site to verify digital drawings. It is important to have a full understanding of the site before people start to make the design and layout of the SRCC, so that the work could be applied in the frame of the limitations and people could try to solve the problems that may meet during the process of developing the site. It will reduce the possible errors in the design work and keep the loop in the estimated schedule.

5 Design

From the project background and my analysis above, the design objectives and criteria of the SRCC has been cleared. The SRCC for onboard support of autonomous ships if the very first stage and foundation of the AuReCo project. The SRCC needs to include all work stations on a ship in order to be able to research different targets/stations in normal offshore operation: vessel, crane, winch, etc. Comparing to the functions being conventionally controlled and supervised from onboard the vessel, the SRCC should provide a level of safety equivalent or better.

To achieve these goals, the design of SRCC will be divided into mainly two parts from the system perspective: the visual system and the control system, then wrap all the hardware into a site arrangement that could fulfill the needs and meet the classifications.

For the design of the visual system, the objective is to develop a space where the operator could gain a seamless, immersive experience like in the real world. It should provide similar FOV as in the stations, isolated environment to the surroundings of SRCC, and has a real-time visual response to the operations.

For the design of the control system, the objective is to meet the high-quality industrial standard for the operator to use while keeping the flexibility for multi stations' tasks and the possibility of upgrading alone with the software in the future development. The design process will be further divided into a control system of navigation bridge and control system of generic stations on a vessel, to meet different control stations' requirement.

For the final arrangement of the site, it is essential that it fulfills the needs of the SRCC with remote control, information report, state analysis, decision making, case study, model test, and research - for ship design and research purpose in the simulator.

After design finished, a test of the SRCC will be carried out in the next chapter to show how the SRCC could be used to fulfill the needs of ship owners, research teams, and verify the reliability and performance of it.

5.1 Visual system design

Base on the analysis in the previous section, the following design objectives for the visual system of the simulators has been got.

- Vertical FOV:

  About 50 degrees FOV in a vertical line – 10 degrees to the upper edge and 40 degrees to the lower edge.

- Horizontal FOV:

  Minimum 120 degrees, ideally more than 180 degrees if possible.
- Navigation bridge:

  An individual simulator for the vessel, including bridge console and chair
- Generic operation station

  A multi-functions simulator for two operators, based on projects, this simulator could work as rig crane, vessel crane, bridge, ROV, etc. to fulfill the operation requirement.
- Visualization command station

  A debriefing area with the video system, collecting and visualizing data from operating stations, and the environment like weather and ocean status.
- Product family design for all required domes, to keep same look and feel, saving production cost at the same time.

5.1.1 Size and shape

5.1.1.1 **Navigation bridge**

Based on the available area from previous analysis, a 4m diameter dome fits well for the navigation bridge, where the operator could gain at least a 2m distance to the projection screen from the center of the dome.

From site analysis, the height of the room has been got, which is2.7m from the finished floor to fall down ceiling. We tried to push the limit as much as possible to gain more projection area and full use of the room. However, it also needs to consider components at fall down ceiling that must take in space at the edge or inside the dome, for example, cooling unit, fire sprinkler, CCTV camera, etc. Also, during the construction stage, when the team cooperates with the dome installation with other site work that already in process, it is important to implement the assembling of the dome within the limit of available working space. So in principle, leaving a 4-5cm gap at the top will give enough tolerance for a nice result.

A double skinned dome could nicely isolate the operating environment from outside of the dome for light and soundproof. It solved the structure issue by using only a single skinned dome to provide a much stable result for self floor standing feature and keep the curved shape as a solid projection surface over time. Besides the structure advantage, the double skinned dome also provides a nice finished looking for a futuristic high tech simulator. General dimensions are as in Figure 23.

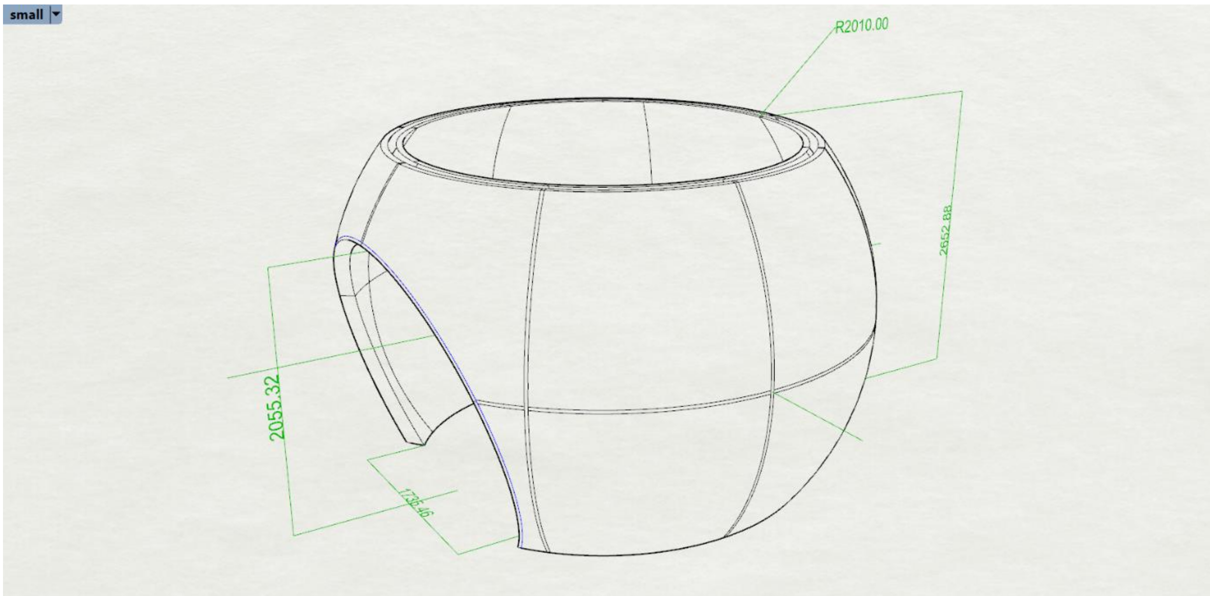


Figure 23: Sketch of navigation bridge dome

5.1.1.2 **Generic operation station**

Since the 4m double skinned floor standing dome has been chosen for generic stations, the design should try to use the same size and look for the operator station to keep them as a product family for the SRCC. (Figure 24) Also, reuse as many pieces of the element as possible will save the mod cost in fiberglass production, which is the main part of the total cost.

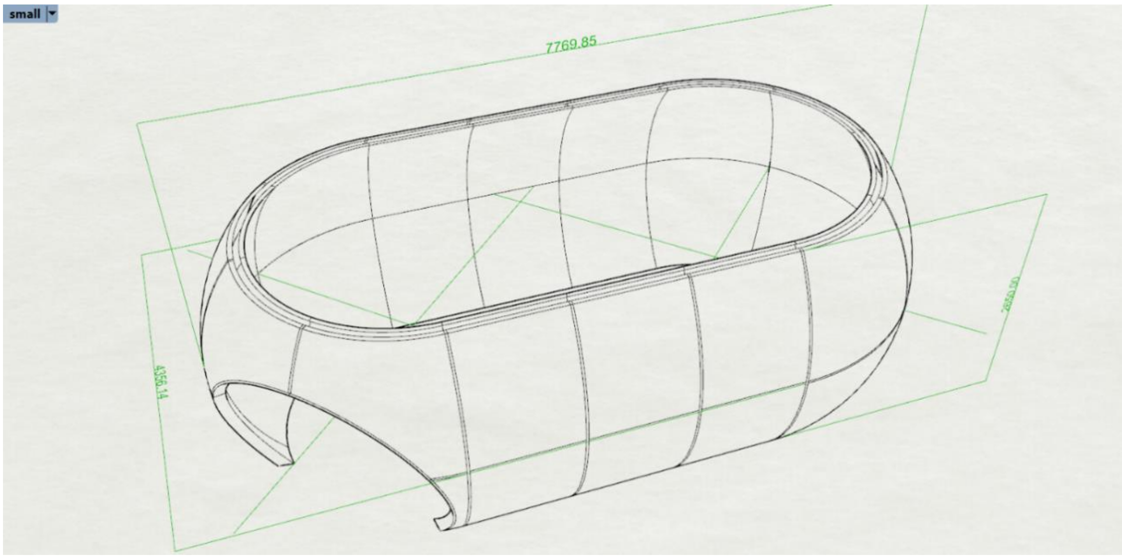


Figure 24: Sketch of the generic operation station dome

By using a stretch shape of the 4m dome, two visual zones (Figure 25) on each end(red and blue) and a flat blended zone(pink) in the middle part could be gained, which could provide either one complete visual(red+pink+blue) for cooperating operations or two separated visuals(red+1/2pink, 1/2pink+blue) for multi-station control.

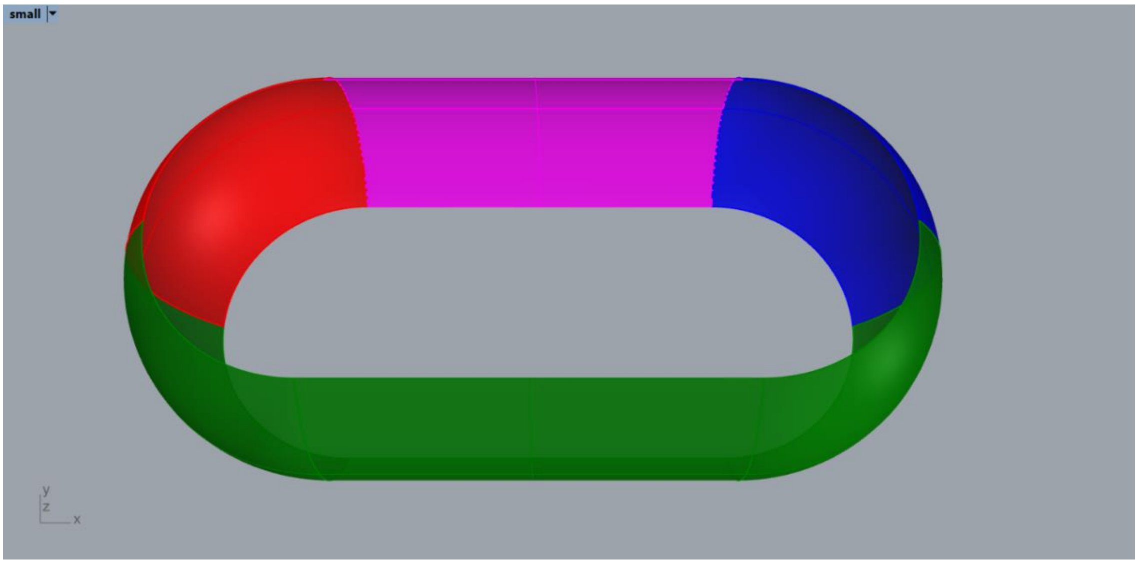


Figure 25: Visual zones for stations, pink area represents the blended zone in the middle

Similarly, to the navigation bridge dome, the height of the generic operation station dome will be set at the same level. Considering the projection equipment that might be used inside of the dome, the actual control equipment might be limited due to the space requirement of safety. That will need to be tested in the later stage of the design to find an optimized solution.

The door for the generic operation station dome has been set to one side of the dome instead of the middle backside due to the following considerations:

1. To create a more isolated environment in the dome
2. Avoid sound echo
3. Use the same design of fiberglass panel to the product family and reduce the production cost

5.1.2 Projection screen

From the previous analysis, the required FOV that the design should try to achieve in the dome has been cleared. The following are verification of FOV in the current design.

5.1.2.1 **Navigation bridge dome**

The operator eye position at 1.6m has been set to replicate as in the actual vessel and slightly above dome equator to get the best visual experience. Compare to required 50 degrees FOV in the vertical direction to the front, and the design now have over 90 degrees projection field, which could provide much more visual content in simulation.

In the horizontal FOV, the plan is to give as much projection area as possible. Compare to required 120 degrees, it can easily gain 180 degrees now in the current design and might be able to get even more in the final set up. The projection area also affected by equipment inside the dome, e.g., console and chair. The equipment may block the projection image and create shadows on the screen. The design will try to find the best solution in the later stage of the design loop, but so far, the current design has fulfilled the requirement for FOV for navigation bridge dome.

5.1.2.2 **Generic operation station dome**

The operator eye position has been set at the same level as the navigation bridge dome, and the vertical front FOV is the same as the navigation bridge dome.

In the horizontal FOV, due to the door set up at one side, it will not be possible for the near door operator to reach a FOV over 180 degrees, but still, it fulfilled the requirement of 120 degrees for each operator and provided more than that.

5.1.3 Projector pre set up

In this section, a preset up for the projectors will be made in order to have a forecheck on the projection screen and have a proximate position of the projectors in mind before the design work moves forward to the control system design, so it could take that in the count during the next step and avoid possible conflict to smooth the design loop. OSC senior engineer Geir Atle Storhaug mainly processes this part of work based on my suggested projector position.

5.1.3.1 **Projector selection**

Barco F22 is the most used FHD projector among all of OSC simulators. Other types of projectors also been used, for example, Epson or BenQ laser projectors. Compare to laser projectors, Barco used a light bulb, which is a disadvantage for a lifetime. However, on the other hand, the size is the only ¼ of Epson laser projectors, which is perfect for a small size dome, like in this project, and since both domes are floor standing, it will be easy for maintenance work like changing of the light bulb, etc.

5.1.3.2 **Navigation bridge dome projector pre set up**

Based on the designed operator eye position. Different projector set up has been tried for the best visual quality, which could fit for various console/chair control system set up. The following images are showing one of the options.

From Figure 26, people can see that more than 180 degrees of FOV have been gained in the horizontal direction, which will create a nice surround visual environment for the user. Besides, each projection image has enough blend zone in between, so it can have nice blending to combine them into one complete visual image.

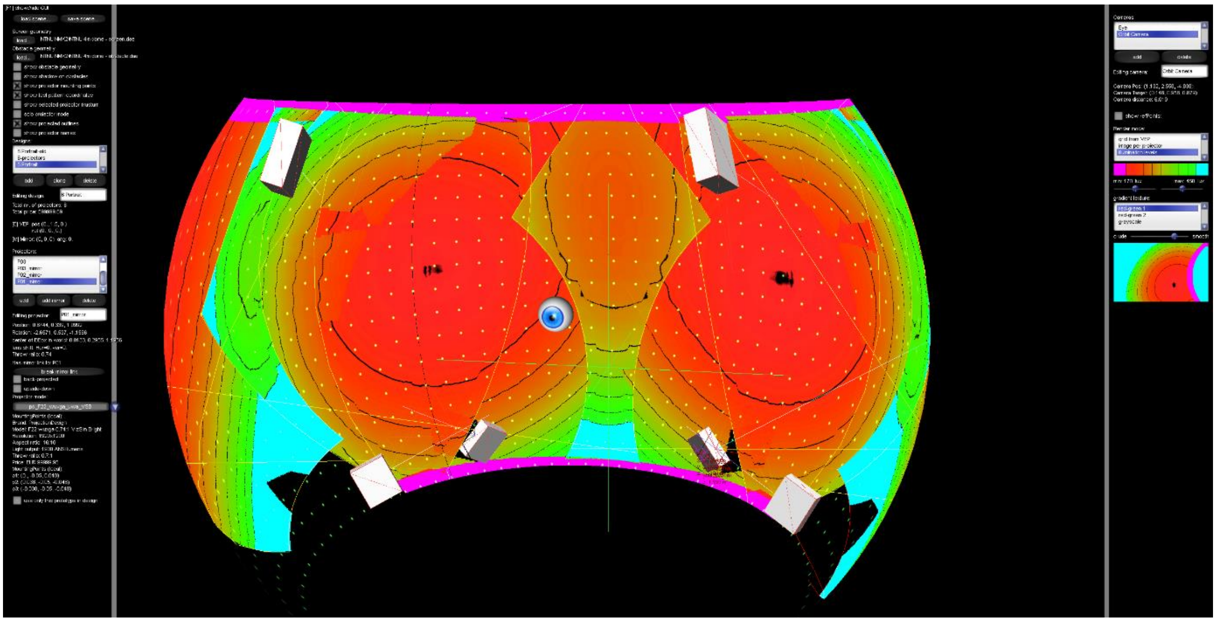


Figure 26: Balanced light intensity of the projectors

Depends on the projectors' position and angle, the projected images on the dome is varying in shape and distance. The nearer light ray shoot to the projection screen, the brighter it will be. The light intensity needs to be balanced by adjusting each projector to create an even brightness image.

To combine the images from different projectors, a geometry correction on each projector needs to be applied. By checking the grid from VEP (Virtual eyepoint), people can have a preview of the final combined image form operator's position and adjust the visual for the user.

5.1.3.3 Generic operation station dome projector pre set up

For the operation station, the design tried to have much area covered as possible to create a similar feeling as the navigation bridge dome. The following are some images for one set up.

From Figure 27, people could see that at the inside end of the dome, the horizontal FOV is over 180 degrees.

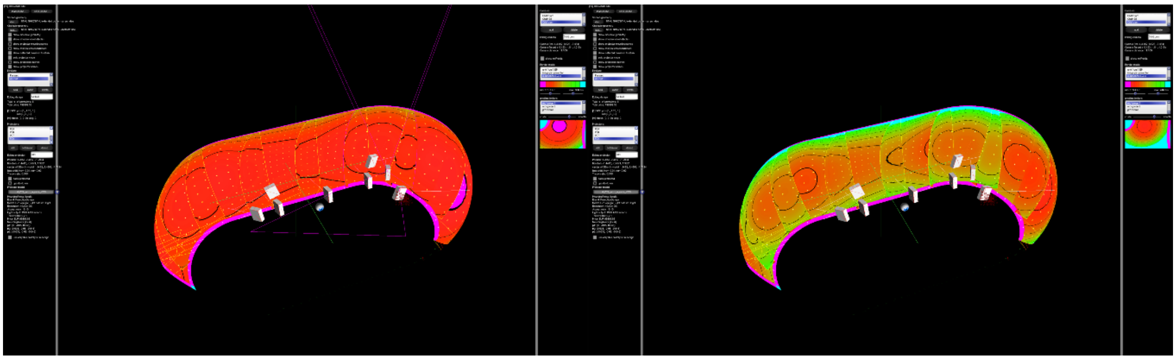


Figure 27: Balanced low and high light intensity of the projectors

For the light intensity, since this is an operation station dome, two pre setups has been made: an even brightness with low intensity and a brighter set up with less even result(Figure 27). Depending on the status of the dome, it could use differently preset for the simulation to get the best result.

5.2 Control system design(console, controllers, chair)

For the control system, Different setups will be designed for both domes and provide different possibilities of function for each dome. The setups will be tested in the 3D package and for the team to choose from. Real and up to date hardware is required to be installed in the control system for delivering the expected experience of realism.

5.2.1 Navigation bridge dome control system

For the navigation bridge, a 4m dome cut down shape has been designed, which provides about 7.18m^2 floor area at a radius of 1.5m.

5.2.1.1 **Operation chair**

Due to space limitations, it is hard to implement a full-size navigation console as in the original vessel bridge. Instead, an operator chair with an elevated base will provide enough function. For controlling the vessel, it needs a controller for thrusters and monitor of radar, ECDIS, conning, etc.

The basic concept is to develop a new design of the armrest for the Recaro seat, which could be used for navigation bridge, crane simulator, and forklift simulator, etc. The finished design should be a modular product and be friendly for both user and maintenance/update.

Design requirements

- Vessel control arms with azimuth handle, to support different vessels - research vessels as Gunnerus or PSV vessels as Olympic Challenger
- Crane control arms
- Wheel and pedals or vessel control console box
- Easy to switch between different simulators for the user
- Easy to maintenance for the service engineers
- Potential to update/transform to other simulators
- Nice looking but affordable to produce

5.2.1.2 **Design process**

Based on the concept model, a first draft model has been made in AutoDesk Inventor and shaped with a bent aluminum plate as the main structure. All control unit has been implemented into one area, instead of having multiple components on the armrest, this way now will provide a more simplified way of using for both the operator and service work.

As the chair will be used not only for the vessel but also for crane, ROV, and many other demanding simulators, fitting in as many controllers as possible is the biggest challenge. Through research, that Rig crane has been found may contain the most controllers on the operator chair in all types of simulators. If the design can fit in all controllers for Rig crane, then it can quickly solve the others.

Based on the draft version, a prototype has been built to spot the potential issues during the production stage. Some issues have been found and gave important information to make improvements. That is an excellent experience learned from practice for designers. By collecting all feedback from different teams, the 3D model was modified, then the final design drawings were released and ready for production. A lot of the parts have been updated in the new version of the drawing. A lot simplified for production and assembly work. The new version of armrest now avoids most of the issues it had earlier and is more user friendly for both the operator and service work. By using a key to unlock the push-lock on side panels, people can fast and easily reach the inside part and make necessary modifications. A test build(Figure 28) in Inventor proved the final design and provided instruction for assemble work in production, which saved both times, work, and cost for NTNU.

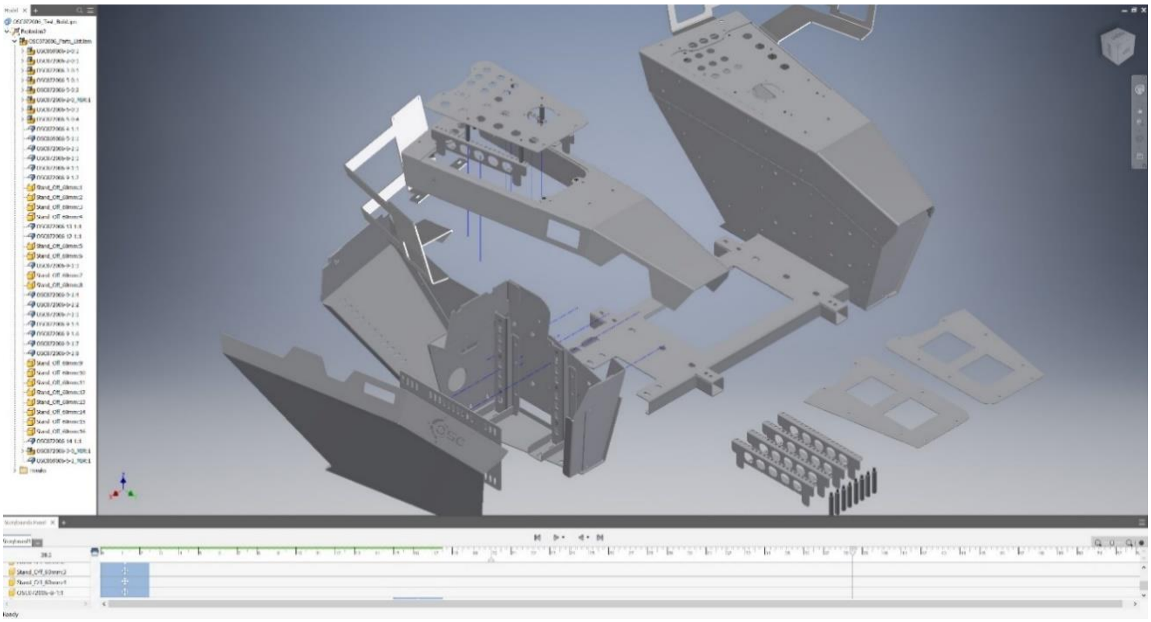


Figure 28: Test build up in Autodesk Inventor

5.2.1.3 **Elevation base**

What it needed here is a base to attach underneath the operation chair and let the operator sitting at the designed eye height in the dome to achieve the FOV requirement. Compare to the chair design, and a base is just an elevation unit without too many technical requirements. It is essential to lower the center of gravity, keep it solid and stable even with the operator standing on the footrest to meet the safety classifications. Beyond that is to keep the same style of the hardware in the SRCC.

The base is built by three layers of pallets. Heavy and solid while being flexible to move in and out. A step component attached to the main body, which could be moved away in transition. Cable port has been placed on the front side for easy plug and connects to the chair. The final layout of the vessel dome shows as in Figure 29.

Figure 29: Finished operator chair in navigation bridge dome

5.2.1.4 **Navigation bridge dome console**

Based on the space in dome, it is not possible to implement a full-size navigation console as in the original vessel bridge. Instead, it will use a compact bridge console for this simulator. (Figure 30)

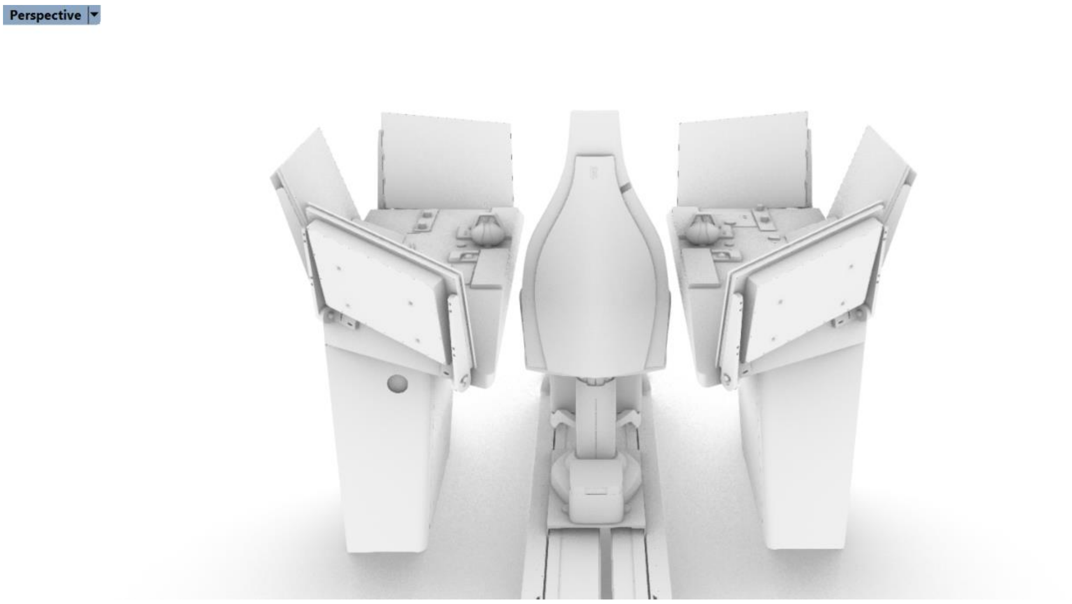


Figure 30: Compact bridge console

The console provides enough monitors and controllers for navigation. One other advantage of using this console is that it created blind spots behind the console body from the operator position, which will benefit us when placing the projectors.

However, the disadvantage of using this bridge console is that it been made specifically for a vessel control purpose and hard to be modified for this dome to be used as another simulator.

5.2.2 Generic operation station dome control system

5.2.2.1 **Operator chairs**

Based on the pre projector setups, it has been found that using the same set of chair and base as in the navigation bridge dome here will be a problem. The projectors are placed right over the operators' sitting position. So if the elevate the control system to about 0.5m from the floor, then the space overhead will be very limited and cannot fulfill the requirement for safety.

As an alternative, the operator chairs could be placed directly on the floor. (Figure 31) Since this dome will be used as operation stations, a more generic solution will certainly fit better for it.

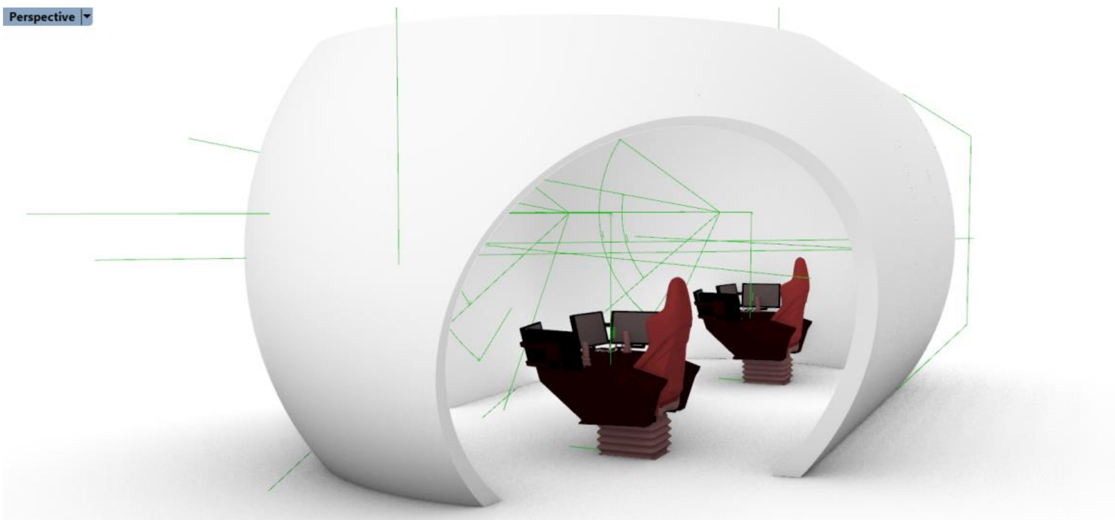


Figure 31: Generic operation station dome chairs

5.2.2.2 **Generic operation station dome console**

As people can see in the previous set up, the actual observation position of the operator is a bit lower than designed due to the reason of the projector set up. The design could not elevate the chair for 0.5m because that will leave not enough room above. But it could be solved by using a console for standing operations on the floor to gain a better eye height in the dome.

Following the guidelines of the console design, a list of requirements has been made and then a draft version for the console has been designed in AutoCAD following ergonomic rules. Drawings for more detail in size and layout showing in Figure 32.

Requirements:

- The console is made for Fore bridge operators, two or three operators will be sitting in the console.
- A separate top plate with cut out will be needed for controllers

- In the center console, server PC will be put in, and will need a removable plate on the left side. In the front and backside, need some slots for cooling purposes.
- 7 x 22” touch monitors will be embedded into the console top part.
- USB ports needed on the console to easily connect extra controllers and transform into different types of simulators.
- The consoles should keep a simple but nice-looking form.

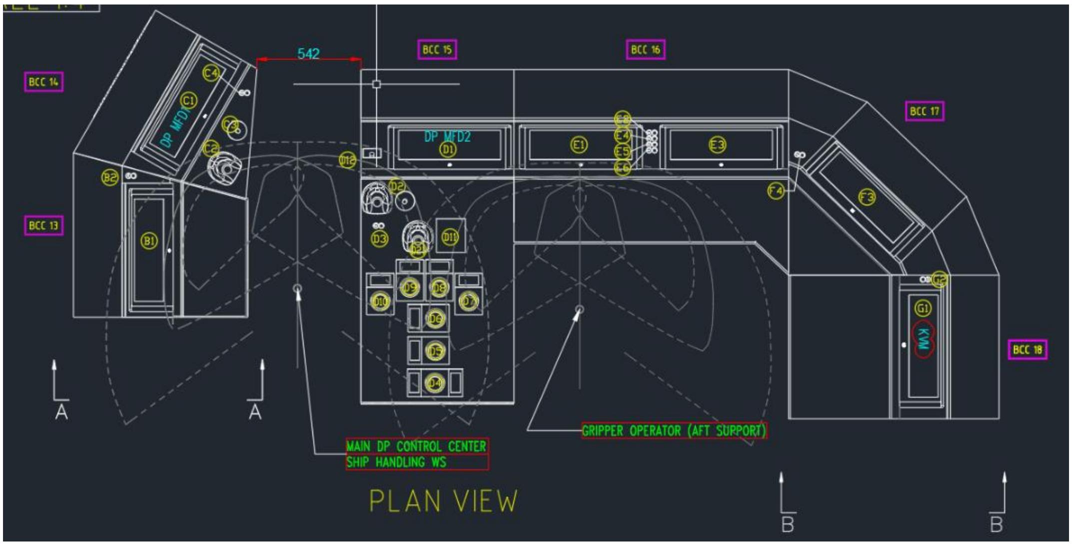


Figure 32: Console concept top view with operator reach range

5.2.2.3 **Design process**

The first draft of the console group was made simply in Rhino to verify the space and size for possibility. Further, develop the idea of console parts as a modular product. The model has been checked with the designed eye position at 1.6m. It fulfills the requirements of the guidelines and provides enough FOV for operations.

Some 3D renders (Figure 33) have been made to visualize the setup better.

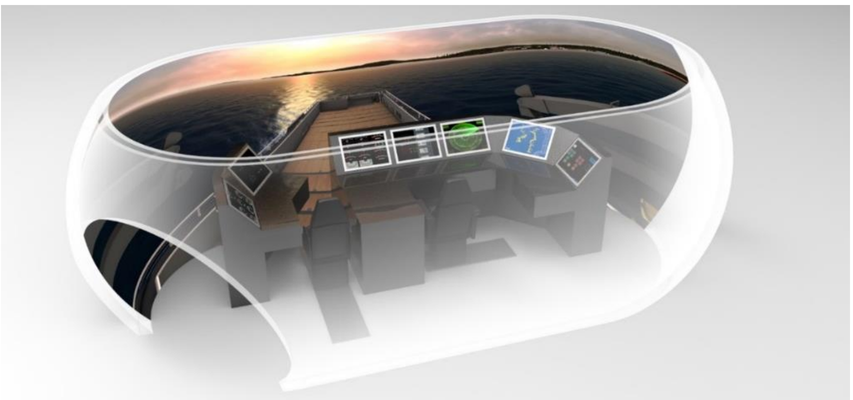
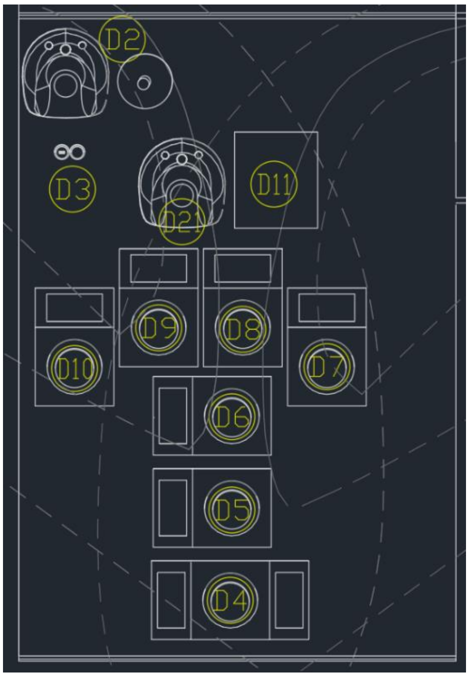


Figure 33: Concept 3D render

In a further development of the design, a modular console unit has been made in Inventor. All parts have been designed with industrial production requirements.

A controller layout (Figure 34) on the console has been made following the rules of ergonomic design for general use for the vessel. In the simulator, the software could choose to use different numbers of the controller for different vessels. Besides. This panel could be easily changed by switching a different top plate with another set of controllers and connect to the server. All control units have been placed following the rules and within the comfort reach range of the operators.



D2: DP heading knob

D3: KVM USB and OSD PB

D4: BT control lever

D5: RT FWD control lever

D6: RT AFT control lever

D7: ST PS out control lever

D8: ST PS mid control lever

D9: ST SB mid control lever

D10: ST SB out control lever

D11: Control transfer station

D21: Conning trackball

Figure 34: Center console controller layout

Due to the design of the switch plate on the top of the center console, the controller group is able to be changed and reorganized easily. That is an important feature for the upgrading of equipment in the future. After the layout of the controllers been decided, the final version of the console group can now be made with many more details in Autodesk Inventor. (Figure 35)

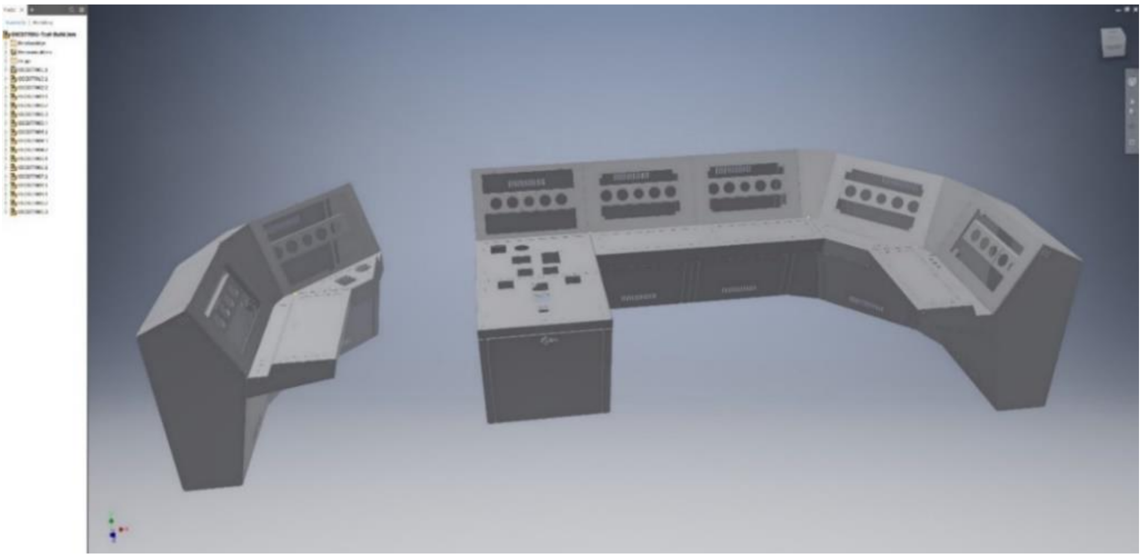


Figure 35: Test build in Inventor

5.3 The final visual system set up

With all control hardware design work complete, different setups could be implemented into the pre-setup of projector plans and verify the solution. If things do not go well with the pre-setup, then either modify the projectors' position or go back to the control unit and change the design will be needed. This part of verification work was also proceeded by OSC senior Engineer Geir Atle Storhaug to check the design result.

Since the work process was trying to make the design of the control unit within the frame of the pre-setup visual system, it is less likely that they need to be changed in the design here. The experience from other projects shows some modifications of the projectors' position will solve most of the issues that will be found in the implemented product.

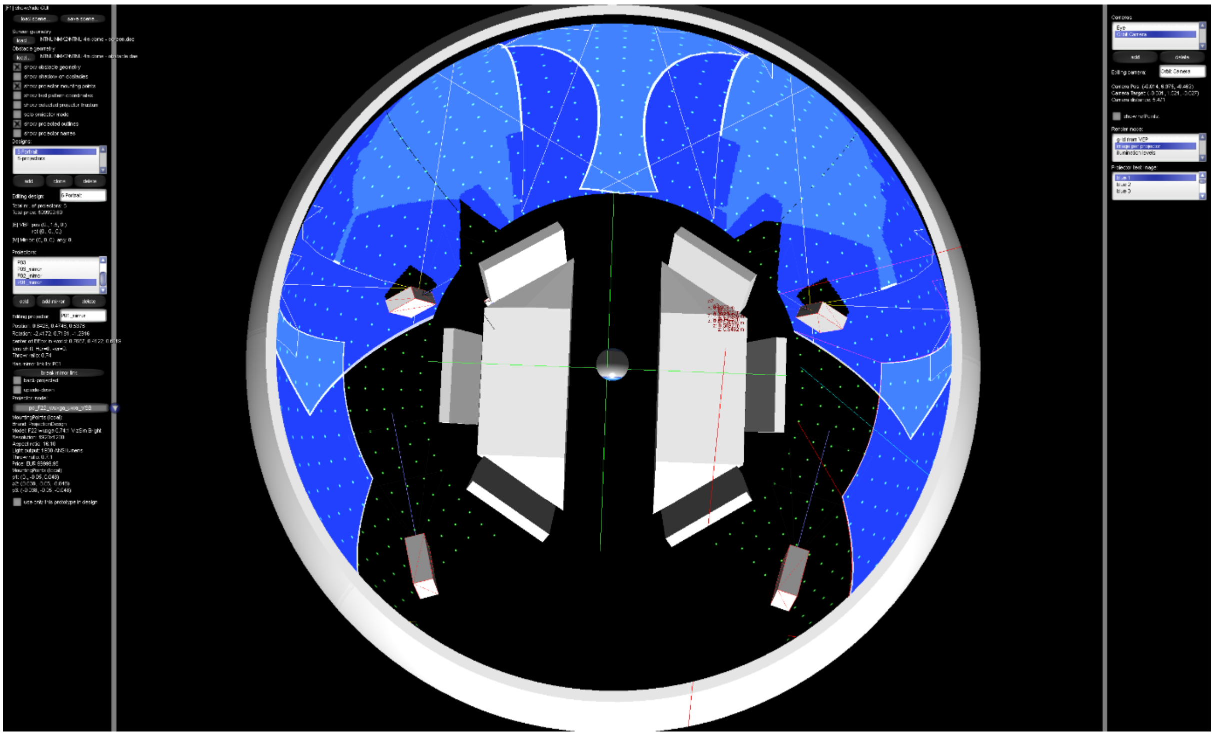


Figure 36: Top view of navigation bridge dome with compact console installed

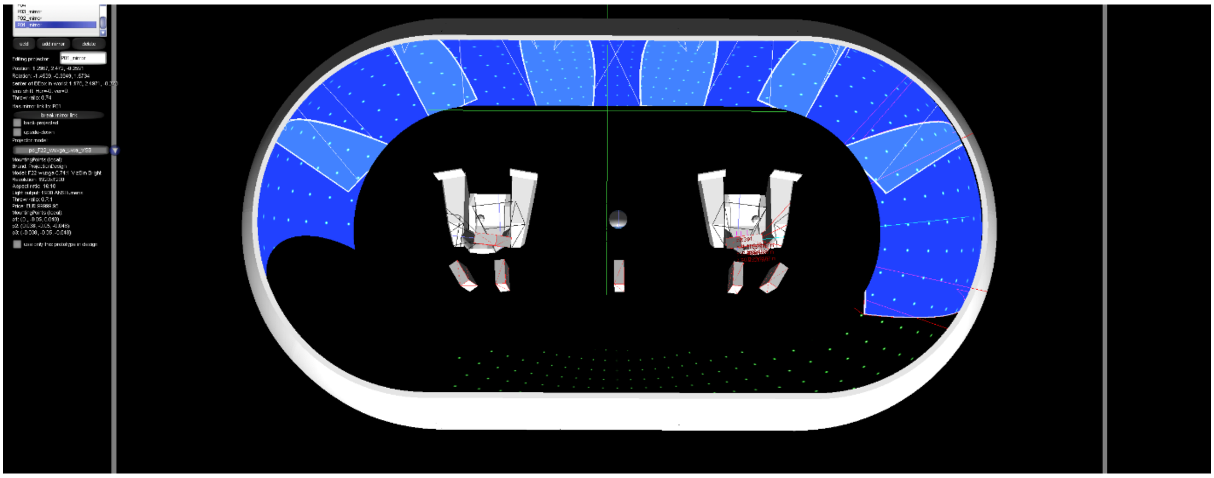


Figure 37: Top view of the generic operation station dome with two operator chairs installed

Here I just list some of the test images as an example of the final set up of the projectors' position after control units been installed. (Figure 36 and Figure 37) As people can see, the projection images were not affected by the hardware, and from the operators' perspective, all projectors are located in blind spots, which will not distract them during the simulation. Hence the design can continue on the site arrangement for the SRCC.

5.4 Data information wall design

According to the requirement of NTNU, the centre will need one or two video walls to present the real-time data of the vessel, current weather, and sea condition, also the prediction data for the debriefing team to follow operation status and make a decision at any stage. It also provides the possibility to let the debriefing group customize window size and position. Hence the video wall should be placed around the debriefing area and should not have other objects in between to block the view. In order to clearly read the content clearly from a distance, the size of monitors should be at least 40 inches, which raises the requirement for the construction when usually a video wall contains more than six units.

Based on the product list from the supplier, I made a design of the truss layout for the video wall. It provides space to hang up 9* monitors up to 55 inches and also turns the video wall into and a separate wall between the SRCC and the corridor. The site owner could also hang up the foil on the backside of the truss to create a more isolated area for the SRCC or just leave it open to make it semi blocked for showing to the public.

5.5 Site arrangement

Through the previous design process, now the final design layout for the site could be made and build up in the 3D world. (Figure 38) In this way, the project team could experience the site in a digital twin and test out the layout before there's any work started on the site. It's both time and cost-efficient.

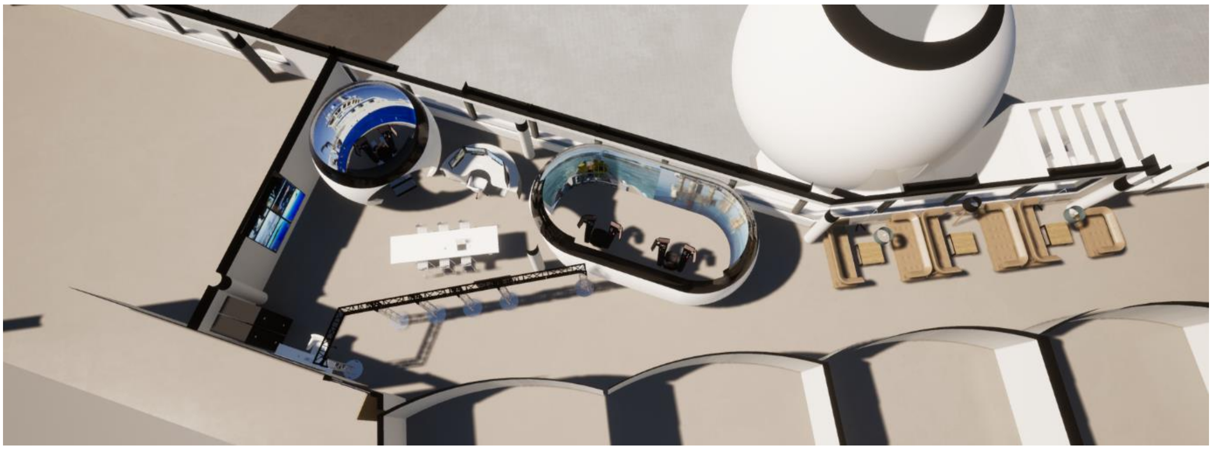


Figure 38: Overview of the site's digital twin.

The human factor challenges at this stage for the SRCC is to fulfill the requirements of teamwork to reduce misunderstanding during the interaction. Therefore, it needs a reliable communication system between stations and let actions to happen in real-time. A debriefing area in the center area with data info surrounding will help to reduce misunderstandings, report time, and contribute to the decision making. (Figure 39)

Figure 39: Debriefing table

Figure 40: 360 views of the site

In order to have a better experience of the site, I made a 360 walkthrough for the virtual site, and people can scan the QR code to check the result. (Figure 40) I've also exported a project file that people could run on a PC, use mouse and keyboard or VR gear to walk into the 3D site to check the setups. This program will be stored in a memory stick and delivered along with this thesis. More 2D renderings are attached in the appendix.

5.6 Design alternatives

5.6.1 Dome

The current dome that provided for the navigation bridge in this thesis is a 4m diameter dome, with cut off shape both on the top and bottom. It fulfilled the FOV requirements for general vessel navigation purposes in SRCC.

If the team ever wants to use the navigation bridge as an offshore vessel aft bridge in the future, then the requirement for FOV may change in order to allow the operator to check the things on going on the deck. So the projection area needs to be increased. Another dome type could provide a solution to this. However, on the other hand, it used an enclosed shape on the top, which not only has a higher cost on the dome itself but also raised the other requirements like cooling, fire safety, etc.

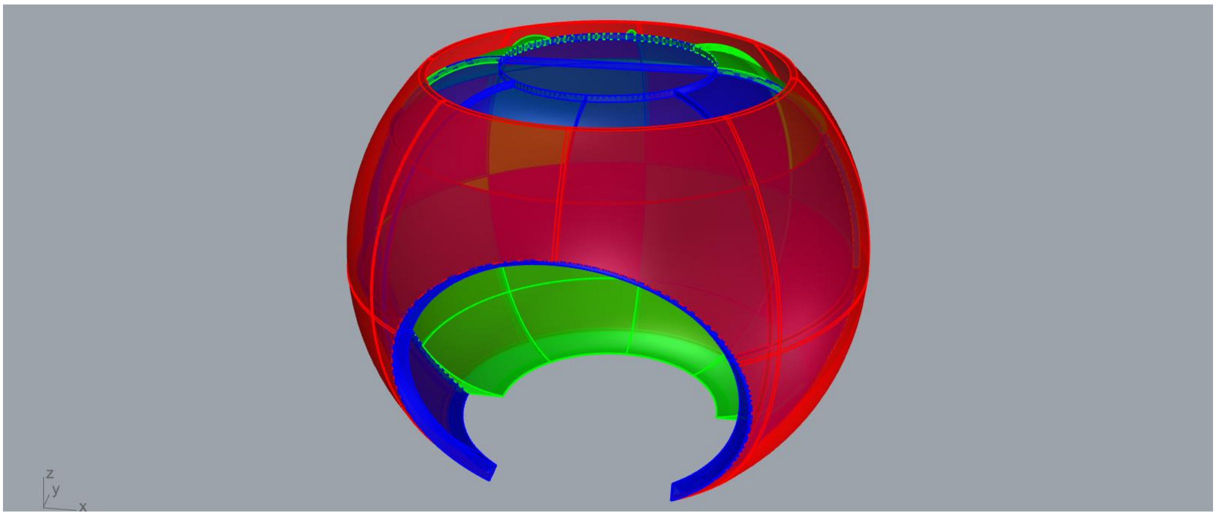


Figure 41: 4m Dome with more projection area

5.6.2 Bridge house

Compared to the current set up, a full-size bridge with a 13m diameter dome will undoubtedly provide a more realistic environment of the SRCC. Correspondingly it will require a much bigger area than what has been given in the current location, and the cost will be a huge difference.

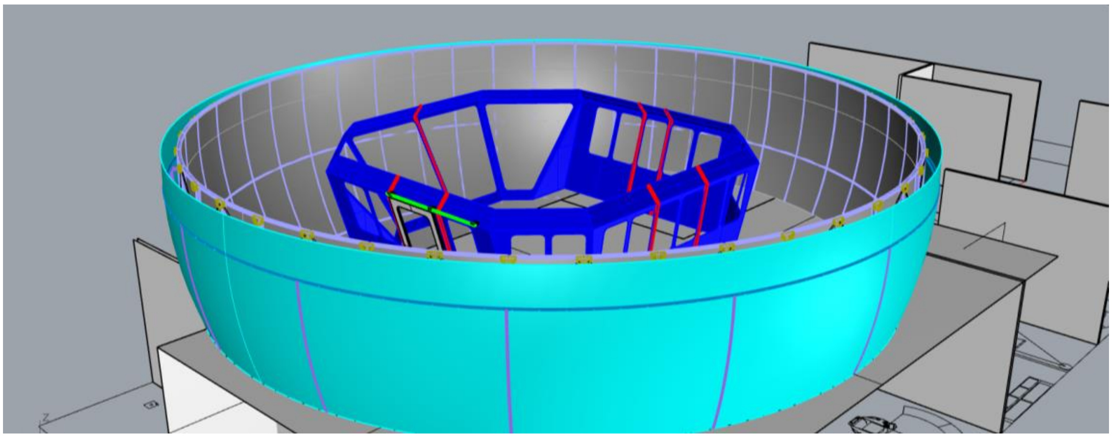


Figure 42: Full-size bridge with 360 views

6 Test cases of the SRCC

Now the SRCC has been built up. An operation test needs to be carried out in it to evaluate the performance, even though the necessary software and communication infrastructure are still in development. The role of SRCC is like a switch between the real-world and the virtual world. It provides the testing and operating environment for different usage. It is not only a control centre for remote operations but also a simulation site for virtual prototypes and digital twins. The following cases will show the performance and reliability of the SRCC, then it's value for the maritime industry.

Few test cases will be listed as examples to:

1. Prove the concept for using the SRCC for remote control operations.
2. Show the ability of the SRCC to be used as a testing tool for ship designers.
3. Show the ability of the SRCC to be used for understanding and live decision support tool for shipmasters.
4. Show the value of the SRCC for ship owners by reducing transportation costs and human errors.

6.1 Prove of concept

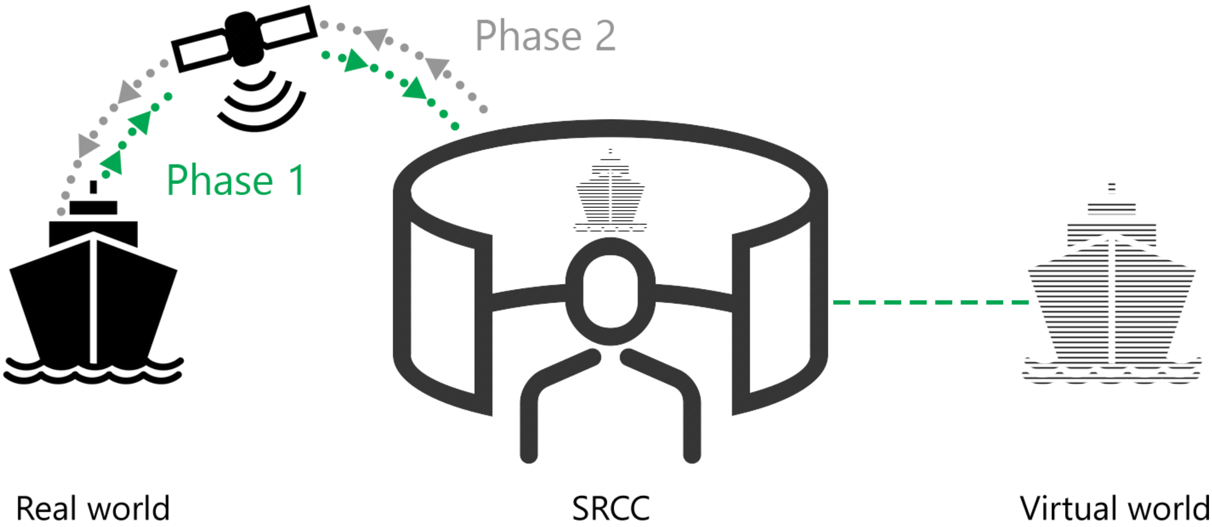


Figure 43: Data transition phases of SRCC

In chapter 1, a possible scheme of the support system based on the digital twin has been shown. The concept is to transfer sensor data signal from the real vessel through a network, as phase 1 in Figure 43, store and analyze in the server of SRCC, calculate in the core of the software, then visualize the environment and object state in the SRCC.

SRCC takes over the operation and sends a signal back to the vessel, as phase 2 in Figure 43, to update the commands to the actuators (thrusters, propellers, and rudders). In the end, a quantification of contributes between input parameters like environment data, and output like ship position will be made for further research.

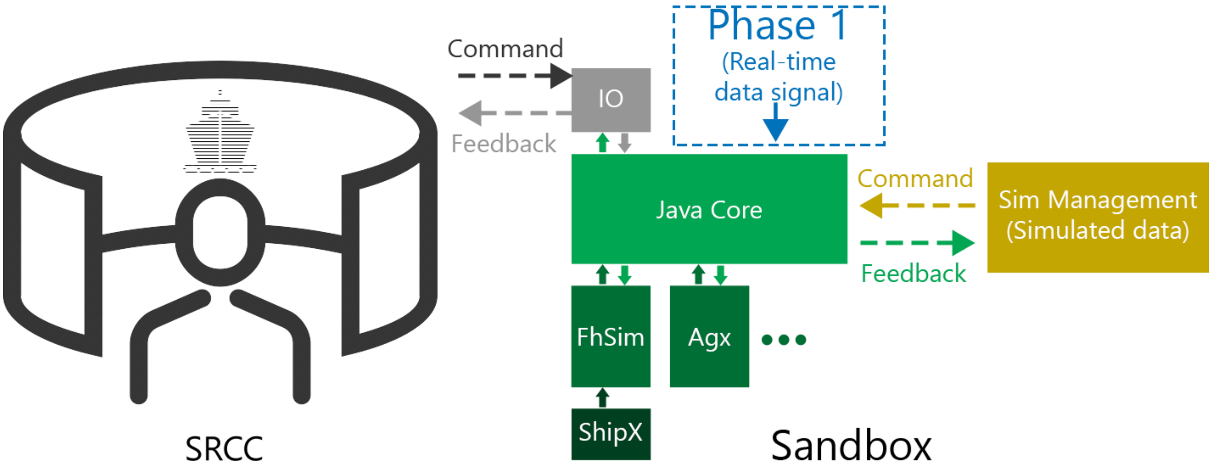


Figure 44: Simulation system

In the current OSC simulation system as in Figure 44, the operators in SRCC observe the virtual scene from the projection screen, update the commands from the control system. The commands signal been sent to the Java core through an IO. The core also receives commands from the simulation management program, as virtual sensor signals, of parameter changes like wind and wave condition change for the environment. The function of receiving real-time data signal is not fully implemented yet. The core takes commands from the virtual sensor signals, in addition to the commands from the control system, analyzes and calculates parameters of the objects in the scene, generates the necessary input for the corresponding physics engine, e.g., core calculates wave spectrum, and then send it to FhSim. FhSim continues the calculation of the wave response based on the hydrodynamic vessel model from ShipX, then send the result back to the core to update the state for the vessel's position, orientation, speed, etc. In the end, the core sends updated parameters through IO to the visual system and updates the visual for the operator.

To prove the ability to apply remote control operation, since the SRCC is not fully developed in the software layer and real-time communication layer yet, it will starts first by putting in the data log from the real operation as virtual signals into the SRCC through the simulation management program to simulate phase 1. By doing that, a scenario with continuous state change will be created and then simulate the same operation in the SRCC. After that, instead of sending a command signal back to the real vessel, the command will be sent into the virtual world to simulate phase 2 and check the state of the digital twin, see if that shows sensible behavior in the simulator, and match the expectations of the vessel motion in the real-world. In this way, the concept of using the SRCC to apply remote control operations will be proven. At the same time, the performance of the visual system and control system could be checked to see if they have provided the required feature for remote control operations, evaluate them by the classification rules.

6.1.1 Zigzag comparison test

In this section, a test case in the SRCC will be applied by me using OSC simulation software on the site. The test is to reproduce an operation that has been taken on the Gunners, and the simulated test result will be used to compare with logged data from the real vessel to evaluate the performance of the SRCC.

In the first step, the measured data from Gunnerus will be used in the SRCC, to build up the scene in the simulator, try to match the original state of the environment and vessel. An experiment description of Gunnerus (Figure 45) on the 21st, Nov 2019, which a zigzag test took on the vessel between 12:23 am to 12:39 am has been applied by the research team.

Zigzag test	first 10deg is rudder angle, second 10deg is heading change,main course 255deg, surge speed 70%RPM	12:23	10-10deg	
		12:25	15-15deg	
		12:29	10-20deg	
	main course 286deg	12:30	20-30deg	
		12:33	20-20deg	may have error
		12:36	30-30deg	
	for drone video,repeat	12:39	20-20deg	

Figure 45: Experiment description of Gunnerus (Li 2019)

A CSV file of sensors log for the whole day is to be found in the appendix, which recorded the location of the vessel, environment information, thruster feeds, and power output during the day. A clean up to the datasheet has been proceeded by me to get the necessary data as input to simulate phase 1, including wind direction and speed. The speed of the vessel for the test was found in another GPS log, which is 9.7kn. The Doppler Current Sensor on the vessel was not being used to record wave data. At the same time, the Hemos system(used on the vessel to record state log) has a bug – the GPS logs show a low resolution, so the location data logged was wrong, which makes it not possible to check wave data based on location. Due to the lack of wave information, the test has been decided to continue with a normal calm sea state for general test conditions. Some issues have been found while processing the data set. The time recorded in the data set shows an offset to the other reports obtained from the vessel.

As the report (Figure 45) shows, the real operation was finished in only 16min, which includes 7 zigzag tests of Gunnerus. Zig-zag test is the maneuver where a known amount of helm is applied alternately to either side when a known heading deviation from the original heading is reached. (IMO 2002) Zigzag tests are used for documenting yaw-checking and course-keeping abilities. The standards are based on measures of the first and second overshoot angles.

The 10/10 zigzag test of Gunnerus finished in a very short period, which is less possible for the environment to have a dramatic change, and that creates the possibility to use simulated weather transition to replace the signal receiving process. It will also reduce the effect of lacking wave data to the simulation result, too.

In order to simulate phase 1, a transition period has been set up for the environment parameters to create continuous state change in the simulator and set the value to match the measured wind speed and direction from the CSV file. A zigzag test of 10/10 will be taken in the simulator to reproduce the operation. The result of the simulation will be compared with the data obtained to evaluate the performance of SRCC then prove the concept.

Figure 46: Test of SRCC

The test was taken in the SRCC generic operation dome, as shown in Figure 46. The visual system provided enough FOV for the operator, the human-perceived visual representation of the environment – the seabed and shore topographies, wave and vessel motion – on the projection screen matches the physical state on the indicators and digital sensor data. It shows a sensible movement of the vessel under that environment status. By simulating the data intake from the signal, the simulator updates the visual for the operator. It achieved phase 1 of remote control - receiving data and update status in the virtual world.

To simulated phase 2, a control test of the digital twin in the virtual world will be applied. In the CSV file, the logs of each thrusters’ angle and power output, as well as the heading of Gunnerus was recorded in every second. About 100s data log of the thruster’ angle and power output during the 10/10 zigzag test will be used as a reference input for the digital twin test, and the heading data will be used as the measurements to be compared with the simulation result. (Figure 47)

As tested, the digital twin could not reach 9.7kn speed, but 8kn at maximum. To continue with the test, both thrusters have been kept at 100% output in order to keep ship speed and get as close to the original test as possible. After the test started, both controllers were turned 10deg at the same time to send commands to the simulator. The visual shows that the digital twin executed the demand operation. With the state changes, the new status of the vessel has been observed on the projection screen. It shows the expected motion of the digital twin in the simulator. The recorded data log from simulation also proved that the digital twin had received the commands from the control system. Hence, it achieved phase 2 of the remote control – update control commands to the actuators. The test log was saved at about 100s from the test started to be compared with the measured response.

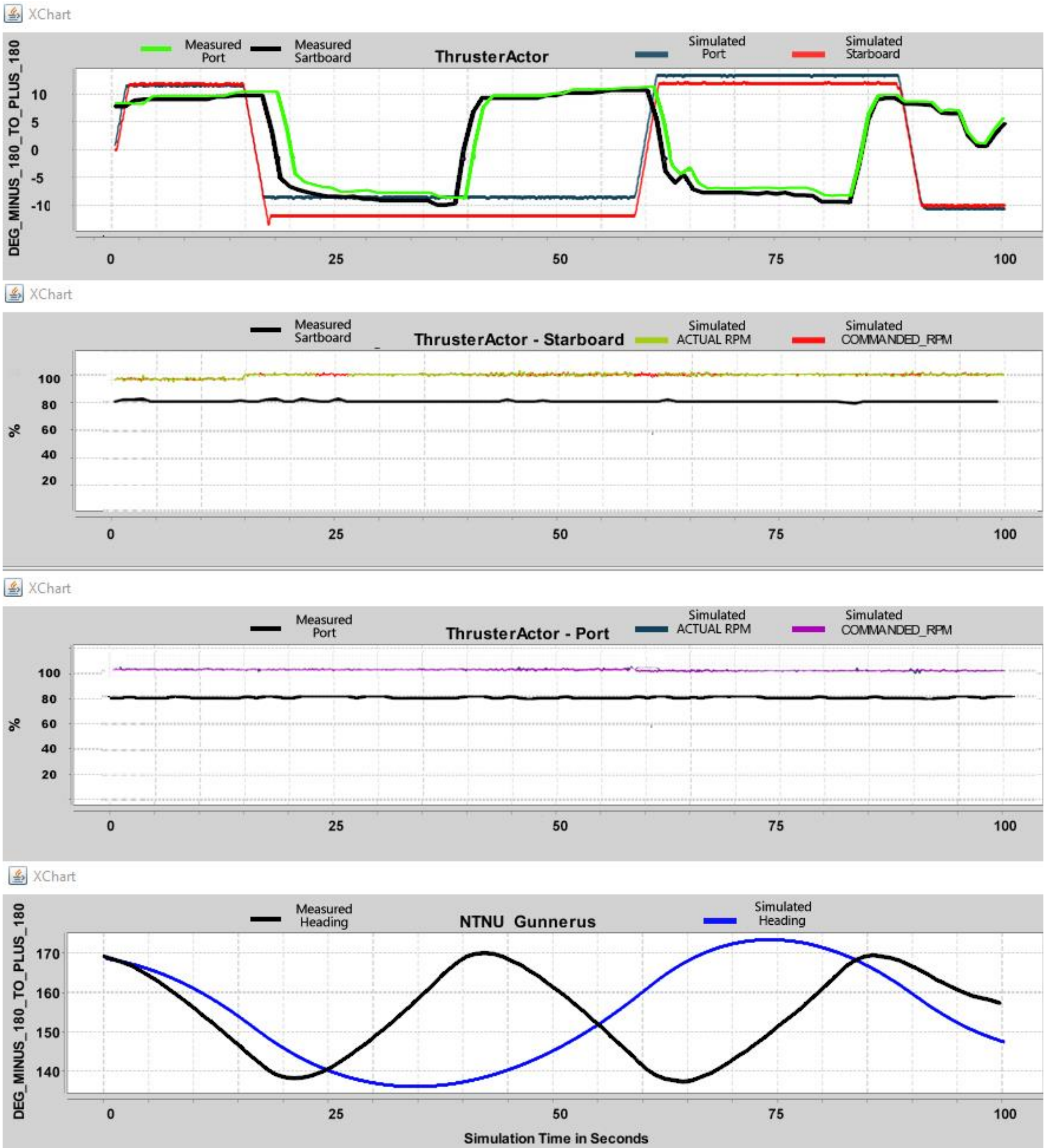


Figure 47: Graph of the measured and simulated test result

The plotted graph shows it used a longer time to achieve the second 10deg heading change than the real operation. (Figure 47) From the data log on the axis, people can see that the power output of the thrusters was at a much higher rate – 100% than 80% in the real operation. Still, the digital twin could not reach 9.7kn, and there are many reasons to explain this, most likely the model needs to be further tuned: e.g., some of the data of the thrusters were not delivered from supplier, so it is difficult to set the parameters of thruster in the software for the digital twin.

In the simulation, the test speed of the digital twin is lower than the real operation, which will end in lower inertia on the vessel in theory. It is obvious that change the heading at a lower speed will be easier than at a higher speed, and it will take a shorter time to achieve the angle change. However, the plotted graph shows the opposite thing. Hence, we see there's a lot of limitation in the current version of the Gunnerus digital twin. It could not give a plausible result at this stage yet. It needs to be further investigated in the software to find out the reason. The result from the test is the SRCC shows the possibility of doing that type of operation. More discussion about this test will be written in 6.1.3.

6.1.2 Test case with the deck crane

In further test cases, other workstations have also been tested in the SRCC, like crane operation from the generic operation station dome, applied a load case in addition to the vessel operation. Due to a lack of similar operation data from the real vessel, there was no comparison been applied in detail. The recorded simulation process in the virtual world has been compared with a drone record footage of Gunnerus, in which it was taking a subsea lift from the deck crane. Both videos will be delivered in the appendix file with this thesis. From the video, we can see the systems worked well and showed sensible physics on the objects in the scene.

Figure 48: Video records of real and simulated crane operation

Theoretically, if the software development and real-time communication infrastructure could fulfill the need, people could achieve both phase 1 and phase 2 of the remote control operation by intaking real-time data of environment status and changing the signal receiver from the digital twin to the real vessel in the SRCC. The performance of hardware fulfilled the requirement of classification rules for the SRCC.

6.1.3 Discussion of the Gunnerus digital twin test

In the test, the possibility of using the SRCC for remote control operation has been proved. The result shows that the visual and control systems proved their ability for specific operations in the test, which is what the SRCC could achieve at this stage of the project. The real sea trials are difficult to reproduce because the environmental conditions are not recorded 100% by the sensors. Even if we have the full sea state data (wave height and direction), it still needs precisely the same waves (exact same spectrum) to have a 100% reproducibility. According to the developers, the digital twin of Gunnerus was tunned in the simulator for slow speed operations, like DP and crane operations, so the performance is not ideal in transition. Besides that, it also has the limitation of the hull model, the thruster model, the thrust commands, the physics solver, the time constants for the response of the system, and so many factors that can affect the test result.

6.1.4 Future works

What has been shown here is the possibility of the hardware to do the operation with the level of today's technology. Some future works need to be done before the site could be used as a fully functioned SRCC:

a. The software needs to be further developed to implement more functions, e.g., the ability to tune the parameters of the model manually or automatically in a simulation when a problem been found.
b. Better data (not more data) will be needed for testing in the simulator. It would be critical to have the necessary data to test and evaluate the performance of SRCC. A method to clean up and select useful data need to be developed to reduce the preparation work for better efficiency.
c. A more systematic approach is needed to collect, curate, and compare the real and simulated data. An individual test is not enough to prove the performance. A systematic group of test samples will be needed to prove the reliability of the SRCC.
d. The real-time communication infrastructure needs to be developed and implemented into the SRCC to achieve the goal of remote control operation.

Along with the software and communication infrastructure development, more test and research will be applied, and the performance of the SRCC will be evaluated with a real vessel involved in the future, then it could also be used to benefits the following groups.

6.2 Using the SRCC for ship designers

The performance of the simulator in SRCC has been proved in the previous test. As a ship design student, how can I get benefit from the simulator in the SRCC?

6.2.1 Test tool for design ideas

A paper of rapid prototyping of ship models to be used in real-time time-domain simulations with hardware in the loop and humans in the loop for VP of offshore operations has been written recently by the researchers of NTNU. In the paper, a validation with Virtual Sea Trials (VST) has been applied in the SRCC by using its software Sandbox. Sandbox is a tool that enables people to build complex simulation scenarios in a short time, take the test, and plot graphs to evaluate the result. It is an efficient tool to test ship motions under different environmental conditions. By importing 3d and hydrodynamic models of the vessel, the ship designers could check how their design performs in the virtual world at any stage of the design loop.

Usually, the ship motion problem is split into two, the seakeeping and the maneuvering. The seakeeping theory is concerned with the out-of-plane motions in waves at zero or constant speed, where the hydrodynamic coefficients and wave forces are calculated as a function of the wave excitation frequency. The maneuvering theory, on the other hand, is concerned with the in-plane motions at a constant forward speed in calm water, assuming no waves. (Major, Zghyer, et al. 2020) Virtual prototype models solve both theories in (faster than) real-time. VP are digital models that mock-up or simulate the behavior of existing or conceptual systems. VP find usages in design, training, proof of concept of new equipment, and planning for advanced offshore operations. Moreover, they can be simulated in desktop solutions by experts during the design phase or in full mission simulators with a whole crew of marine and offshore engineers, in which case the VP needs to be integrated with control systems such as handles and dynamic positioning systems. Virtual see trials offer cost benefits over expensive full-scale sea trials or model tests in towing tanks, they also offer more consistent tests and reproducible weather conditions, under the scrutiny of uncertainty assessment. (Major, Zghyer, et al. 2020) The test of VP in SRCC will show the potential of using it as a reference for model-based ship design in the simulator.

It is also a fast way to test out how different systems in the vessel affects/will affect on each other, e.g., how much impact of different deck cranes has to the stability of the vessel under different environment status. An example is the co-simulation specification Function Mockup Interface (FMI) – which is a current state of the art for virtual prototyping of maritime systems – has also been implemented into the simulator. (Figure 49) It allows the connections of loosely coupled sub-models into a co-simulation, thereby connecting domain-specific simulations and load-balancing the computing-intensive simulations. (Chu 2018)

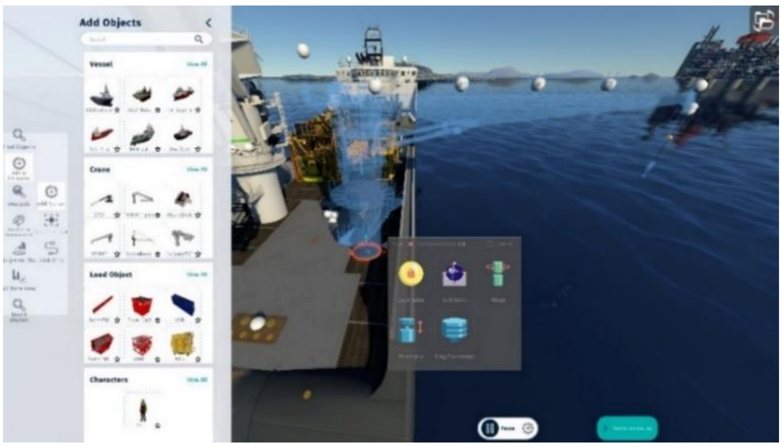


Figure 49: Add deck crane using FMI

6.2.2 Test case – Validation with Virtual Sea Trials

Figure 50 depicts an extract of the VST report (Major, Zghyer, et al. 2020), a test relevant for maneuverability and DP:

- Full speed forward trial
- Crash stop test
- DP crab maneuver (only sway)
- DP Pirouette maneuver (only yaw);
- Low velocity decay tests in surge, sway and yaw.

Vessel data PK410 - NTNU Gunnerus			
Full speed forward: 10.63 Knots			
Name	RPM	Pitch [deg]	Azimuth [deg]
conMainPort	204	25	0
conMainStarboard	204	25	0
Crash stop distance/time: 121.06 m / 0.53 min			
Name	RPM	Pitch [deg]	Azimuth [deg]
conMainPort	204	25	180
conMainStarboard	204	25	-180
DP Crab maneuver sideways speed: 1.47 Knots			
Name	RPM	Pitch [deg]	Azimuth [deg]
conMainPort	117	25	90
conTunnel	275	30	0
conMainStarboard	0	25	0
DP Pirouette maneuver yaw speed: 387 deg/min			
Name	RPM	Pitch [deg]	Azimuth [deg]
conMainPort	102.0	25	-90
conTunnel	275.0	30	0
conMainStarboard	0.0	25	0
Decay time to 5% of initial value from:	Surge 2.5 Knots	Sway 1.47 Knots	Yaw 60 deg/min
	94.8 seconds	50.8 seconds	7.7 seconds

Figure 50: VST Virtual Trials' Data (Major, Zghyer, et al. 2020)

A crash stop is typically performed during real sea trials from the wheelhouse poster, and it indicates how fast the ship can stop from full steam ahead to 0 by applying maximum backward thrust, displaying the thrust allocation.

The DP crabbing test shows speed and thrust allocation for a sideways sway. The DP pirouette is a constructed test in which the vessel rotates around its center of gravity (yaw), with minimal surge and sway velocity. The constructed decay tests in the surge, sway, and yaw from a small initial value, without applied thrust, are representative values of the damping in the respective dimensions. The thrust allocation is either generic, based on a simple algorithm, or manually overwritten in the Ship's java implementation. The results presented in Figure 50 are plausible but need to be verified by real-life tests.

In the report, a zigzag test is also added as a prove for the concept of approach. In the presented VST report, only 20/20 zigzag tests are performed. In principle, the first overshoot angle should not exceed 25 in the 20/20 test regardless of the length-to-speed (L/V) ratio, and the second overshoot has no limit. The results are plausible but need to be compared with real values.

By testing the VP in the SRCC, people could use the simulator, which implemented the advanced physics engines to calculate the states, along with the advanced visual system to observe the behavior, record the performance and validate the models. The VST Report of Gunnerus in the paper indicates that the simulated model behaves realistically. Although there are many sources of human and programmatic errors that may happen in the test, it still shows the value of the SRCC to be used as a tool for VP, and the potential it could contribute to many other different types of researches for the ship designers.

6.3 Using the SRCC for shipmasters

From previous tests, it has been proved that the performance of the simulator in the SRCC could provide fast and plausible results. How could shipmasters get benefit from the in the remote control operations?

6.3.1 Real-time observation

Simulations have been used for maritime training for a long time. In the early years, it is a step at the end of the project as a case study for training new crews. As technology develops, the current offshore projects are using simulation as project support tools. They bring in simulation technology in the early stage of the project, building virtual prototypes, and let the crew do the test in the simulator before the real operation starts to prove the concept and analyze the risks.

In the SRCC, people could use the simulation as a tool for real-time analyzing and live decision support for onboard. We already know that the digital twin could be used before the operation for testing, as well as in operation with real-time data infeed for live monitoring. That means people are not being limited to where they are anymore. In the traditional way, the shipmasters have to use watch cameras at different locations to try to get a better overview. By using the simulator to monitoring the real-world, they now have the ability to fly around in the virtual world and following the offshore operation from any position at any time and get a full understanding of what is going on – even under the ocean as Figure 51.

Figure 51: Digital twin of subsea installation operation

6.3.2 Live decision support

If people then use the simulation management program as in 6.1, to feed in predication environment data from the weather forecast, they will be able to use the simulated result as a reference to the future state, then get the advantage for decision making onboard for shipmaster.

As described in 6.1, from the real-time sensor data, the SRCC could analyze and calculate the states of environment and vessel, then update correspondingly. By taking in the predication data of the environment, people could calculate the predicted states, As shown in Figure 52.

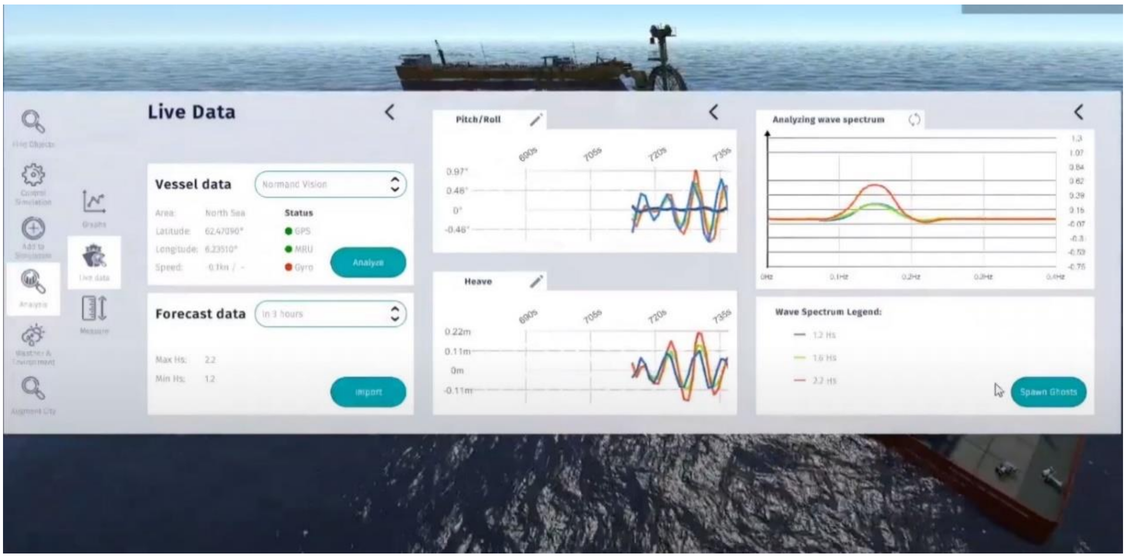


Figure 52: Prediction data analyzing

In order to predict the effect of environmental change on the operation, the analysis will take data from the future time periods than that point of time onboard. In the next step, a ghost object will be generated in the simulator in addition to the "real" digital twin (which shows the current status) for test operation.

The officer in SRCC could test the planned operation on the ghost object by driving the control stations to show the predicted result and send over to the shipmaster as a reference. As it shows in Figure 53, the "real" crane is at the parking position, and the load object is on the deck.

Three layers of ghost objects been generated in red, green, and blue colors, which corresponding to the operation been taken under three different environmental conditions in a future time. That helps the shipmaster to make decisions onboard for which time period suits best for the operation, so it could reduce risk and achieve as planned.

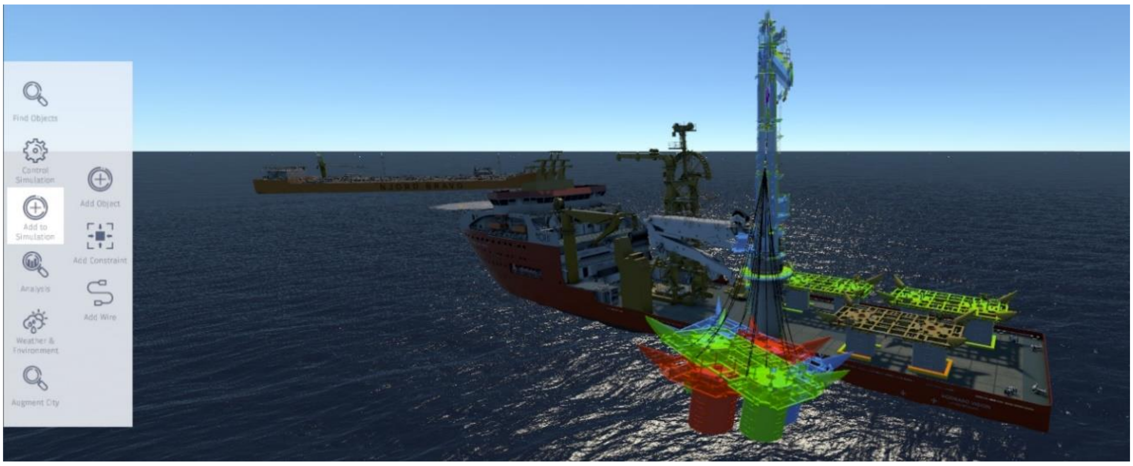


Figure 53: Ghost objects in a simulation

In this case, the way of using SRCC as an onshore supporting tool for the shipmaster has been shown. Instead of having to work with high levels of conservatism, the SRCC now provides the ability to let people onboard have a full overview of the status, and the ability of live decision support to predict the conditions for shipmasters to have a better understanding of the operation. That has great value for the projects in the future.

6.4 Using the SRCC for ship owners

From previous cases, the possibility of using SRCC for onshore support for the shipmaster has been shown. How could it benefit the shipowner?

One example has been given by the DNV GL ROMAS project to explore the concept of moving the engine control room from the ship to a shore-based engine control centre. The ship’s machinery and automation system provide power for propulsion, as well as several other functions on board. On modern ships, these systems are highly digital and operated with a high degree of automation. With the concept of using SRCC, the ship’s engine control room can be moved to onshore(Figure 54), from where a chief engineer can operate the propulsion and auxiliary machinery systems of a single ship or a fleet of vessels.

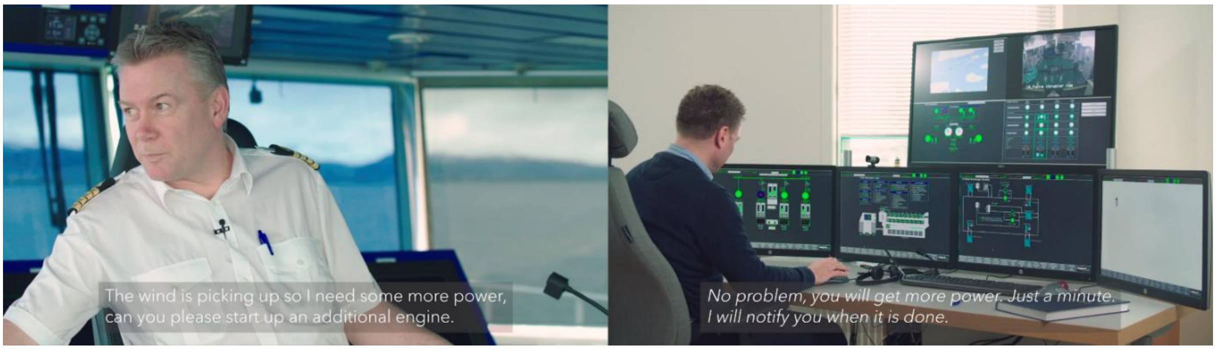


Figure 54: Engine control from SRCC (ROMAS project)

6.4.1 Detect potential issue

Today, 98% of the world’s ships are performing maintenance on a primitive basis, unrelated to the real status of critical ship components. Just like the predefined workshop intervals in cars, critical ship components are maintained on a regular, sometimes unnecessary basis. E.g. Ship engines are operated differently from ship to ship due to unpredictable environmental and operating conditions. Consequently, random degradation patterns occur, which todays maintenance approaches fail to detect. As a safety measure, too much maintenance is performed based on the engine supplier's conservative assumptions. With the technology of SRCC develops, sometime in the future, people could rely on the measured data and digital twin to analyze the engine operated information in the simulator, detect potential issue and give maintenance advice in advance.

6.4.2 Reduce transportation cost

The example above shows by using the SRCC, the crew member could be reduced in transportation, and the vessel could be redesigned to improve efficiency in new ways. For example, the systems needed to make the vessel livable for the crew can be reduced and simplifying the design. This could open up more space for cargo, possibly make loading easier, or allow for a more aerodynamic profile.

Cargo ships are normally a much slower option than cargo planes or even trucks, so their core advantage is usually being a much lower cost option. This is why the shipping industry is always trying to find ways to bring down operating expenses. To keep international volume increasing, the industry needs to make shipping as cheap as possible. (Walker 2019) Overall, bringing down the cost for ship owners can make shipping new products across the world economically viable, opening new market opportunities.

6.4.3 Reduce human error and risk

AGCS UK Marine Claims Manager, Kevin Whelan says that while the indicators are that, overall, shipping safety has improved when incidents do occur, it is primarily down to human error. In fact, going back over the years, the human error component is on the increase. So, while safety has improved overall, when there is a casualty, the human error element is more likely to be the cause. (AllianzGlobalCorporate&Specialty 2012)

It is estimated that 75% to 96% of marine accidents in the shipping sector can be attributed to human error. (AllianzGlobalCorporate&Specialty 2012) Furthermore, AGCS analysis of almost 15,000 marine liability insurance claims between 2011 and 2016 shows the human error to be a primary factor in 75% of the value of all claims analyzed – equivalent to over $1.6bn of losses. By developing the remote control technology and autonomous shipping, the SRCC could provide a solution to reduce human error and therefore bring down costs related to accidents and insurance.

7 Summary

Remote Control Centres are the future of shipping technology. This master thesis proposes a novel approach to merge class certification with vessel-specific aspects and building topology. The product of my design shows it's potential value for ship designer, shipmaster, and ship owners – from the design stage to the end-user, and the research value for future development – to the entire maritime industry.

7.1 List of Contributions

In this section, the contributions of my work to the «OSC – NTNU forskningslab» project is listed.

1. Navigation bridge dome design

The dome has been designed in Rhino and made for navigation bridge. Drawings of dimension, material, and fixing have been made in AutoCAD for production.

2. Generic operation station dome design

The dome has been designed in Rhino and made for generic operation stations. Drawings of dimension, material, and fixing have been made in AutoCAD for production.

3. Generic operation chair design

The chair has been designed in Inventor and could be used for different operation stations. Drawings of dimension, cutting, bending, welding, and assembling has been made in Inventor for production.

4. Console group design

The console group has been designed in Inventor and could fit for different types of stations by change content on embedded touch screens. Drawings of dimension, cutting, bending, welding, and assembling has been made in Inventor for production.

5. Visual system design

The projection screens have been designed along with both domes. The data monitoring system has been designed in Twinmotion with the site layout, including the support frame.

6. Control system design

The control system on the operation chair and the console has been set up along with the design develops. Both physics controllers and virtual controllers have been used in the design for different parts by embedded controllers and touch monitors.

7. Site arragement design

The site arrangement of stations' layout has been designed in AutoCAD and visualized in Twinmotion for 3D review.

8. Power and network design

The power and network arrangement has been designed in AutoCAD for the stations, including the document of cable length, path, the position of sockets, and power output.

9. Verification test

The verification test has been applied by using OSC simulation software on the site. The simulated result has been recorded and compared to evaluate the performance of hardware combined with software.

For the objectives of the thesis, the following list of stations has been finished in my design of centre:

- Navigation bridge
- Operation station (aft bridge)
- Crane
- WROVs
- Winch
- Operation manager (onshore and offshore)

The detailed technical drawings of my designs, including production drawing for two types of domes, operation chair, console group, visual and control system configurations, are now OSC property and could not be shared in this thesis. Hence only general arrangement, list of components, and drawing of overview dimensions will be attached in the appendix and will be uploaded separately from the thesis.

The other main points of the hardware design requirements have also been achieved: the workstations are flexible to fit different simulators and have the potential to be easily upgraded in the future. For the interface of controllers, the design has followed the commonly used in the industry and use proper physics buttons and controllers fo the necessary part of the control system. For some part of the control system, touch panels have been implemented for virtual UI, which is based on software development and more flexible for different simulators.

The concept and the ability of the SRCC have been proved by taking tests as described in chapter 6. The visual systems' performance has achieved the goal of giving a seamless, immersive experience. The visual representation on the dome synchronized with the physics model of objects in the scene and shows real-time simulation states. The control systems also work as expected. The SRCC fulfilled the classification rules of hardware facilities and safety requirements. The test result of Gunnerus digital twin in the current software version was not ideal, but that could be solved by further development.

Furthermore, the SRCC shows its value not only as a command centre but also as a research site for ship designers. It provides the environment with real-time simulation and real physics to test design ideas within the virtual world with high efficiency. That enables the ship designers to test their work at any stage in the design loop, which will make the work much easier than ever before. The SRCC also provides the ability for a better overview of the status and onshore live support for the shipmaster, which could reduce the risk during offshore operation. Furthermore, by developing remote control and autonomous shipping technology, the transportation cost and human errors of shipping will be reduced, new markets and opportunities will be brought to the maritime industry.

This thesis documented my research and design process of the NTNU SRCC, shows its ability for remote control operation and the potential value to the maritime industry. My design work is a contribution to the «OSC – NTNU forskningslab» project and is the very first stage of the whole AuReCO project. It can serve the rest of the project and also many other studies of ship design in the future.

By finishing this thesis, I have achieved the following points, shared the research results and experience of designing an SRCC to future projects:

7.2 Work under safety culture by following the new guidelines

The remote control centre has been designed based on the specifications of target vessel Gunnerus, following 2019 ABS ergonomic vessel bridge design guidelines, in advance with DNV-GL's new guidelines for autonomous and remotely operated ships. The new guidelines cover new operational concepts and technologies, setting the standard for the future of shipping.

7.3 Fulfilled requirements while keeping flexibility

The SRCC is designed based on the requirements of NTNU and site conditions. Some parts compromised with the site status but tried to gain as much as possible – for example, and the ceiling height limits the FOV in the vertical direction. This thesis followed the specification of the target vessel and verified that the dome projection area could fulfill the need. The control system could be easily modified to use as a different control station. For the software side, the team could use station assignment to assign control stations as rig crane, vessel crane, STS crane, reach stacker, ROV, etc. It provides a full possibility for researching in the SRCC.

7.4 Built a site with value for the industry

The SRCC is not only a command centre but also a simulator-based research site. It could contribute to today's maritime industry from the design stage to the end-user, even future developments. It shows the power of the technology that brings new opportunities to the traditional industry.

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Appendix

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OSC
OFFSHORE SIMULATOR CENTRE