CONCEPTUAL DESIGN OF A HULL CLEANING SUPPORT VESSEL IN THE ARAG AREA

Delft University of Technology
Master Offshore & Dredging Engineering
Confidential

Author:
L. M. Middelburg

Supervisors
Dr. ir. S.A. Miedema
Dr. A.J. Laguna
Dr. ir. R.G. Hekkenberg
Ir. A.M. Noordstrand

TU Delft

TU DELFT | Dr.ir. S.A. Miedema
Dr. A.J. Laguna
Dr.ir. R.G. Hekkenberg

FLEET CLEANER | Ir. A.M. Noordstrand

WRITTEN BY | L.M. Middelburg

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AUTHOR	L. M. Middelburg
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POSTAL ADDRESS | Offshore and Dredging Engineering
Faculty of Mechanical, Maritime and Materials Engineering
Delft University of technology
Mekelweg 2
2628 CD Delft
The Netherlands

EMAIL AUTHOR | l.middelburg@icloud.com

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PREFACE

This Thesis is my final project for my master offshore and dredging at the TU delft. It is a combination of using the knowledge I obtained at the TU delft and implement it in solving a complex problem for Fleet Cleaner.

I would like to thank Fleet Cleaner for the opportunity they gave me to do my master Thesis at their company. Firstly, I would like to thank Alex for helping me keeping my focus but simultaneously giving me all the freedom to develop my own conceptual design. I also would like to thank Cornelis for his help in structuring my analysis and obtaining my final result. Furthermore, I would like to thank my girlfriend for her fine eye for detail and design.

I would like to thank my family for endless support in this somehow long trajectory. They stimulated me to finish this Thesis and they kept me motivated during the process.

Furthermore, I would like to sincerely thank my TU supervisor; Dr.ir. S.A. Miedema. He gave me the opportunity to write a thesis about a subject that had my personal interest. Furthermore, he kept me motivated in the times that I did not have a clear direction of thoughts.

Lastly, I would like to thank Mr. Laguna and Mr. Hekkenberg for participating in my graduation committee.

My gratitude for the above-mentioned people is tremendous.

Kind regards,

Lodewijk Middelburg, Delft

ABSTRACT

Fleet Cleaner is a Dutch company which developed a robot for cleaning the underwater area of seagoing vessels. The robot collects the cleaned-off marine growth and is therefore capable of improving the fuel efficiency of the vessel without any disturbance of her normal schedule. The installation is stationed on a support vessel which sails around ports to deliver services in Amsterdam, Rotterdam, Antwerp and Ghent. (ARAG)

During cleaning operations, the current support vessel showed practical limitations. A better design will improve Fleet Cleaner's services. To accomplish this, the main goal of this thesis is to develop a conceptual design of a hull cleaning support vessel in the ARAG. This objective is accomplished by dividing this Thesis in three parts.

In the first part of this Thesis a thorough analysis is made on the operation and the support systems used for hull cleaning and other similar maritime services. This shows the different available concepts and arrangements of similar equipment. Finally, the Fleet Cleaner support vessel was analyzed and the limitations were assessed. The conclusion was drawn that the current configuration of the support vessel is not efficient, safe, suitable for 24/7 operation or durable for the Fleet Cleaner equipment.

In the second part of the Thesis, the conceptual design is made by combining constraints and requirements. The scope of this Thesis is limited to refitting an inland vessel and to support a modular system which is capable of cleaning seagoing vessels above 120 meters long in the ARAG area. With these constraints, the maximum dimensions of the support vessel are specified. The support vessel needs to fulfill the following requirements:

Figure 1: Overview of requirements for the conceptual design

These requirements are covered by analyzing suitable working principles for each requirement and combining them to an optimum in a morphological chart.

Finally, in part 3 the combination of chosen working principles is presented in the final conceptual design. This concept presents the support vessel called Thunderbird One. This vessel is in transit, a normal dry cargo vessel. However, when a seagoing vessel needs to be cleaned, the cleaning robot comes out of the cargo hold and Thunderbird One transforms into a cleaning station. The cargo holds functions simultaneously as deck space and sheltered maintenance station. Furthermore, the umbilical is guided by a (de-) mountable roller chute. Lastly, she is equipped with custom fenders, a knuckle boom crane and a built-in generator.

The main conclusion of this Thesis is that the conceptual design will increase safety, quality of work and finally the efficiency of the operation. The presented conceptual design is embraced by Fleet Cleaner and will be implemented as soon as possible.

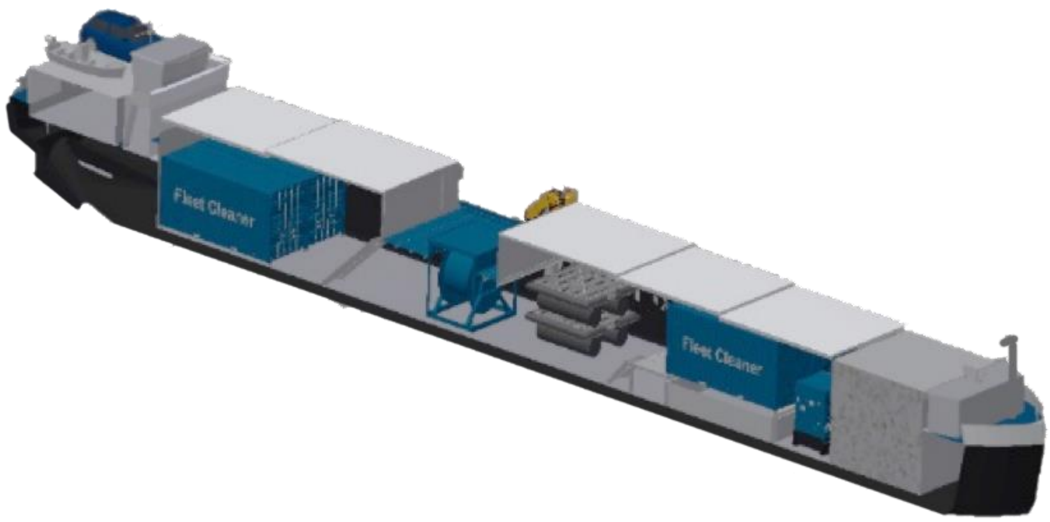


Figure 2: Conceptual design of Thunderbird One

LIST OF ABBREVIATIONS

ARAG	Amsterdam, Rotterdam, Antwerp and Gent
AF	Anti Fouling
DP	Dynamic Positioning
IMO	International Maritime Organization
TBT	Tributyltin
R.O.V	Remote Operated Vehicle
GAC	Gulf Agency Company
GCC	Gulf Cooperation Council
VT	Verenigde Tankrederij
OSR	Oil Spill Response
IBO	Intermediate Bulk Container.
AIS	Automatic Identification System
TLQ	Temporary Living Quarters
HSE	Health Safety and Environment

Table 1: List of abbreviations

TABLE OF CONTENTS

CHAPTER 1 – INTRODUCTION

This chapter will introduce the reader to the basic concepts of hull cleaning and current developments in the market. Furthermore, it will introduce the company named Fleet Cleaner and describe what motivated the writing of this Thesis.

1.1 INTRODUCTION OF HULL CLEANING

In the early days vessels were protected from fouling by coatings which contain the very effective organotin Tributyltin (TBT). This toxic particle effected sex changes in animals, killed sea life and it eventually also entered our food chain. Therefore, the International Maritime Organization (IMO) banned in January 2003 the application of TBT based antifouling paints (Showalter & Savarese, 2005). Since then, the shipping industry started to use less effective fouling release coatings, which constantly release small portions of toxic biocides in the sea. These anti-fouling (AF) systems are less effective in keeping the hull clean and therefore fouling is currently still a problem for the ship-owner and charterer.

Description of conditions of fouling release coatings	Increase in resistance and shaft power at 15 kn (μm)	Increase in resistance and shaft power at 15 knots
Typical as applied AF coating	150	1 %; 1 %
Deteriorated coating or light slime	300	9 %; 9 %
Heavy slime	600	17 %; 18 %
Small calcareous fouling or weed	1.000	29 %; 31 %
Medium calcareous fouling	3.000	44 %; 47 %
Heavy calcareous fouling	10.000	69 %; 76 %

Table 2: Overview of added resistance (Schultz, Bendick, Holm, & Hertel, 2010)

The table above illustrates that fouling causes significantly extra drag which will lead to a higher fuel consumption and emission rate. Therefore, most big shipping companies are regularly cleaning their hull when they have the opportunity.

1.2 DESCRIPTION OF HULL CLEANING

Figure 3: Handheld cleaning tools

Hull cleaning has been evolving since IMO banned the use of TBT in marine coatings. At first divers scraped the fouling with hand tools, which was very time consuming, due to the large wetted surface. To fasten this process, a diver operated brush cart was developed. Although brush carts are currently the most common practice for hull cleaning, they also have big disadvantages. The brushes often damage the coating and they do not have a capture system to collect the invasive species which may travel the hull. Almost all big European ports have banned hull cleaning without a capturing system. Due to this regulation, ship owners only have three options for hull cleaning:

- Cleaning at the anchorage area
- Cleaning in a small port where environmental regulations are less strict.
- Cleaning in a big port, by using a new cleaning technique with a capturing system.

For the first two hull cleaning options the vessels must be delayed or rerouted. The third cleaning option is the most favorable, which is why there are several companies trying to develop a cleaning technique with a certified capturing system.

Furthermore, the wetted surface of seagoing vessels is very large and cleaning it by hand is something that can be considered to be very difficult. For big container vessels, the wetted surface is tremendous. For illustrative purpose, the below table shows the calculation of the wetted surface area of the Maersk MC-Kinney Moller (Triple-E efficiency.)(n.d.). Cleaning such a surface within the port time is comparable with cleaning around 4 soccer fields (± 27.000 m^2), within 24 hours. Furthermore, due to the poor underwater sight, you can consider doing this blindfolded.

Figure 4: Cleaning brush cart

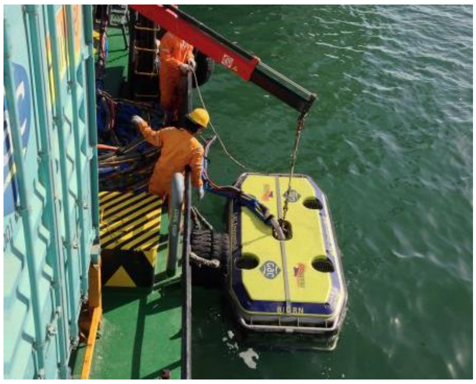


Figure 5: Hullwiper Cleaning R.O.V.

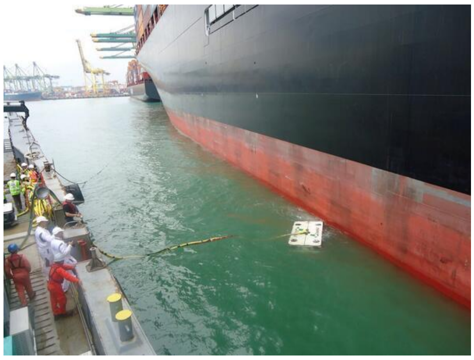


Figure 6: Cleanhull cleaning R.O.V.

Length (L)	399	M
Breadth (W)	58	M
Given draught (D)	15,7	M
Cb (blockcoef)	0,7	M
Cm	0,95	M

$$S = L(2D + W) \cdot sqrt(Cm)\left(0{,}530 + 0{,}632Cb - 0{,}360(Cm - 0{,}5) - \frac{0{,}00135L}{D}\right)$$

Flat bottom	16.199	m^2
Sides	10.783	m^2
Total surface given draught	26.982	m^2

Table 3: Calculation of wetted surface

Lastly, commercial diving is not risk free and a recent survey and analysis of fatal accidents in the commercial diving sector showed that there have occurred 577 diving fatalities over the last 40 years (Showalter et al., 2005). The below figure shows the distribution in more detail.

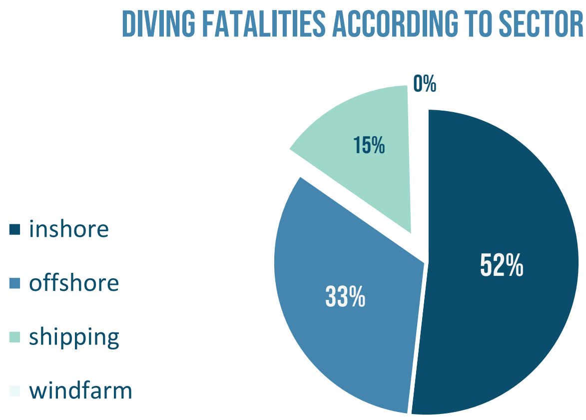


Figure 7: Pie chart of diving fatalities

1.3 FLEET CLEANER

Fleet Cleaner is a new Dutch innovative company that developed a Remote Operated Vehicle (R.O.V.) system that cleans ships in strictly regulated ports. The company developed their system after studying the desires from big shipping companies and implemented these desires as boundary conditions for the development process.

The first prototype was constructed to create a proof of principle. This prototype was a magnetically attached robot that is capable of driving under and above the waterline. With this prototype, the working principles were proven, and the innovative technology was patented. The company started the development of a commercial unit and in April 2017, Fleet Cleaner cleaned its first commercial vessel in the Port of Rotterdam.

The hull cleaning installation consists of a robot and many supporting systems that deliver the (hydraulic) power, the data processing and filters the wastewater. This entire support system has been located on an old sand hopper, which is currently used as hull cleaning support vessel.

1.4 PROBLEM FORMULATION

To successfully develop a hull cleaning installation, a lot of research has been done to develop the cleaning robot. The result is a complex machine that uses high pressure water, hydraulic power and pressurized air to drive over a ships surface and clean it simultaneously. The development of this robot took several years and will continuously be updated and improved during its usage.

The other part of the installation is the support vessel which includes all the supporting elements. The current installation is an old sand hopper with a deck full of pumps, filters, computers, etc. This configuration of vessel and supporting elements is developed in a relative short time period and is not ideal configurated. It has been built with modular supporting elements, which makes it easy to adjust if necessary.

Current vessels that are used for, by example, fishing, dredging or pipe-laying all have different shapes, sizes and arrangements. For Fleet Cleaner, operating in hull cleaning is new and there is not yet an ideal support vessel for their custom operation.

Since the first cleaning operation, Fleet Cleaner has learned that the demand for their services is rapidly growing. It is clear that one of Fleet Cleaner's installation can be more than fully booked serving the Amsterdam, Rotterdam, Antwerp and Gent area (ARAG). Therefore, this area will be the scope of operation for this conceptual design.

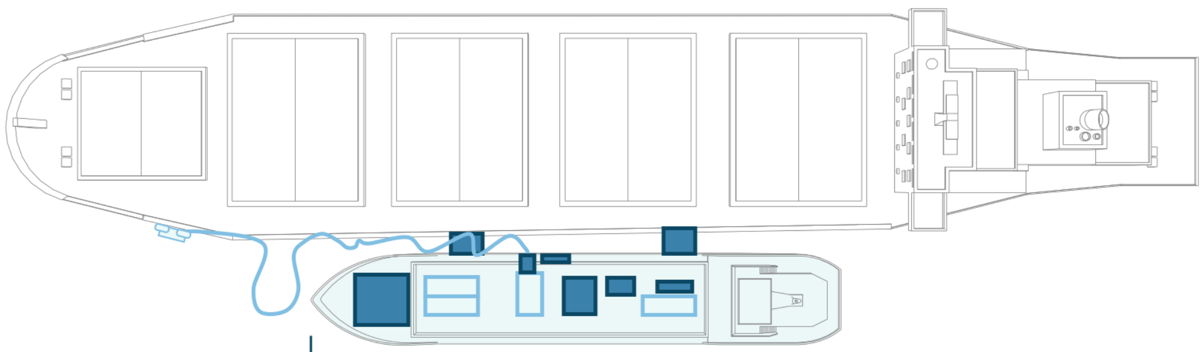
The main objective of this Thesis is to develop a conceptual design of a hull cleaning support vessel in the ARAG area.

With this conceptual design Fleet Cleaner has insights on the configuration for their support vessels and can therefore optimize their service.

To obtain the conceptual design for a hull cleaning support vessel in the ARAG area the current support vessel is analyzed thoroughly. After the limitations are found, multiple principles are researched that can possibly solve the limitations. Finally, a concept is designed which combines current working principles in an optimal way.

1.5 THE SCOPE OF THIS THESIS

The scope of this Thesis is to design a conceptual design for the entire hull cleaning installation besides the Fleet Cleaner installation (the R.O.V. itself, her internal support system and her umbilical). The illustration below gives a clear overview on what is in the scope of this Thesis and what is excluded.



SCOPE OF THIS THESIS	EXCLUDED FROM THE SCOPE OF THIS THESIS
SUPPORT VESSEL	FLEET CLEANER R.O.V. + UMBILICAL
UMBILICAL GUIDANCE	CONTROL ROOM AND STORAGE ROOM
SYSTEM TO CREATE A SAFE DISTANCE	HP WATER AND HYDRAULIC POWER CONTAINER
LAUNCH AND RETRIEVAL SYSTEM	UMBILICAL REEL
ACCOMMODATION	FILTERING CONTAINER
ELECTRICAL POWER SUPPLY	

Figure 8: Schematic overview of the scope of the design

The Fleet cleaner installation consists out of all the equipment needed to have the robot operational. This part is excluded from the scope of this Thesis. This thesis focusses solely on the support vessel and the equipment to support the Fleet Cleaner installation in the ARAG.

To further understand the system principles of the support vessel it is important to understand her functionality. The basic functions of the support vessel are:

- Support the hull cleaning installation
- Provide a safe working environment
- Transport the hull cleaning installation to the vessel that need to be cleaned

The lead time for constructing a new vessel is too long and is economically not feasible for Fleet Cleaner. Therefore, the design of this Thesis is restricted to the conversion of existing inland vessels.

1.6 THESIS APPROACH

The main objective of this thesis is to make a conceptual design of a support vessel. The concept will fulfill the functions that are listed in chapter 1.5 and simultaneously optimize productivity, safety of life, safety of the environment and maintenance. To cover this objective, this thesis is divided in three sub-objectives. Concurrent to the three sub-objectives, this Thesis is split up in three parts. The figure below gives a clear overview of this Thesis build-up.

MAIN OBJECTIVE	PART	SUB-OBJECTIVES	APPROACH
	PART 1	Identify the main limitations of a hull cleaning support vessel	- Literature study on support systems - Literature study on support vessels - Literature study on limitations
DEVELOP A CONCEPTUAL DESIGN OF A HULL CLEANING SUPPORT VESSEL	PART 2	Develop the optimal working principles for a hull cleaning support vessel	- Establish the constraints - Establish the requirements - Combine working principles
	PART 3	Present the developed model	- Present the embodiment of design - Provide conclusions and recommendations

Table 4: Overview of research structure

This Thesis contributes to the industrial and academic field. The many variables that need to be considered around the support vessel demand a structured academic analyzing method which combines currents concepts and innovation to develop a concept vessel that is primary designed for hull cleaning. The hull cleaning operation is a relatively new operation and there are currently no vessels constructed exclusively dedicated for hull cleaning. Developing and arranging a “new” type of vessel is a challenging objective.

Fleet Cleaner will benefit enormously from the research and outcome of this Thesis, since it is one of their goals to optimize their operation. This Thesis will help with their ambition to build more installations and corresponding support vessels. When the next installation is constructed, this thesis will be used to design the support vessel in the ARAG and will be the starting point for other locations.

Part I - Support systems

The first sub-objective of this thesis is to identify the main limitations of a hull cleaning support vessel. To achieve this goal, a thorough analysis will be given on support vessels that are currently used for hull cleaning and other maritime services.

MAIN OBJECTIVE	PART	SUB-OBJECTIVES	APPROACH
DEVELOP A CONCEPTUAL DESIGN OF A HULL CLEANING SUPPORT VESSEL	PART 1	Identify the main limitations of a hull cleaning support vessel	- Literature study on support systems - Literature study on support vessels - Literature study on limitations
	PART 2	Develop the optimal working principles for a hull cleaning support vessel	- Establish the constraints - Establish the requirements - Combine working principles
	PART 3	Present the developed model	- Present the embodiment of design - Provide conclusions and recommendations

Table 5: Overview of research structure (Part 1)

CHAPTER 2 – HULL CLEANING OPERATION DURING PORT CALL

This chapter describes the procedure of a hull cleaning operation when a seagoing vessel enters the port.

2.1 BERTHING OF A SEAGOING VESSEL

When a seagoing vessel is coming to a port, it usually first waits at the anchorage area until the terminal berth is available for loading or unloading. Just before the vessel enters a port area, it is obliged to have a certified pilot onboard. Usually this pilot is brought onboard by a high-speed vessel. If the vessel is deeply loaded or the sea is too rough, the pilot can be brought onboard by a helicopter. Subsequently the seagoing vessel will be assisted by towing boats that help the vessel align and berth. Successively, the linesman comes with smaller boats to assist the seagoing vessel with their lines. Finally, the vessel is safely berthed and ready for the discharge operation.

Figure 9: Berthing of seagoing vessel

2.2 TYPES OF BERTHS

There are multiple types of berths available in a port. For a hull cleaning operation, a separation is made in two types of berths. The distinction is based on the possibility to berth the support vessel at each side of the seagoing vessel.

Quay-typed berths

The quay-typed berth is whenever a seagoing vessel is moored directly to land. This is the most used principle. This configuration results that the hull cleaning support vessel is only able to moor at one side of the seagoing vessel.

Figure 10: Quay typed berth

Buoys-typed berths

The buoy-typed berth is a berth without any direct connection between the vessel and land. These berths are mostly used for ship-to-ship transport, or as a layby berth when seagoing vessels must wait or have maintenance. The most common manners are either Buoys or Dolphins, which are illustrated below.

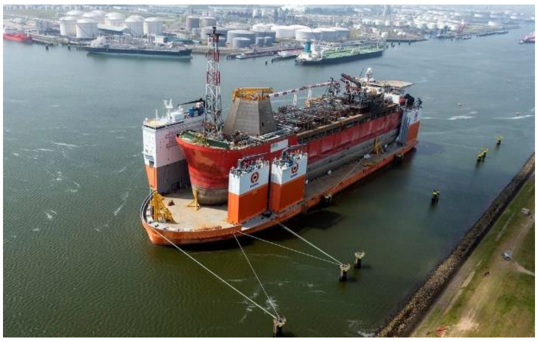


Figure 11: Dolphins

Figure 12: Buoys

The main goal of Fleet Cleaner is to deliver the hull cleaning service without causing any downtime. Meaning that the cleaning operation does not interfere with the normal cargo operations. Therefore, the hull cleaning must be able to clean vessels at both quay-typed and buoys-typed berths.

2.3 OPERATIONAL PROCEDURE OF THE HULL CLEANING OPERATION

The following enumerated actions describe the process of a hull cleaning operation for a seagoing vessel at berth.

1. Operator crew board the support vessel

The hull cleaning operation is executed by two Fleet Cleaner operators. Besides the operators, the captain and his deckhand are responsible for the sailing of the support vessel. Both operators need to board the vessel before the support vessel heads to the cleaning area. When onboard, a briefing takes place with both the R.O.V. operators and the ship's crew.

2. Sailing the support vessel to the cleaning location and checking the system

After the briefing, the vessel sails to the cleaning location. Simultaneously the operators start up the cleaning system and check whether all systems are working properly.

3. Deploying the fendering system

When the support vessel is close-by the seagoing vessel at a quiet and safe place, the fenders are deployed using the crane. They are then tied to ship creating a safe working distance between the support vessel and the seagoing vessel. This safe working distance protects workers from failing objects such as twist locks etc.

4. Berthing alongside the seagoing vessel

The hull cleaning support vessel berths alongside the seagoing vessel. The crew of the seagoing vessel lower thin pulling lines to the hull cleaning support vessel. These lines are then tied to the bigger ropes of the support vessel. The crew on the seagoing vessel then pulls the ropes up and ties the end to the seagoing vessel. Lastly the support vessel uses a winch to create the final tension and the ropes are tight on the support vessel. The engine is shut off and water-based activities can be started.

5. Deploying umbilical

First, all the cables in the umbilical are detached from the support vessel. Then the umbilical deployment begins. Depending on the size of the vessel and the scope of cleaning, a specific part of the 150m long umbilical is deployed into the water. Lastly the cables are attached again.

Figure 13: Umbilical storage

6. System check, switching magnets on

The system is checked again, and the magnets are switched on and tested.

7. Attachment of the R.O.V. to the seagoing vessel

The R.O.V. is lifted in a crane and turned from a horizontal to a vertical position. Since the R.O.V is attached at three points it can make this rotation. This maneuver is done by using the winch on the crane which lowers the attachment point in the middle and therefore increases the tension in the upper webbing slings. It is then moved to the ship's hull and the R.O.V. operator attaches it.

When it is attached, the crane is lowered, and the webbing slings are detached from the crane. The crane is rotated back to its origin.

8. Cleaning in progress

The cleaning operation continues and the R.O.V. makes straight lanes cleaning the complete surface.

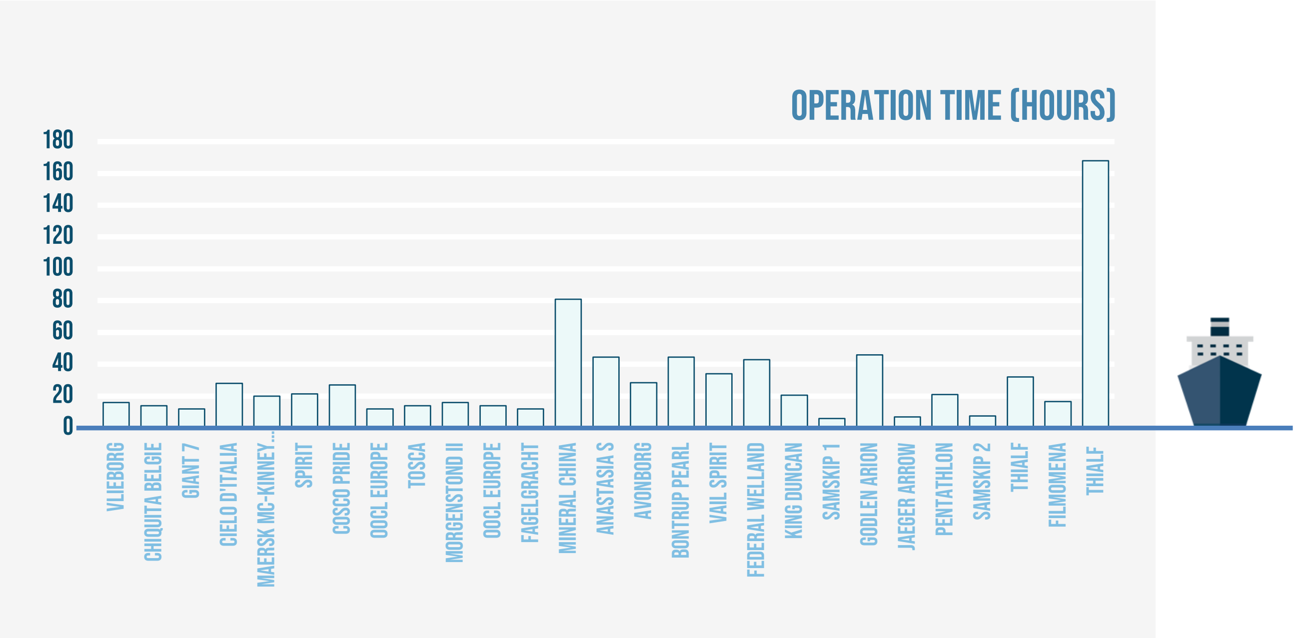


Figure 14: Overview of operational hours

The graph above gives the amount time needed as experienced during the cleanings done in the previous year. The time that it takes to clean a vessel depends on:

- The size of the vessel
- The amount and type of fouling
- Whether only the vertical sides or also the large flat bottom need to be cleaned

As can be seen in the above figure, the operational time of the Thialf exceeds the average cleaning time tremendously due to the difficult shape of the vessel and the extremely large surface.

To make a realistic estimation of the time needed for a cleaning, the Thialf is left out of the calculation, setting the maximum number of operational hours to 81.

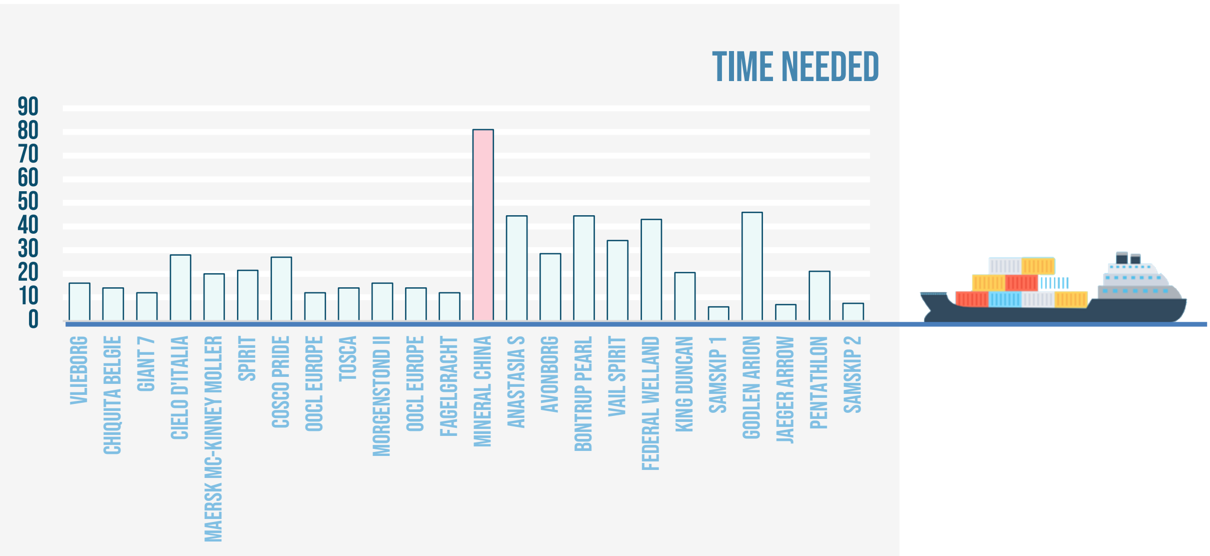


Figure 15: Corrected overview of operational hours

A general shift of an operator is 8 hours. Whenever a cleaning takes longer, operators are substituted by a new shift taking over. The new shift either stays onboard or will be brought and picked up by the linesman boat.

Although the Fleet Cleaner installation is continuously improving in speed, it means that for cleaning the Mineral China approximated 11 crews were needed. This means that 10 taxies were needed from the linesman.

Ideally the robot is only retrieved when the surface is fully cleaned. However, the robot often also needs retrieval when it has fallen off or when maintenance is needed.

9. Cleaning terminated

Whenever the cleaning operation is terminated, the first thing that needs to be done is to shut off the magnets and the system. If not, the R.O.V. picks up every steel object ever fallen into port at that location.

Figure 16: Magnetic connection

10. Umbilical retrieval

After the cleaning is terminated, the cables are detached from the umbilical reel. Then the umbilical is retrieved with the use of the umbilical reel. The R.O.V. is dragged over the seabed and will finally come floating to the sea surface.

11. R.O.V retrieval

When the R.O.V. is floating, an operator grabs a webbing sling with the use of a boat hook. The webbing sling is taped to the R.O.V. and with the use of a boat hook it is pulled onboard. The webbing sling is placed in the crane and the R.O.V. is lifted on the deck. The situation is then the same as before the operation and if the cleaning is not finished yet, the procedure starts over again from action point 5.

12. Departing alongside the seagoing vessel

When the cleaning is successfully finished and there are no more water-based activities, the engine can be started. The lines will be slacked so that the crew of the seagoing vessel can detach them. Finally, the lines are retrieved, and the support vessel sails away to a quiet and safe place.

13. Retrieve the fendering system

At this safe place, the fenders are retrieved with the use of the crane. They are placed back on the deck of the support vessel and the crane is placed back in its original position.

14. Sailing the support vessel to the pick-up location and checking the system

When the fenders are safely secure on deck, the vessel can head back to the pick-up location. The operators simultaneously check, store and clean the equipment.

15. Berth the support vessel at the pick-up location and departure operator crew

When the vessel arrives at the pick-up location, it will berth in her conventional manner. Finally, the Fleet Cleaner operators leave the support vessel and the cleaning operation has ended.

Besides the cleaning operation, the support vessel also has conventional services such as bunkering, waste disposal etc. These activities are planned during downtime or can even take place simultaneously with bunkering.

2.4 OPERATIONAL PROFILE OF THE CURRENT SUPPORT VESSEL

To determine the operational profile of the current support vessel, the Cormoraan, a data analysis is performed on the Automatic Identification System (AIS). This system is obligated for vessel of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. (Resolution A.1106(29))

Combining the AIS data with the internal cleaning data of Fleet Cleaner, this assessment is made.

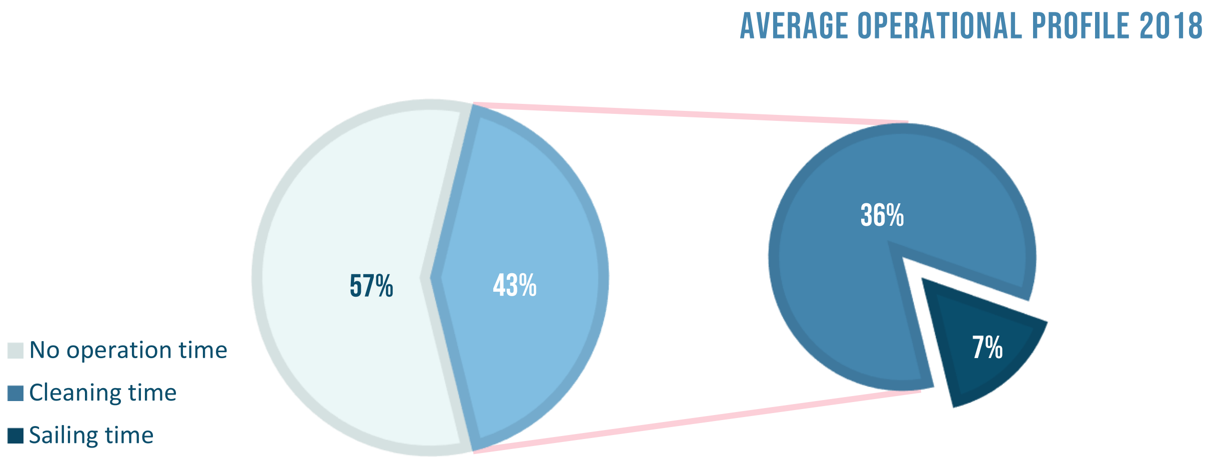


Figure 17: Overview of operational profile of the support vessel

The above figure is based on a 24/7 timeframe. The support vessel has been considered sailing when the vessels speed exceeds 1 knot. Furthermore, the cleaning time has been taken from the reports given to the costumers.

CHAPTER 3 – HULL CLEANING SUPPORT INSTALLATIONS

This chapter describes the support installations that are used by different companies to deliver their hull cleaning service around the world. Each paragraph describes a different company and the support installation they developed for their hull cleaning operation.

3.1 FLEET CLEANER

Figure 18: Fleet Cleaner R.O.V. cleaning above the waterline

3.1.1 General background

Fleet Cleaner is a Dutch company that developed a hull cleaning R.O.V. that is attached with the use of magnets. Supporting the R.O.V., the system needs to deliver electricity, hydraulic power, data, high pressure water, and pressurized air. The fouling is captured and pumped to the support vessel. All these supporting systems are fitted in containers which are placed on an inland vessel. The company currently has one installation and is operational in all Dutch Ports.

3.1.2 The support vessel

The support vessel of Fleet Cleaner in the Netherlands is an old sand hopper named the Cormoraan. Fleet Cleaner experienced the following properties of the current support vessel.

- The vessel has a maximum speed of 12 knots (AIS)
- The vessel has a sleeping accommodation for five people
- The vessel has a deck space of 165 m^2
- Not all deck space is used
- The vessel is not seaworthy
- The vessel needs to be certified to enter petroleum ports
- The vessel is equipped with a winch at the front and at the back of the vessel
- The vessel has a bow thruster
- The vessel always must have a captain and a deckhand

Figure 19: Inland sand hopper

Figure 20: Fleet cleaner support vessel

3.1.3 The support system

Umbilical reel

The R.O.V. is connected to the support vessel with an umbilical. This umbilical is stored on an old agriculture reel which is powered by an electrical power drive. Fleet Cleaner experienced the following properties of the current Umbilical reel:

- It can only (un-) wind when all the cables of the umbilical are (un)plugged
- It takes several minutes to (un)wind
- The rotating wheel without cover can create an unsafe situation
- The force on the umbilical is accumulated on pressure points

Figure 21: Agriculture reel

Crane

To attach the R.O.V. to the vessel, a crane with a winch is used. The crane can lift the R.O.V. and with the use of the winch it can be rotated from a horizontal to a vertical position.

- Uses the combination of crane and winch to rotate R.O.V.
- The maximum workload of the crane is 1170 Kg (fully extended 20,5m)

Overflow storage

The old sand hold of the Cormoraan is filled with empty containers which have a double function. Not only do they act as a foundation of the working deck, they also act as an overflow storage for whenever the filter installation is malfunctioning.

- It creates a strong foundation for the working deck
- It creates an overflow capacity

Portable security video system

To protect the equipment from thieves a portable security video system is placed on the support vessel.

- It has a security provision

Generator

The support system needs electrical power to operate. A mobile generator is placed on deck with an Intermediate Bulk Container for storage of fuel. (IBC).

- The IBC has a capacity of 3.000 liters which is enough for 100 working hours
- The generator delivers 400 KW

Filtering container

To prevent the Port from being polluted, the Dutch Authorities have strict regulations for the filtering system of a hull cleaning installation. (artikel 6.2, eerste lid, onder a., van de Waterwet, n.d.). The wastewater cannot be dumped if it:

1. Is visible polluted by coating or particles
2. Contains more than 100 mg/l of unsolved particles
3. Contains more heavy metals then 5 mg/L

To meet these criteria, Fleet Cleaner have developed a filtering installation consisting of multiple filtration steps.

The water comes out of the umbilical it will enter the first step of filtration. This filtration step is a continuous process and is based on a rotating tube that is cleaned by nozzles from the inside of the tube. The illustration below illustrates the first filtering step.

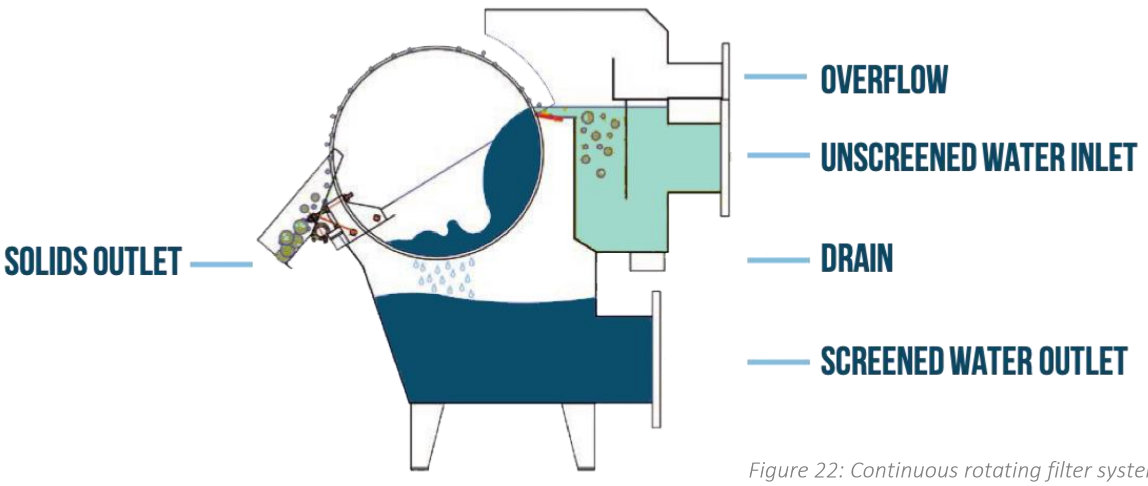


Figure 22: Continuous rotating filter system

The second filtering step is also a continuous process, but the filtering is based on a different principle. This step is based on a meshed conveyer belt. When the residue on the conveyer belt is not letting the water pass, the water level will rise. A sensor measures the water level and when the water level is too high, the conveyer belt will turn a clean piece of conveyer that is able to let the water pass again. The advantage of this system is that because the conveyer belt is cleaned with an air knife, the residue is relatively dry and therefore easier to transport.

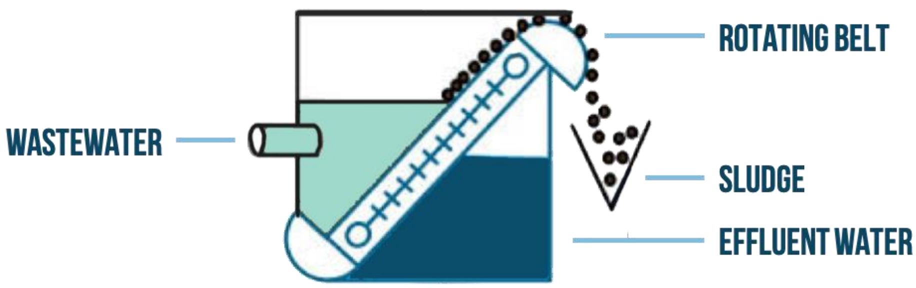


Figure 23: Continuous filter belt system

The last step of the filtering system is discontinuous. It is a combination of bag filters. These filters are relatively cheap and can be easily disposed in the normal waste treatment. The two filter bag systems are placed parallel so that the filters can be replaced without stopping the process. First a filtration step of 25mu is made and finally the wastewater is filtered until 1mu.

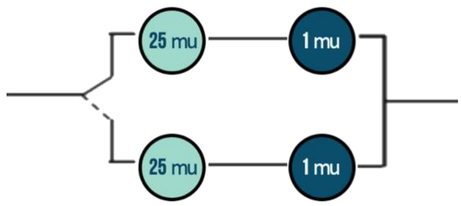


Figure 24: Discontinuous filter bags

Fleet Cleaner experienced the following properties of the current filtering installation:

- It meets the criteria for filtering up to the standard of the Dutch authorities.
- It is spacious
- It is a continuous process

Water, air and hydraulic container

High pressure water system

To create high-pressure water from seawater, multiple steps must be taken. The general overview of the water flow system is given in the figure shown.

The high-pressure water system has the following properties:

- Maximum working pressure water should be 350 bar
- The maximum water flow is 80 l/min

Hydraulic pressure system

To power all the hydraulic motors and cylinders, a hydraulic power pack is installed into the container.

- The maximum working oil pressure should be 200 bar
- The maximum flow is 134 l/min

HP COMPONENTS

1. Sea water
2. Feed pump
3. Coarse filter
4. Water tank
5. Pre-pressure pump
6. Filter
7. High pressure water pump
8. Overflow
9. Flow to umbilical

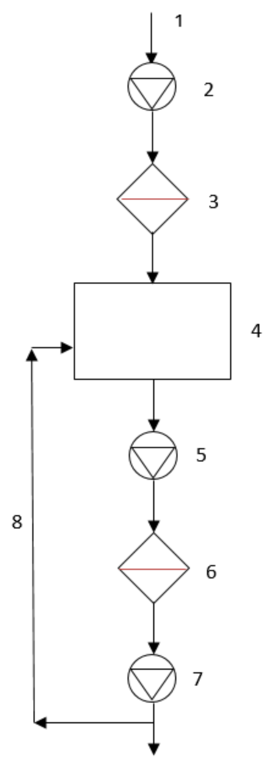


Figure 25: High-pressure water system

Pressurized air system

The air system provides the necessary air pressure that is needed for the on/off switching of the magnets. Also, the compressed air can be used for cleaning parts with an air gun.

- The maximum working air pressure should be 12 bar
- The maximum flow is 400 l/min

Control and storage container

The last part of the Fleet Cleaner support system is the control and storage container. One side of this container is used as a storage room for spare parts and to store the Fleet Cleaner safe and clean when it is not used.

Figure 26: Control room

The other side of the container is the control room. In the control room the robot is operated by two operators. In the control room there are multiple screens to have good visual of what happens with the robot while it is cleaning the vessel's hull.

3.1.4 Modularity

The Fleet Cleaner support system is currently all fitted in standard 20 feet containers and an umbilical reel. The only exception is the crane which is welded into the side of the support vessel. The advantage of this configuration is that the containers can be placed on any support vessel that has enough space for the installation. Furthermore, experience has learned Fleet Cleaner that ability to change complete systems has been very valuable.

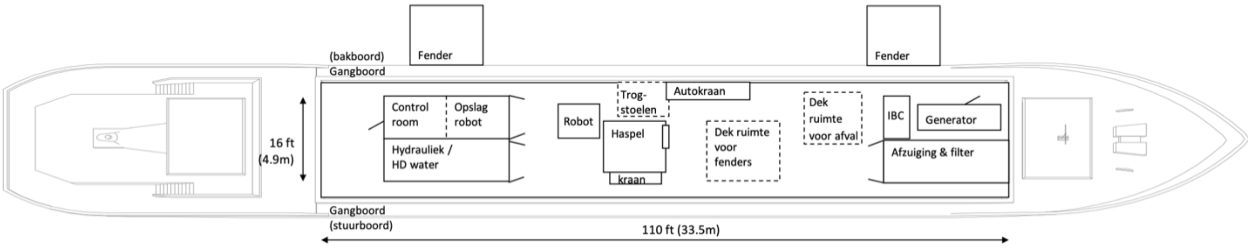


Figure 27: Fleet Cleaner's overview of equipment

The downside of the modular design is that the vessel is not really constructed efficient and that certain parts, such as pumps and generators are placed in a support container although the support vessel has them already onboard.

One of the important problems of the current design is that it is uncomfortable for the operational crew to work and therefore decreases productivity. The crew prefers not to sleep in the accommodation. This results that crews must be brought and picked up by a linesman. This not only brings extra costs, but also causes problems with the transfer of cleaning information. Furthermore, if the accommodation is suitable to be slept in, the backup crew could be woken up for maintenance during emergency situations.

3.2 GAC

3.2.1 General background of GAC

The Gulf Agency Company (GAC) is a shipping agency company that is originally from the United Arab Emirates. It is a privately-owned shipping agency that bought The Hullwiper technology and is delivering the hull cleaning service with it. (Doran, 2016).

Figure 28: GAC Hullwiper

The Hullwiper is a thruster propelled underwater drone which presses itself against the vessels hull. It cleans the surface with the use of high-pressure water jets. Currently GAC's Hullwiper is operational in the following locations:

- Port of Said and Port of Suez in Egypt
- Port of Algeciras in Spain
- Port of Singapore
- Port of Gothenburg, the Sound, Great Belt and Skaw areas in Scandinavia
- Port of Rotterdam in The Netherlands
- Port of Southampton in the United Kingdom
- Port of Khalid, Port of Rashid, Port of Fujairah and the Port of Jebel Ali in UAE. Also serving the Port of Qatar in the Gulf Cooperation Council (GCC

Figure 29: GAC global stations

3.2.2 The support vessels

The support vessel of each of the locations of the GAC installation is different and is described for each location independently. Sadly, but understandable, not all the companies show their support vessel in detail and only the properties of a support will be described if known.

GAC's Hullwiper in Egypt operated by GAC Egypt

In Egypt the Hullwiper is operated by GAC itself. The only information found is figure 30.
("GAC - Egypt", 2014).

Figure 30: GAC Egypt

GAC’s Hullwiper in Spain operated by GAC Spain

In Spain the Hullwiper is operated by GAC itself. There is not much information to be found. Only figure 31 gives information regarding the support vessel. ("GAC - Hull Cleaning Solution", 2017).

Figure 31: GAC Spain

GAC’s Hullwiper in Singapore operated by T&T Salvage

In Singapore the Hullwiper is operated by a company that is providing a wide range of services including OPA 90 response, salvage, diving and marine firefighting services. The following two pictures are found showing the Hullwiper installation on two different vessels ("T&T salvage", 2015).

Figure 32: GAC Singapore

The first vessel could not be found. The second vessel is the SSE CAMELIA. This vessel is an oil spill response vessel as well as a dive support vessel and has the following properties:

- The support vessel is 24m x 6,0m x 2m
- The support vessel is seaworthy
- The support vessel has a max. speed of 10 knots
- The support vessel has a standard accommodation for people
- The support vessel needs to be certified to enter petroleum ports

Figure 33: SSE CAMELIA Singapore

GAC’s Hullwiper in Scandinavia operated by Frog marine services

In Scandinavia the Hullwiper is operated by a Scandinavian diving company named Frog Marine Services. The support vessel of this installation is a tug vessel named the Frog Taurus. ("GAC EnvironHull - Hull cleaning solutions - World Cruise Industry Review", 2017)

Figure 34: Frog Taurus

This support vessel has the following properties:

- The support vessel has a maximum speed of approximately 7.1 knots
- The support vessel has accommodation for six people
- The support vessel is seaworthy
- The support vessel needs to be certified to enter petroleum ports

GAC's Hullwiper in the Netherlands operated by Holland Diving International

In the Netherlands the Hullwiper is operated by a Dutch diving company named Holland Diving International. The support vessel of this installation is a pontoon without any propulsion. If the pontoon needs to be replaced, a push/towing vessel is hired to push. (Barten, 2018)

Figure 35: Ponton Holland Diving Int.

This support vessel has the following properties:

- The support vessel has a maximum speed of approximately 8 knots
- The support vessel has no standard accommodation for people
- Not all deck space is used
- The support vessel is not seaworthy
- The support vessel needs to be certified to enter petroleum ports
- Relatively less costs during downtime

GAC's Hullwiper in the United Kingdom operated by GAC Southampton

In the United Kingdom the Hullwiper is operated by GAC itself. The only information found is figure 36. ("HullWiper - HullWiper launches pilot scheme at Port of Southampton", 2018)

Figure 36: GAC Southampton

GAC's Hullwiper in the middle east is operated by GAC Middle East

In the Middle East the Hullwiper is operated by GAC itself. The only relevant information found is on figure 37. ("GAC EnvironHull launches HullWiper Middle east", 2013)

Figure 37: GAC Middle east

This support vessel has the following properties:

- The support vessel is seaworthy
- The support vessel has a standard accommodation for people

3.2.3 The support system

The support system of GAC is shipped in containers and all have the similar configuration.

Umbilical storage

The R.O.V. is connected to the support vessel with an umbilical. This umbilical is stored hanging on hooks. The slacking of the umbilical is done by hand.
The umbilical storage has the following properties:

- The (un)winding of the umbilical is done by hand
- It takes several minutes to (un)wind
- The accumulated force on the umbilical cannot be large as it is pulled by a person
- It can create unsafe situations if an umbilical is handled by someone during storms

Crane

As the R.O.V. does not need to be attached to the vessel, the crane is only needed to deploy the R.O.V. into the water. The crane has the following properties:

- It can be shipped with the installation and uses the foundation of the shipping container to counterbalance destabilization forces during operation.
- The maximum workload of the crane is unknown but must be able to carry the R.O.V. Which is assumed to have a maximum weight of 1.000 kg.

Figure 38: GAC Crane on support vessel

Filtering installation and overflow storage

The filtering of the wastewater is done on board on the R.O.V. The Hullwiper is pumping the wastewater through a filter bag below the waterline. When the filter bag is full, the R.O.V. needs to be lifted out of the water and the filter bag can be replaced.
This way of filtering has the following properties:

- No need for expensive and spacious filtering installations above the waterline
- No need to pump the wastewater back onboard
- Discontinuous cleaning procedure
- Very debatable whether all the fouling can be filtered by such a simple filtering mechanism.

Generator

The support system needs electrical power to operate. A mobile generator is placed on deck with an IBC.

- The power and fuel usage of the generator is unknown

Water and hydraulic power

The HullWiper is powered with high voltage of 600 volts. Onboard of the R.O.V. a submerged powerpack hydraulically powers the robot and the high-pressure water system.

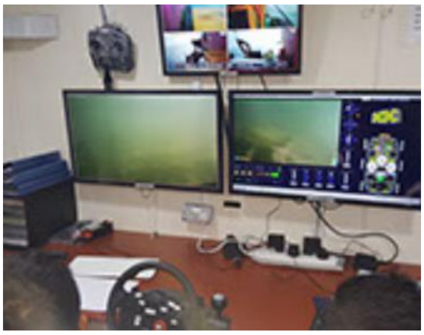


Figure 39: Control and Storage container

Control and storage container

The control room of the Hullwiper is inside a container.

3.3 CLEANHULL

3.3.1 General background of Cleanhull

Cleanhull is a Spanish company based in Gibraltar. They are currently operational in the port of Algeciras with their own developed CleanROV ("Cleanhull", 2016).

Figure 40: Cleanhull R.O.V

As can be seen in chapter 3.2, the CleanROV has great similarity with the Hullwiper. It is as well a thruster propelled underwater drone which presses itself against the vessels hull. Furthermore, it also cleans the surface with the use of high-pressure water jets.

The reason for the similarities is because they were both a resultant of the same concept. The R.O.V.'s were originally designed and build in OSLO by Robert Anderson and James Bassedone. After a disagreement, Mr. Anderson continued with the Hullwiper and Mr. Bassedone continued with Cleanhull.

The difference between the installations is that the Hullwiper has a submerged hydraulic power pack and the CleanROV has placed the power pack above the waterline.

3.3.2 The support vessel

The support vessel used by Cleanhull is an old fishing vessel which is transformed into a hull cleaning support vessel named the Cleanhull Tres.

Figure 41: Cleanhull support vessel

This support vessel has the following properties:

- The support vessel is a former fishing vessel now used for hull cleaning
- The support vessel has standard accommodation for people
- The R.O.V is controlled from within the support vessel

- The support vessel is a seagoing vessel
- The support vessel is 33.99 m x 7,8 m x 3,4 m
- The support vessel has 1.105 KW of engine power
- The support vessel has a service speed of 14 knots

3.3.3 The support system

Control room

The R.O.V is controlled from out a control room within the hull cleaning support vessel.

Crane

As the R.O.V. does not need to be attached to the vessel, the crane is only needed to deploy the R.O.V. into the water. The crane has the following properties:
- It is built within the vessel
- The maximum workload of the crane is unknown but must be able to carry the R.O.V.
- Which is assumed to have a maximum weight of 1.000 kg

3.4 C-LEANSHIP

3.4.1 General background of C-Leanship

C-LEANSHIP AS is founded by the Danish engineer Jesper Hoejer. C-Leanship provides hull cleaning in Singapore, using the ShipShiner Technology, which consists of a Saab remotely operated vehicle and a washing unit, developed by C-leanship. (C-Leanship, 2018)

The Shipshiner is based on the same concept as the CleanROV and the Hullwiper. It is also pushed against the hull with the use of thrusters. The difference with the Hullwiper and the CleanROV is that they claim to have a positioning system. Their partner, Saab is a respectable player in the R.O.V. market. The knowledge regarding underwater positioning can be of great value.

3.4.2 The support vessel

The only picture that can be found is figure 42. Not many information can be gathered other than it is a seagoing vessel and that it has a built-in crane.

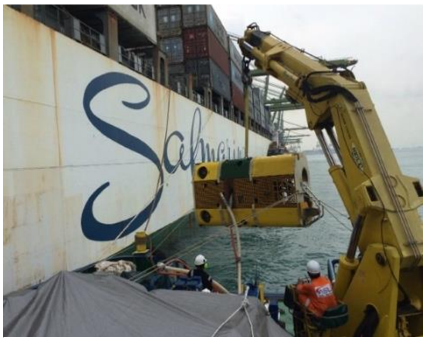


Figure 42: C-leanship crane

3.4.3 The support system

Crane

As the R.O.V. does not need to be attached to the vessel, the crane is only needed to deploy the R.O.V. into the water. The crane has the following properties:

- It is built within the vessel
- The maximum workload of the crane is unknown but must be able to carry the R.O.V.
- Which is assumed to have a maximum weight of 1.000 kg

3.5 CLEANSUBSEA (FORMER GRD FRANMARINE)

3.5.1 General background of CleanSubSea

During the writing of this Thesis, GRD Franmarine changed its name into CleanSubSea ("CleanSubSea -Envirocart", 2016). This Australian diving company has developed a diver operated hull cleaning vehicle named the Envirocart.

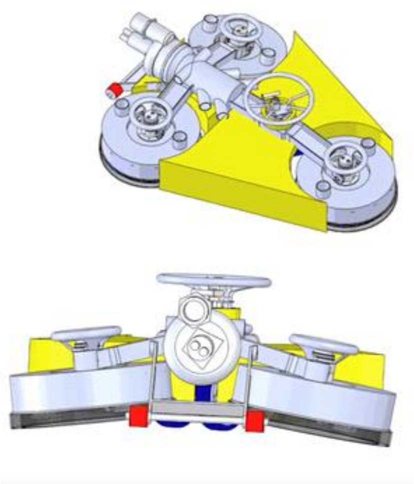


Figure 43: Cleansubsea conceptual design

The Envirocart uses three sets of blades that rotate 20 mm above the surface of the hull. The high-speed rotation creates a powerful vortex that sucks the biofouling from the hull. Furthermore, the fouling and debris is pumped upwards and filtered onshore. The filtering installation consists of multiple steps and can process up to 2.000 liters every minute.

3.5.2 The support vessel

The company claims that the Envirocart is a fully mobile system that can be packed into a standard 20 feet shipping container. After thorough investigation it showed that the company does not use a support vessel. Their operation is fully modular and completely fitted into containers, which can be placed on land or on whatever type of vessel that is big enough to station it on.

Figure 44: Cleansubsea brush cart

3.5.3 The support system

Generator

The support system needs electrical power to operate. A mobile generator is used with an IBC.

- The power and fuel usage of the generator is unknown

Filtering container

The company is not mentioning anything about the particulars of their filtering system. However, in a promotional video, it consists of multiple filtering steps including:

- A conveyer belt type of filtering
- A bag filtering setup
- An UV treatment system

Overflow open IBC

After a filter container, an open IBC acts as an overflow storage until the filtering water gets released into the ocean

Hydraulic powerpack

The Envirocart is powered by hydraulic power which is paced into the top white container in figure 45.

Diving support equipment

The lowest white trailer is full of the diving support equipment. It contains the storage of the diver's umbilical and the provision of air and communication.

Storage container

The top white container stores the R.O.V. and the umbilical.

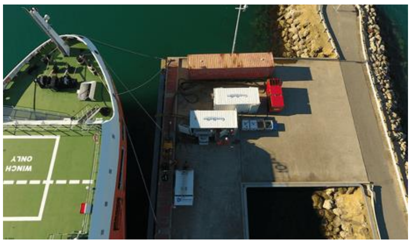


Figure 45: Cleansubsea equipment

3.6 ECO-SUBSEA

3.6.1 General background of ECO-Subsea

ECO-Subsea is founded by the two brothers, Tor M. Østervold and Klaus Østervold. The Norwegian system is currently available in Southampton but can be also shipped to Sweden, Norway or Denmark. They developed a remote-controlled mini-submarine equipped with a cleaning and debris-collection technology. ("Ecosubsea", 2015)

Figure 46: ECO-Subsea R.O.V.

The R.O.V. of ECO-Subsea is based on the same principle as the other R.O.V.'s. Thrusters push the R.O.V. against the hull and it can drive over the surface. However, this system pumps the fouling above the waterline where it is filtered.

3.6.2 The support truck

ECO- Subsea has an interesting concept to support their installation. The Norwegian brothers decided to place all the equipment in a truck instead of on a support vessel.

Figure 47: ECO-Subsea support truck

This truck has the following properties:
- It is modular
- It can be transported easily to other ports
- Relatively less costs during downtime
- It has no sleeping accommodation
- The truck needs to be certified to enter petroleum ports
- It will be difficult to get approval for other terminals besides container and Ro-Ro
- It is not seaworthy
- Uses a trailer-based system

3.6.3 The support system

Generator

The support system needs electrical power to operate. A mobile generator is used with an IBC.
- The power and fuel usage of the generator is unknown

Filtering container

The company is not mentioning anything about the particulars of their filtering system.

High pressure pump

The system cleans with the use of high-pressure waterjets. No more particulars are given regarding the high-pressure water pump.

Launch and recovery system

The system is deployed using a crane. The umbilical goes on a separate winch which is attached to the crane. The R.O.V. can be retained by the umbilical.

Storage container and cockpit

The left cabinet is the cockpit and storage unit of the system.

3.7 TABLE OF PROPERTIES LEARNED FROM HULL CLEANING COMPANIES

PROPERTIES SUPPORT VESSEL	FLEET CLEANER	GAC	Cleanhull	C-Leanship	CleanSubSea	ECO-Subsea
Use a support vessel	✓	✓	✓	✓	✓	
Uses a trailer-based system						✓
The support vessel has a maximum speed of 7.1 knots		✓				
The support vessel has a maximum speed of 8 knots	✓					
The support vessel has a maximum speed of 10 knots		✓				
The support vessel has a maximum speed of 12 knots		✓				
The support vessel has a maximum speed of 14 knots			✓			
The support vessel has a standard accommodation for people		✓	✓			
The support vessel has an accommodation for five people	✓					
The support vessel has an accommodation for five people		✓				
The support vessel/ truck has no accommodation						✓
Not all deck space is used	✓	✓				✓
The support vessel is seaworthy		✓	✓	✓		✓
The support vessel is not seaworthy	✓	✓				✓
The support vessel needs to be certified to enter petroleum ports	✓	✓				✓
The support vessel has winches	✓					
The support vessel has a bow thruster	✓					
The support vessel always has to have a captain and a linesman	✓					
Only allowed at RoRo terminals						✓
The support vessel is 24m x 6,0m x 2m		✓				
The support vessel is 33,99m x 7,8m x 3,4m			✓			
The support vessel has a deck space of 165 m2	✓					
Relatively less costs during downtime		✓				
The support vessel has 1.105 KW of engine power			✓			
The support vessel has 265 KW of engine power	✓					
The support vessel is a dedicated hull cleaning support vessel			✓			

Table 6: Table of properties support vessel

PROPERTIES SUPPORT SYSTEM	FLEET CLEANER	GAC	Cleanhull	C-Leanship	CleanSubSea	ECO-Subsea
Stores the umbilical on a reel	✓					
Stores the umbilical by hanging it on hooks		✓				
Unable to unwind while the umbilical is connected	✓					
Umbilical takes several minutes to (un)wind	✓	✓				✓
The Umbilical can create unsafe situations	✓	✓				✓
The force on the umbilical cannot be large as it is pulled by a person.		✓				
The force on the umbilical is accumulated on pressure points	✓					
Uses the combination of crane and winch	✓					✓
Has an overflow storage	✓				✓	
Has a security provision	✓					
The IBC has a capacity of 3.000 liters which is enough for 100 working hours	✓					
The generator delivers 400 KW	✓					
The filtering system meets the criteria of the Dutch regulations	✓	✓				
The high-pressure water pump has a maximum working pressure of 350 bar.	✓					
The maximum water flow should be 80 l / min	✓					
The hydraulic pressure should have an oil pressure of 200 bar	✓					
The hydraulic power should have a flow of 134 l/min	✓					
The system uses a hydraulic power pack	✓				✓	
The support system uses high pressurized air	✓					
The high pressurized air should have a maximum working pressure of 12 bar	✓					
The high pressurized air should have a maximum flow of 400 l/min	✓					
The support system has a separate control room	✓	✓				✓
The support system has a separate storage and maintenance room	✓				✓	
The support system is modular	✓	✓			✓	✓
The crane is modular and shipped with the support system		✓				✓
The crane has a capacity of lifting 1.000 kg	✓	✓				✓
There is no filter system above the waterline		✓	✓			
There is pump that needs to pump up the wastewater	✓			✓	✓	✓
There is no continuous cleaning procedure		✓	✓			
The support system has a generator	✓	✓	✓	✓	✓	✓
The support system has a IBC	✓	✓	✓	✓	✓	✓
The crane has a capacity of lifting 1.000 kg				✓		
The support vessel has a build in crane	✓		✓	✓		
The crane uses the foundation of the container for its strength	✓					✓
The control room is inside a container	✓	✓				✓
The control room is within the support vessel			✓			
The filtering system consist out of multiple steps	✓				✓	✓
The filtering system solely consist out of a bag filter		✓	✓			
The support system also has diving equipment		✓	✓		✓	

Table 7: Table of properties support vessel

CHAPTER 4 – MARITIME SUPPORT INSTALLATIONS

This chapter describes several maritime support installations that have a similar function of supporting a maritime technical service in the ARAG area.

4.1 CONVENTIONAL FOSSIL FUEL BUNKERING VESSEL

Bunker suppliers are one of the oldest maritime service providers in the port. In 2005, the ten biggest bunker companies controlled around 20 to 25 percent of the market. Today that's over 50 percent (Demant, 2015). The Port of Rotterdam is after Singapore and Fujairah, the third biggest bunkering port in the world with an annual sale of 10.5 million metric tons of fuel. (Ship and bunker, 2016)

To analyze the current configuration of bunker vessels, a known modern big bunker vessel is studied named the Vorstenbosch. This vessel is owned by the Verenigde Tankrederij (VT) and is the biggest bunker vessel of Europe. (Witte, 2011)

Figure 48: Vorstenbosch tanker & control room

This bunker vessel has multiple innovations implemented. One of the innovations is that they used a different type of construction, the so called Scheldehuid-type. Due to this construction, these structures are less sensitive for leakage and therefore allowed to carry more cargo. Normal tanks are not allowed to carry more than 380 m3 per tank, in contrary to the 1.000 m3 a Scheldehuid-type tanker can carry ("Bureau Voorlichting Binnenvaart - Vorstenbosch", n.d.)

Figure 49: Scheldehuid-type tanker

This bunker vessel has the following properties:

- The bunker vessel is 147 m x 23 m x 5,4 m
- The bunker vessel has a deck space of 2.500 m^2
- Capable of transporting 13.317 ton (553 trucks)
- The bunker arm can reach 35 m high
- The bunker arm is equipped with a stairway and safety provisions
- There is an advanced navigation and cargo system
- The support vessel is equipped with a winch at the front and at the back of the vessel
- The bunker vessel is equipped with a Dynamic Positioning system
- The bunker vessel is equipped with a "Scheldehuid"
- The bunker vessel has 4.473 KW of engine power
- The bunker vessel has a maximum speed of 10 knots
- The bunker vessel has an accommodation
- The vessel is certified to enter petroleum ports

Another interesting concept is that the VT runs a pilot program on another vessel of their fleet named the Valburg. This vessel is equipped with a magnetic connection system called the Docklock (Schuttevaer, 2014).

Figure 50: Valburg equipped with Docklock

Due to the Docklock system, a vessel can be moored efficient and without the use of people. It is also compensating for waves and height differences due to tied difference. The company claims that mooring takes 10 seconds, unmooring 5 seconds.

4.2 LNG BUNKERING VESSEL

The Shell Western LNG B.V. Trading Rotterdam B.V. (Shell) hyper-modern bunker vessel Cardissa has arrived in the Rotterdam port approach area. This ocean-going vessel enables Shell to supply clients throughout Europe with liquefied natural gas (LNG) from the Gas Access to Europe (Gate) terminal in Rotterdam. The Cardissa can carry 6,500 m3 LNG (Port of Rotterdam, 2017).

Figure 51: Shell's Cardissa

This bunker vessel has the following properties:

- The bunker vessel is 120 m x 19,4 m x 5,8 m
- The bunker vessel can transport 6.500 m^3 LNG
- Capable of loading 1.000 m^3 LNG per hour
- The bunker vessel is seaworthy
- The bunker vessel has a maximum speed of 11 knots
- The bunker vessel has accommodation
- The bunker vessel is certified to enter petroleum ports

4.3 WASTE RETRIEVAL VESSEL

Another service which is delivered during port time is the retrieval of waste. Logically, the seagoing vessel produces waste, and during their voyage they are storing this onboard. To investigate the waste retrieval vessel, a Dutch vessel of Bek & Verburg is studied.

Figure 52: Invotis IX

The Invotis IX is a new innovative waste retrieval vessel which operates in the Port of Rotterdam. It uses a big crane very similar to the bunker vessel to retrieve the waste from the higher seagoing vessels.

The Invotis IX is a hybrid vessel, propelled by a Diesel-Electric engine. It is capable of sailing one hour fully electric and then needs an hour to fully recharge the battery. Furthermore, it uses Gas To Liquid (GTL) which gives less emission than traditional fuel. Lastly, they separate almost all the waste and only 7% of the collected waste is not recycled (Van Wendel de Joode, 2017).

This waste retrieval vessel has the following properties:

- The support vessel is 44 m x 9 m x 4,9 m
- The support vessel has a maximum speed of 8,9 knots
- The support vessel has accommodation
- The engine of the waste retrieve vessel is Diesel-electric
- The support vessel is equipped with a crane
- The support vessel is certified to enter petroleum ports

4.4 OIL SPILL VESSEL

Whenever an oil spill occurs, the polluter needs to make sure it gets cleaned up as soon as possible. To do such a service, special Oil Spill Response (OSR) Vessels are designed. To investigate such support vessels, the HEBO-CAT 5 is further investigated. (HEBO, 2005)

Figure 53: HEBO-CAT 5

As can be seen in the above, the HEBO-CAT 5 is a catamaran shaped vessel. The unique feature of this vessel is that it has two hydraulic arms which can widen and collect all the surface oil.

This waste retrieval vessel has the following properties:

- The support vessel is 28,55m x 13,32 m x 2,02 m
- The support vessel has a maximum speed of 11 knots
- Total beam of sweeping arms is 19 m
- High pressure washer is delivering 2 x 300 bar
- The support vessel is equipped with a high-pressure water pump
- The support vessel is equipped with a hydraulic powerpack
- The support vessel is equipped with two hydraulic cranes

4.5 TABLE OF PROPERTIES LEARNED FROM MARITIME SUPPORT INSTALLATIONS

PROPERTIES SUPPORT SYSTEM	Vorstenbosch	Cardissa	Invotis IX	HEBO-CAT 5
She is 147 m x 23 m x 5,4 m	✓			
The bunker vessel is 120 m x 19,4 m x 5,8 m		✓		
The support vessel is 44 m x 9 m x 4,9 m			✓	
The support vessel is 28,55m x 13,32 m x 2,02 m				✓
She has a deck space of 2.500 m2	✓			
Capable of transporting 13.317 ton (553 trucks)	✓			
The bunker arm can reach 35 m high	✓			
The bunker arm has a stairway and safety provisions	✓			
There is an advanced navigation and cargo system	✓			
The support vessel is equipped with a winch at the front and at the back of the vessel	✓			
The bunker vessel is equipped with a Dynamic Positioning system	✓			
The bunker vessel is equipped with a “Scheldehuid”	✓			
The bunker vessel has 4.473 KW of engine power	✓			
The bunker vessel has a maximum speed of 10 knots	✓			
The support vessel has a maximum speed of 11 knots				✓
The vessel is certified to enter petroleum ports	✓	✓	✓	✓
The bunker vessel is capable of transporting 6.500 m^3 LNG		✓		
Capable of loading 1.000 m^3 LNG per hour		✓		
The bunker vessel is seaworthy		✓		
The bunker vessel has a maximum speed of 11 knots		✓		
The bunker vessel has an accommodation	✓	✓	✓	✓
The engine of the waste retrieve vessel is Diesel-electric			✓	
The support vessel is equipped with a crane			✓	
Total beam of sweeping arms is 19 m				✓
High pressure washer is delivering 2 x 300 bar				✓
The support vessel is equipped with a high-pressure water pump				✓
The support vessel is equipped with a hydraulic powerpack				✓
The support vessel is equipped with two hydraulic cranes				✓

Table 8: Table of properties learned from maritime support installations

CHAPTER 5 – LIMITATIONS

This chapter describes the current limitation of the support vessel. These limitations will be the foundation of the conceptual for a hull cleaning support vessel in the ARAG area.

5.1 THE NECESSITY OF A DECKHAND

The current support vessel is 62 m long. The Dutch authorities have regulation describing that whenever a vessel is longer than 55 m, it needs to be sailed by a captain and an additional deckhand (H De Boer & Minister Verkeer en Waterstaat, 2008). However, if you study the operational profile of the support vessel, it seems that the vessel does not travel a lot. It is mostly sailing within the Port of Rotterdam and it only sporadically sails to Amsterdam, Ijmuiden, Flushing or Sluiskill.

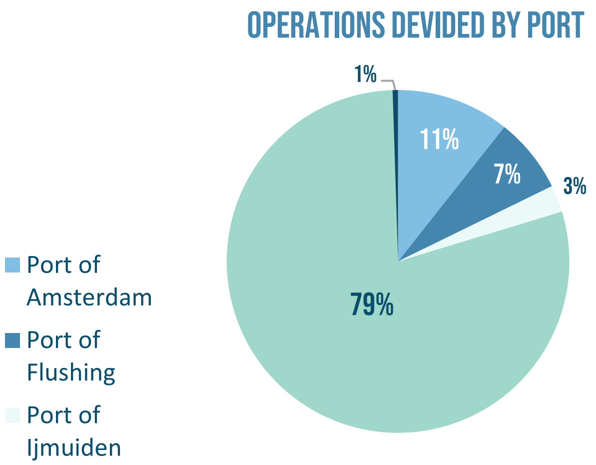


Figure 54: Pie chart of operations

The task of the deckhand is to assist the captain with the berthing procedure. However, during the berthing procedure the operators of the Fleet Cleaner installation are also onboard to assist. Therefore, the fact that the vessel is longer than 55 meter is a limitation of the current support vessel.

5.2 A SUITABLE WORKING ENVIRONMENT

The goal of Fleet Cleaner is to achieve a maximal rate of occupancy for the cleaning installation. Ideally, this means that the vessel sails from operation to operation. To realize that, there should be a suitable working environment to operate, live and do maintenance. Furthermore, these goals should be achieved in all weather conditions.

5.2.1 Comfortable control room

The current control room is built into half of a twenty-foot equivalent unit. The working area is around 7,44 m^2. The control room has built in heating and it has no air-conditioning. There are two chairs and one field bed for operators to sleep.

The operators do not have room to properly change their clothes and due to the limited space, it becomes messy easily.

This control room is experienced to be too small and not comfortable enough to work in on a daily basis.

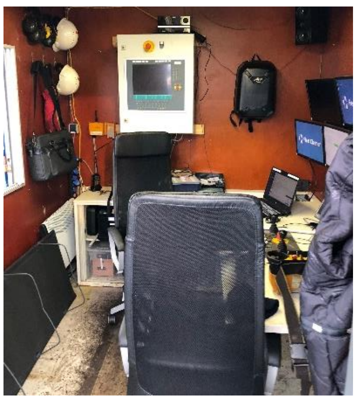


Figure 55: Control room

5.2.2 Suitable living accommodation

The current accommodation is solely for the captain and the deckhand. It has the only bathroom onboard and the general status is in old condition. The deckhand has a room which is 5 m^2 and they sleep in bunk beds. There are no closets and no personal room for relaxing.

The current living accommodation is not suitable to be lived in 24/7 by a captain and a deckhand.

5.2.3 Practical working conditions

The maintenance of the Fleet Cleaner R.O.V. and her support installation is done onboard. The other half of the Twenty Foot Equivalent Unit is used to store the robot and if maintenance must be done, the robot needs to be driven out of the storage to have enough space. There are no chairs or proper working tables. The parts of the robot that need repairs cannot be placed on a table and all maintenance is done on the floor.

Figure 56: Maintenance room

If the robot needs maintenance, there is not enough room to do it in the storage room. This means that all the maintenance work is done outside independent of weather conditions.

The current working conditions are not suitable to be worked in for a longer period. The environment is not clean, safe, warm or cold enough to do maintenance. Furthermore, it is expected that due to these unpleasant conditions, mistakes are made earlier.

5.3 A PROPER UMBILICAL DEPLOYMENT/RETRIEVAL/STORAGE SYSTEM

The umbilical is a complex configuration of multiple cables bonded together. As described in chapter 2.1.3, all cables must be unplugged during retrieval and deployment. Not only is the connection lost with the R.O.V., it also means that the length of deployment cannot be constantly adjusted, and a part of the umbilical is dragged unnecessary over the seabed. Lastly, due to the combination of the above two, the internal cables are damaged individually sometimes.

The solution to this problem is to design and purchase a new umbilical which is weaved and covered with polyurethane. Furthermore, a swivel must be built into the reel so that there will always be a connection. Fleet Cleaner is currently in the designing process for such a system. However; the design of the umbilical system is outside of the scope of this Thesis. Nevertheless, the umbilical storage and deployment stinger are in the scope of this thesis.

Umbilical storage

During the cleaning operations of the Thialf (winter 2017), Fleet Cleaner experienced several days of downtime due to the very low temperature. The seawater froze on deck, in the umbilical and caused besides downtime also a lot of damage. The current way of umbilical storage is not suitable for all weather conditions.

Umbilical deployment/retrieval

The Fleet Cleaner R.O.V. is always connected through an umbilical. The force on the umbilical is accumulated through the weight of the R.O.V. and the umbilical plus the forces accumulated on them both. The maximum accumulated force is calculated in Appendix A, resulting that the deployment system should be capable of handling roughly 8.390 kg.

Since in the transverse situation the area of the umbilical will be calculated as diameter times length, the diameter of the umbilical has a linear relation with the drag force. The diameter is designed to be as small as possible but fulfilling the purposes.

Besides, the accumulated force, the umbilical is also retrieved and deployed. The amount of distance traveled of the umbilical over the rollers can be calculated through the following formulas:

$$S = Nmax * D * P \quad \text{and} \quad Nmax = \frac{T}{O} * \propto$$

S:	97	Distance travelled over the roller (km/per year)
Nmax:	197	Maximum number of operations in a year
D:	3,7	Average number of umbilical deployments per operation
P:	133	Average part of the umbilical that is deployed (m)
T:	365	Yearly operational days
O:	1,3	Average operational time needed (days)
α:	0,7	Tine lost due to vessel shifting

Table 9: Distance traveled by umbilical

Due to the current design of the rollers, all the force on the umbilical is accumulated on one point. Furthermore, the distance travelled over the rollers is substantial. The design of the umbilical deployment/retrieval system is not beneficial for the operational lifespan of the Umbilical and it should be solved prior to the (expensive) investment in a new umbilical configuration including swivels, rotary union components etc.

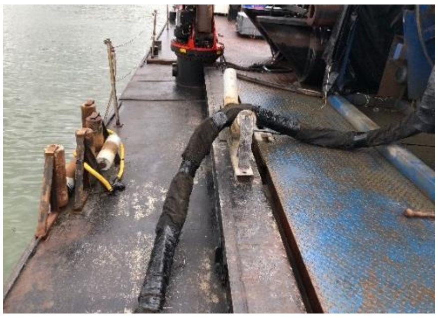


Figure 57: Umbilical guidance

5.4 A SAFE SUPPORT VESSEL

The hull cleaning support vessel used to be an old sand hopper. As described in chapter 3.1.2, the cargo hold is filled with old containers that are simultaneously the foundation of the work deck. On the top deck all the equipment is placed.

When there is strong wind, the Cormoraan is experiencing a rolling motion. This motion has been a limiting factor for the filtering installation. However, the filtering installation can always be bypassed into the cargo hold and therefore it has not been limiting for the operational. Nevertheless, the stability should be at least the same or better for the conceptual design.

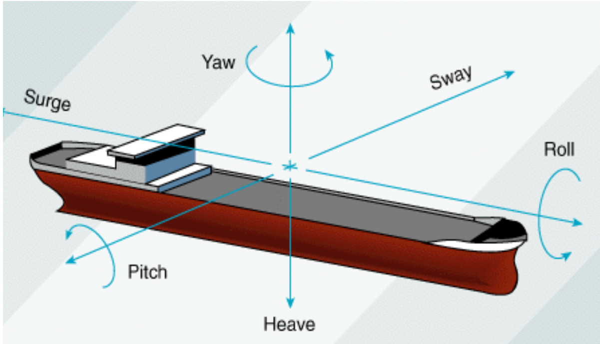


Figure 58: Overview of motions (59: (P. Patil, 2017)

Another limitation of the current support vessel is the restrictive line of sight from the captain's wheelhouse. Due to the high containers in front of the Cormoraan, the line of sight is limited. In the current situation this is solved by placing camera's in the front and back.

The Dutch inland shipping regulations state that a vessels cargo should not limit the restrain of sight to less than 350 m in front of the vessel. It is even allowed to extend it to 500 m whenever there is enough assistance of radar and camera installations. (H De Boer & Minister Verkeer en Waterstaat, 2017)

The Cormoraan is compliant with the Dutch regulations. Nevertheless, these regulations are meant for vessels that have a normal operational profile; they sail more than they are in port. The hull cleaning support vessel must maneuver much more than other inland shipping vessels and therefore the current line of sight is experienced as a limitation of the current configuration.

In an interview, the captain stated that independent of the line of sight, cameras should always be implemented for safety and easiness of maneuvering.

5.5 ALTERNATIVE TRANSPORTATION

A lot of inland vessels have the possibility to carry a car on deck. In the current configuration this is not possible. The ability to have a car could help improve the logistical side such as transportation of operators and providing supplies.

Furthermore, the current support vessel comes with a small boat which is unsuitable and unsafe to be used in the port environment. The small supporting vessel is sometimes used for picking up people, taking pictures etc. The ability of not having a safe one is obstructive and therefore a limitation of the current support vessel configuration.

The current support vessel is not able to carry a car nor a support vessel that is certified to use in ports.

5.6 A REPRESENTATIVE SUPPORT VESSEL

Studying the current configuration of the support vessel, it seems that a lot of space is simply not used. A bigger vessel has higher chartering costs, maintenance cost etc. Therefore, it should be more ideal to use a more space efficient support vessel than the Cormoraan.

5.7 LIMITATIONS OVERVIEW

LIMITATIONS OF THE CURRENT SUPPORT VESSEL:
– The support vessel is longer than 55 m and therefore a deckhand is needed – The control room is too small and not comfortable enough to be worked in daily – The living accommodation is not suitable to be lived in 24/7 by a captain and a deckhand – The current working conditions are not suitable to be worked in for a longer period – The current way of umbilical storage is not suitable for all weather conditions – The design of the deployment/retrieval system is not beneficial for the operational lifespan of the umbilical – The line of sight of the support vessel is too limited for the operational profile of the vessel – The support vessel does not have the ability to carry a car – The support vessel does not have the ability to carry a small supporting vessel – The space on the support vessel is not used effectively

Table 10: Overview of limitations of the current support vessel

Part II – Conceptual Design

The second objective of this thesis is to find the best solution for the limitations described in Part 1. This solution is found by inventorying the used practices found in Part 1 and developing constraints, requirements and finally combining them to a final concept.

Finally, the concept should have established constraints, requirements and a combined optimum.

MAIN OBJECTIVE	PART	SUB-OBJECTIVES	APPROACH
	PART 1	Identify the main limitations of a hull cleaning support vessel	- Literature study on support systems - Literature study on support vessels - Literature study on limitations
DEVELOP A CONCEPTUAL DESIGN OF A HULL CLEANING SUPPORT VESSEL	PART 2	Develop the optimal working principles for a hull cleaning support vessel	- Establish the constraints - Establish the requirements - Combine working principles
	PART 3	Present the developed model	- Present the embodiment of design - Provide conclusions and recommendations

Table 11: Overview of research structure (Part 2)

CHAPTER 6 – SCOPE OF THE DESIGN

Even though the existing installation can successfully clean ships during port time, there are still several limitations as identified in Part 1 of this thesis. Many technical improvements can be made on the existing cleaning installation, but the goal of this thesis is to design an optimal support vessel. This chapter describes the scope of that design.

6.1 SUPPORT VESSEL

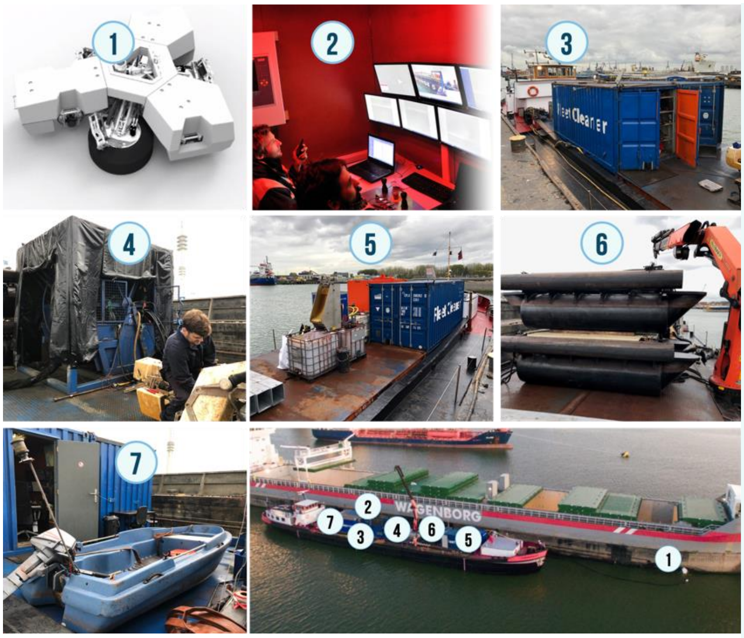
Most of the hull cleaning companies and service providers are operational from a support vessel. However, as can be seen in part 1, one hull cleaning company decided to have a land-based operation.

From the current experience of Fleet Cleaner, it seems that a vessel is preferred over an installation that is stationed on land. With a land-based operation, buoy-typed berths are not accessible. Furthermore, the owners of the quay-typed berths are not always allowing road access to subcontractors due to the added risk and limited added value experienced.

6.2 EXISTING INSTALLATION

Fleet Cleaner design philosophy is to make the installation as modular as possible to provide maximum operational flexibility, standardized production, predictable maintenance and lower construction costs. Furthermore, the installation should be stationed on a support vessel to realize the flexibility.

The below illustration shows the components placed on the Fleet Cleaner support vessel.



1. The Fleet Cleaner R.O.V.
2. The control room
3. HP water and hydraulic power container
4. Umbilical reel with umbilical
5. Filtration system container
6. Fenders to keep a safe working distance
7. Support equipment

Figure 59: Fleet Cleaner components

6.3 AREA BOUNDARY

During the first years of operational cleanings, Fleet Cleaner has experienced that a lot of ideas for improvements and innovations came from operating the installation. As engineers are also operators, systems were tested by the developers themselves. For this reason, the next Fleet Cleaner will also be deployed close to the inventors, in the ARAG area.

6.4 SYSTEM BOUNDARY

The system boundary of the conceptual design in this thesis is the support barge without the cleaning installation placed on it.

As mentioned in chapter 1.5, the scope of this thesis is limited to the parts that are not uniquely designed by Fleet Cleaner B.V. For this Thesis, the scope is limited to the support Barge so that it can be a basis for future expanding to other countries. The system boundary is schematically described in the illustration below.

The lead time for constructing a new vessel is too long and is economically not feasible for Fleet Cleaner. Therefore, the design of this Thesis is restricted to the conversion of existing inland vessels.

Scope of the Design
The installation should be placed on a support vessel
The support vessel should have enough place for the components of the Fleet Cleaner R.O.V.
The support vessel is used in the ARAG Area
The system to create a safe distance
The scope is limited to the conversion of existing inland vessels

Figure 60: Schematic overview presenting the scope of the design

CHAPTER 7 – CONSTRAINTS

To develop a conceptual design of a hull cleaning support vessel, several constraints must be taken into account. A division is made between environmental constraints, and goal-related constraints. The environmental constraints describe the environment where a system needs to operate, and the goal-related constraints describe what a system needs to achieve.

7.1 ENVIRONMENTAL CONSTRAINTS

The area-related constraint is the working area of the support vessel. Obviously, the support vessel is going to be placed in the water, so there are three different area's determined.

At the anchorage area

In port areas such as Singapore, Gibraltar and Panama, the anchorage area is so sheltered that maritime activities are also delivered at this location. Delivering hull cleanings at the anchorage area is a big advantage as a lot of vessels are often waiting there before the terminal has an available slot for them. Another advantage of cleaning at sea is that all the sides of the vessel are freely available. For the ARAG area this is not (yet) applicable.

Open Sea area

Delivering the service on open sea is something that could be of interest for cleaning offshore structures or FPSO's. It can be done with the technology currently available such as Dynamic positioning and motion compensating systems. For the support vessel in the ARAG this is not yet applicable.

Port area

The aim of the Fleet Cleaner company is to deliver the hull cleaning service without causing any or minimize the downtime to the vessels schedule. As can be seen in part 1, there are many other maritime service providers which focus on delivering a service without or minimizing interference with the vessels schedule. Much can be learned from these service providers as they have been evolving their service since the beginning of shipping.

Currently the company is delivering the hull cleaning service in all Dutch ports. As found in part 1, it is common practice for all Dutch maritime service providers to use an inland vessel to deliver their service while the seagoing vessel is loading or unloading.

The size of the support vessel is restrained by the locks and bridges for a specific route. In the ARAG area, the route to Zeebrugge is the current bottleneck. To establish the maximum dimensions, this route is analyzed in the table below. The length is already limited by 55 m due to the necessity of having a lines man onboard (Visuris, & Promotie binnenvaart Vlaarderen & The Blue Road Map, n.d.)

CANAL	MAX W (M)	MAX D (M)	MIN H (M)
Nieuwe Maas	Unlimited	-6	8,4
Noord	Unlimited	-4,8	12,9
Oude Maas	21	-5	11,4
Dordsche Kil	Unlimited	-4,9	Unlimited
Hollands Diep	Unlimited	-6	Unlimited
Volkeraksluizen	24	-4,75	Unlimited 14
Krammersluizen	24	-4,75	14,5
Kanaal door Zuid-Beveland	23	-4,75	9,5
Hansweertsluis	24	-4,8	Unlimited
Westsluis	23	-4,3	Unlimited
Kanaal Gent Terneuzen	>25	-4,5	6,5
Ringvaart Wondelgem	11,5	-3,5	6,67
Sluis Evergem	11,5	-3	Unlimited
Kanaal Gent-Brugge	10	-2,7	7,0
Keersluis Beernem	10,2	-2,5	Unlimited
Sluis Brugge-Oost	10,2	-2,5	Unlimited
Handelskom	11,5	-2,5	Unlimited
Sluis Brugge-Noord	large	-2,5	Unlimited
Groot Handelsdok	11,5	-2,5	Unlimited
Boudewijnkanaal	Larger	-6	Unlimited
Sluis Zeebrugge	Larger	Larger	Unlimited
ARAG LIMITATION	**24**	**-6**	**6,5**

Table 12: Overview of dimensional restrictions

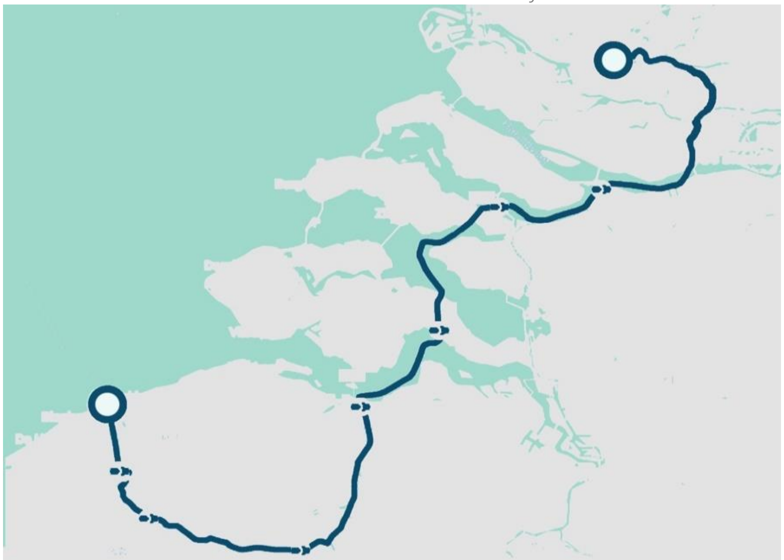


Figure 61: Route from Rotterdam to Zeebrugge

Summarizing the above analysis, the constraints of the dimensions is limited by the following locations:

- Length of 55 m due to the necessity of having a lines man onboard
- The width of 10 m due to the dimensions of the canal between Gent and Brugge
- The draught of 6 m due the dimensions of the Boudewijnkanaal
- The height of 6.5, due to the dimensions of the bridge on the canal between Gent Terneuzen

Engine restrictions

The authorities are implementing legislation that will reduce pollution caused by the inland shipping sector. Summarized, the constraints for designing a support vessel are:

- Starting 01-01-2025, all vessels in the Port of Rotterdam must use engines complying with the CCR2 to propel.
- Until 01-01-2020 it can install engines that comply with the CCR2 fase, after that the engine must be a fase V.

The requirements for the CCR2 fase V are given in the table below (Het Europees Parlement en de raad van de europese Unie, 2016).

POWER	CO	HC	NOX	PM	PN
kW	g/kWh	g/kWh	g/kWh	g/kWh	#/kWh
19≤P<75	5	(HC+NOx≤4,70)		0,3	–
75≤P<130	5	(HC+NOx≤5,40)		0,14	–
130≤P<300	3,5	1	2,1	0,1	–
P≥300	3,5	0,19	1,8	0,015	1×10^{12}

Figure 62: New guidelines or the CCR2 Fase V

7.2 GOAL RELATED RESTRAINTS

Fleet Cleaner aims to clean vessels in the biggest ports around the world. This goal is restricted by the expansion rate and the ability of the robot to clean all types of vessels.

Modularity

For this global ambition, a rapid growth rate is necessary. To realize this growth rate, Fleet Cleaner needs to be capable to ship equipment fast over the world.

Furthermore, the ability of switching out standard components such as generators, hydraulic pumps or filtering installation has been proven to be essential to keep the installation working and therefore the hull cleaning service reliable.

Combining the above, the scope of this thesis is constrained by the fact that the support system needs to be modular. Modularity is defined to be composed of standardized units or sections for easy construction or flexible arrangement. Components should be interchangeable in less dan 5 days.

Cleanable ships

The Fleet Cleaner R.O.V. is constrained by a curve radius of 2.5 m. Physically this means that vessels that are smaller than 120 m are not suitable to be cleaned. This cleaning constraint translates directly to restraints for the support vessel. To attach the R.O.V. to these 120m vessels, the crane should be capable of reaching the waterline.

7.2.1 Constraints overview

TYPE	CONSTRAINT	SPECIFICATION
Environment	Operation in all the ARAG Ports.	– Max length of 55 m – Max width of 10 m – Max draught of 6 m – Max height of 6.5 m – Min 5 m safe working distance – The engine should be CCR2 fase V certified
Modularity	The support system must be modular	– The support system should be interchangeable in less than 5 days.
Cleanable ships	To crane must be capable of reaching the waterline	– The freeboard of the vessel should not be too high. (5m)

Figure 63: Constraints overview

CHAPTER 8 – REQUIREMENTS

This chapter describes the requirements needed to optimize the uptime of the Fleet Cleaner hull cleaning support vessel. A division is made between functional and non-functional requirements. Both these requirements are discussed with a thorough elaboration.

8.1 FUNCTIONAL REQUIREMENTS

Functional requirements define the task or process that it needs to fulfill. The working principles that fulfill these functional requirements are described in chapter 9.

8.1.1 Provide sufficient deck space

As described in chapter 4, experience has taught us that the control room is too small to operate 24/7. The next design will have one control room container and one maintenance container. To facilitate the cleaning installation, there should be enough deck space for the following standard 20 feet containerized elements. (6,06 x 2,44 m)

Element	Deck space
Control room	14.79 m^2
Support container	14.79 m^2
Filtering container	14.79 m^2
Containerized Maintenance container	14.79 m^2
Containerized umbilical reel	14.79 m^2
Maintenance and R.O.V. testing deck space	14.79 m^2
Fender storage space	19.14 m^2

Table 13: Deck space needed

Around the components space is needed to open doors, to do specific maintenance or testing. For these activities the following extra deck space below is marked.

ADDITIONAL SPACE FOR ELEMENTS

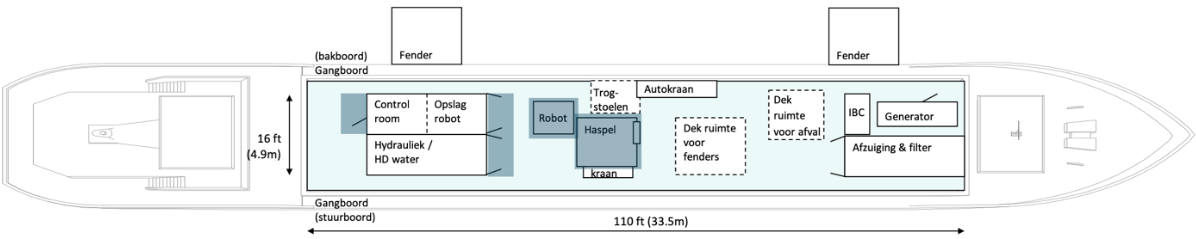


Figure 64: Schematic overview of additional deck space

ELEMENT	Additional deck space
One side opening container	2,98 m^2
Two side opening container	5,96 m^2
Fully accessible container	6,88 m^2
Fully accessible Fleet Cleaner R.O.V.	12,0 m^2

Table 14: Additional deck space overview

As can be seen in the illustration above, some elements need additional space. For the conceptual design, it should be the goal to configure a more efficient configuration and eliminate two sided containers.

ELEMENT	DECK SPACE		ADD. SPACE		TOTAL	
Control room	14,79	m^2	2,98	m^2	17,77	m^2
Support container	14,79	m^2	2,98	m^2	17,77	m^2
Filtering container	14,79	m^2	2,98	m^2	17,77	m^2
Containerized Maintenance container	14,79	m^2	2,98	m^2	17,77	m^2
Containerized umbilical reel	14,79	m^2	6,88	m^2	21,67	m^2
Maintenance and testing deck space	4	m^2	12	m^2	16	m^2
Fender storage space	19,14	m^2	0	m^2	19,14	m^2
TOTAL	97,1	M^2	30,8	M^2	127,9	M^2

Table 15: Deck space per element

Requirement
– Support vessel should have sufficient deck space (127,9 m^2)

Table 16: Requirement for total deck space

8.1.2 Guide the umbilical overboard

As described in chapter 2, the robot is connected via a 150-meter-long umbilical. This umbilical must be guided overboard. Furthermore, the umbilical deployment/retrieval system has showed to be a limitation in the initial design.

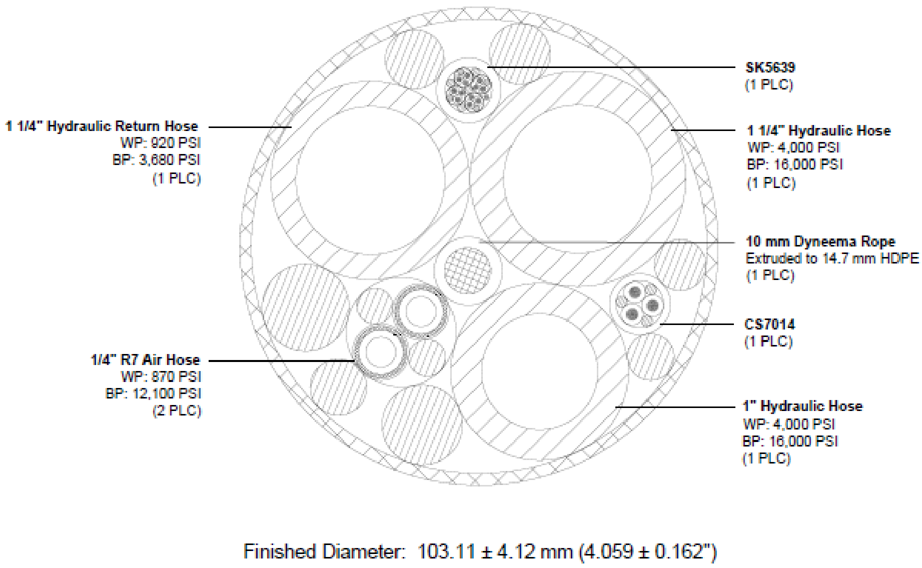


Figure 65: Umbilical overview (Hydrasun, 2018)

The bend radius of the umbilical depends on the internal hoses and material consisting in the umbilical. In the offshore there are specific guidelines for the bend radius. For the current umbilical, the values for the bend radius are given in the table below:

Requirement
– Support a minimum bend radius of 0,77 m
– Support an umbilical travel distance of 97 km per year
– Support a weight of 1.774 KG

Table 17: Requirement for Umbilical

The umbilical is currently considered the most vulnerable part of the current installation. If the umbilical breaks, it will be difficult to remove the robot from the vessel and the concurrent downtime to the seagoing vessel would be a serious (financial) risk.

8.1.3 Provide a safe working distance

Containers are secured together with the use of twist locks and lashings. During the cargo operation these securing mechanisms can sometimes fall down. When a vessel is directly next to the seagoing vessel, these falling object are a safety hazard for the personnel.

Figure 66: Twist lock used to connect containers

Due to this reason all the stakeholders came together and wrote a bunker protocol to minimize the risk of accidents (Centraal Bureau voor de Rijn- en Binnenvaart (CBRB) & Deltalinqs, 2018).

In this bunker protocol a safety zone of 5 meters is assigned around the seagoing vessel. As permission of the terminal is key in the cleaning during cargo operations, Fleet Cleaner adjusted the complete design of the installation to compile with this safety advice.

To do so, special fenders are designed to keep the Fleet Cleaner personal always on a safe distance from the seagoing vessel. Although the fenders increase safety, they decrease production as they must be deployed and collected manually every cleaning.

These fenders have the following specifications:

Length	4,5	m
Width	4.26	m
Height	1.114	m
Weight (Mfender)	2.540	kg
Required deck space	19,14	m^2

Figure 67: Specifications fenders

Requirement
– Support vessel should have fenders that create a safe working distance

Table 18: Requirement for fenders

8.1.4 Launch and retrieval of the robot

When the support vessel is alongside the seagoing vessel, the Fleet Cleaner R.O.V. must be launched and attached before it can clean. To do so, the following actions are done.

1. Lift the Fleet Cleaner R.O.V. horizontally
2. Rotate the R.O.V. to a vertical position with the use of the winch.
3. Attach the R.O.V. with her magnets to the seagoing vessel
4. Detach the lashes of the R.O.V.

The crane needs to be capable of lifting the R.O.V. and a portion of the umbilical. Furthermore, it needs to be equipped with a winch to enable the rotation motion.

Weight RO.V.	700	kg
Length umbilical	150	m
Weight in air*	9,34	kg/m
Weight in seawater*	2,480	kg/m
Breaking load	88	kN
Estimation of max umbilical length out of water	20	m
Safety factor	2	

$$Mrov = 700\ kg$$
$$Mumb = 20 * 9.34 = \ 186.8\ kg$$
$$Mtotal = Mum + Mrov = 886.8\ kg$$
$$Msafe = Mtotal * f\ = 1.774\ kg$$

Table 19: Overview weight R.O.V. & Umbilical

As *Msafe < Mfender*, the fender will be the limit on what the crane should be able to lift.

Requirement
– Support vessel should be equipped with a crane
– The crane should be equipped with a winch
– The crane should be capable of lifting Mfender. (2.540 kg)

Table 20: Requirement to launch and retrieve robot

8.1.5 Accommodate the operational crew

Fleet Cleaner has the ambition to have a high occupation rate. To do so, operators need to be onboard 24/7, 365 days of the year. To facilitate this, the accommodation needs to be suitable. To set the requirements, the laws are studied for such an accommodation.

In Dutch law, not much is stated regarding 24/7 occupation on an inland vessel. In paragraph 3.21, it is mentioned, that it should be adequately furnished for people of the same gender (Sorgdrager & De Minister van Justitie, 1997). Furthermore, the relaxing area should have enough chairs and the bedrooms should have enough space to hang clothes.

In the offshore regulations, there are more restricted rules and guidelines (Offshore safety directive regulator, 2017). It shows that it is not allowed to share beds, (hot bunking) and that every employee that sleeps onboard should at least have 4.5 m^2 personal space for single usage, 9 m^2 for double or triple usage.

To obtain a 24/7 occupation, it seems that the crew onboard should consist out of 8 people, divided up in two teams, alternating 3 weeks on, 3 weeks off. The following four people should be onboard:

Function	Shift
Operator and Captain	1 (06:00-18:00)
Operator and Captain	2 (18:00-06:00)
Operator and lines man	1 (06:00-18:00)
Operator and lines man	2 (18:00-06:00)

Table 21: Operational team

When shift 1 is working, shift 2 can rest and opposite. All the above people should be able to do maintenance on the robot, the installation and the vessel during downtime.

The requirement for the accommodation will be:

Requirement
– Enough relaxing space (enough chairs) – Enough bedrooms for 4 people (4.5 m^2 per person)

Table 22: Requirement for the accomodation

8.1.6 Supply power for the cleaning installation

The electrical power needed for the cleaning installation is delivered by a generator placed onboard. To calculate the total power needed, all the components are specified in table 23.

Component		
High pressure water pump	160	Kw
Hydraulic power pack	90	Kw
Pre-pressure pump	5,5	Kw
Feed pump	5,5	Kw
Cooling hydraulic pumps	2,2	Kw
Cooling hydro pump	1,1	Kw
Fan container	1,1	Kw
Umbilical reel	4,0	Kw
Filtering container	35	Kw
Crane	30	Kw
Drum filter	5,5	Kw
Umbilical cleaning nozzles	5,5	Kw
Compressor	4,0	Kw
Control room	3,6	Kw
Robot	3,6	Kw
Support container	3,6	Kw
Storage container	3,6	Kw
Total	363,8	Kw

Table 23: Overview of electrical power

The total power maximum needed is 363,8 Kw. The generator will have a safety margin of 10%, resulting that a generator should be used with a total power of 400 Kw.

Requirement
– The system needs a generator of 400 kW.

Table 24: Requirement for the supply of power

8.1.7 Non-functional requirements

When multiple working principles can fulfill a functional requirement, a distinction needs to be made. To make this distinction, non-functional requirements are used. These non-functional requirements define how the system should behave and help describe preference and optimization of the final design concepts.

Complexity

Complexity is a broad concept with multiple definitions. The definition of complexity is quite subjective. In this Thesis, complexity is directly related to the amount of labor needed to divert from the standard industrial used concept. It is favorable for the design and of the concept that the complexity is reduced as much as possible.

Safety

Safety is a relative concept because all the working principles may lead to dangerous situations. The risks associated with a specific working principle vary. Therefore, some principles will be safer than others. Some safety aspects that must be considered are falling of objects from the seagoing vessels.

Scalability

The support vessel should be capable of operating in more areas besides the ARAG area. Therefore, it is favorable that the system is relatively easy adaptable to generic support vessels.

Durability

Technological durability means that the component can fulfill the requirements for a relatively long period. The wear associated with specific working principles is therefore an important aspect to consider for the design of the system.

Flexibility

Operational flexibility is the easiness to adjust to certain sudden situations.

8.1.8 Hierarchy of requirements

The hierarchy between the requirements is based on the complexity and the related lead-time needed to implement the working principles. The Fleet Cleaner production department have helped estimating the lead time given in the table below. The complexity defines the hierarchy which is used for the sequence of choosing the combination of the most suitable working principles.

REQUIREMENTS	COMPLEXITY	ESTIMATED LEAD TIME
Provide sufficient deck space	The vessel needs to be completely refitted	– 4 - 8 months
Guide the umbilical overboard	The roller chute is a custom design	– 3 - 6 months
Provide a safe working distance	The custom fenders is a partial custom design	– 2 - 4 months
Launch and retrieve robot	The deployment system is off the shelve, with a complex installation	– 20 -30 days
Accommodate the crew	The accommodation is off the shelve, with minor installation	– 10 – 20 days
Supply electrical power	The electrical power supply is off the shelve, with minimal installation	– 1 – 10 day(s)

Table 25: Hierarchy of requirements

CHAPTER 9 – WORKING PRINCIPLES

In this chapter the working principles that can fulfill the functional requirements are described. Several principles can execute the functions of the support vessel, however only realistic and technical adaptable functions are considered. The working principles are qualitatively described in this stage of the design to have a broad view of all the options. Some examples of working principles used in other fields are given to show the application. All the described working principles are captured in a morphological chart in the final part of this chapter. This overview is used in Chapter 10 to find the optimal working structure.

9.1 PROVIDE SUFFICIENT DECK SPACE

To provide sufficient deck space, a vessel must at least have 127,9 m^2. There are several inland vessels that have that deck space and they will be described per category below (Bureau voorlichting Binnenvaart).

9.1.1 Tanker

Tankers are used to transport wet cargo and powder through the inland waters. In general, there four types of tank vessels exist.

- Type N – Normal
- Type C – Chemicals
- Type G – Gas
- Powder tanker

Figure 68: Tanker

9.1.2 Dry Cargo vessel

Dry cargo vessels are used to transport dry bulk (i.e. coal, grain) or breakbulk (i.e. vessels, large steel rolls etc.) Dry cargo vessels are equipped with hatches to keep the cargo dry. Some dry cargo vessels are specially adjusted for containers with a possibility to rise the wheelhouse. In general, dry cargo vessels are multi-usable. Therefore, most of the inland vessels are dry cargo.

Figure 69: Dry cargo vessel

9.1.3 Inland barge

Inland barges have a very low freeboard. They are typically used to transport sand or dredging material. The vessel is designed that the water that came in with the sand/dredge can easily flow away without sinking the vessel.

Figure 70: Inland barge

9.1.4 Pontoon with push vessel

A push and pontoon combination are often used for hull cleaning configurations. The advantage of this configuration is that the expenses are less when there is less work. However, it makes it difficult to clean in other ports as the speed of transporting such a pontoon is relatively low.

Figure 71: Pontoon

9.1.5 Work vessel

Other service providers in the port use work vessels such as the HEBO CAT. These types of vessel are multifunctional and can be used for all situations. These working vessels are usually also seaworthy.

Figure 72: Work vessel

9.2 GUIDE THE UMBILICAL OVERBOARD

The umbilical is a crucial part of the installation which is subjected to a lot of forces and wear/tear. Currently there are four mostly used principles to guide an umbilical or cable overboard.

9.2.1 Chute

A standard chute is often used for guiding umbilical's or cables and is protecting it from overbending during deployment/retrieval. The construction has a simple design.

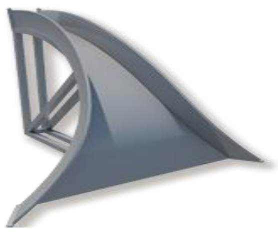


Figure 73: Chute

9.2.2 Roller chute

A roller chute has the same design as a standard chute, only rollers have replaced the standard steel. Due to the rollers, the umbilical will have less drag resistance on the chute itself. However, the forces will be concentrated in the rollers vicinity instead of spreading them on the entire chute. The construction is less simple as it has more moving components.

Figure 74: Roller chute

9.2.3 Sheave

Sheaves are often used to guide cables and umbilical's with smaller diameters. The radius of the sheave is related to the bend radius of the umbilical. The sheave has little to no drag of retrieving/deploying of the umbilical, as the wheel turns proportionally. The sheave is very restricted in handling forces perpendicular to the deployment direction.

Figure 75: Sheave

9.2.4 Roller Sheave

Roller sheaves have the same design as the standard sheaves, only rollers have replaced the wheel. Due to these rollers, the forces of the umbilical will again be concentrated in the vicinity of the rollers. However, for construction purposes, the roller sheave will not need a full circle wheel to protect the umbilical from bending.

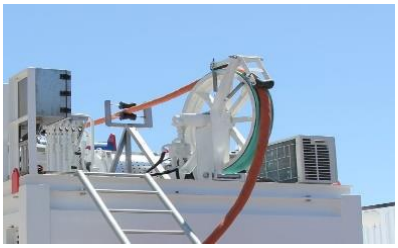


Figure 76: Roller Sheave

9.3 PROVIDE A SAFE WORKING DISTANCE

As mentioned in Chapter 7.1.3, port authorities are currently setting up guidelines to ensure safety around seagoing vessels. To comply with these guidelines, several principles are available to create a safe working distance.

9.3.1 Pneumatic fenders

Pneumatic fenders are the most used transportable fenders. These fenders are widely used in ports and on the open sea. They are constructed out of inflatable multilayered rubber tubes, which are protected by a net of car tires. For passengers' vessels, the net of car tires is removed, due to the possibility of stains on the vessel.

Figure 77: Pneumatic fenders

9.3.2 Fixed structure attached to vessel

A fixed structure can also create a safe working distance. A non-floating construction is then attached to a vessel, which is usually made of a soft rubber compound. This principle is not transportable and very specific for the amount of distance needed.

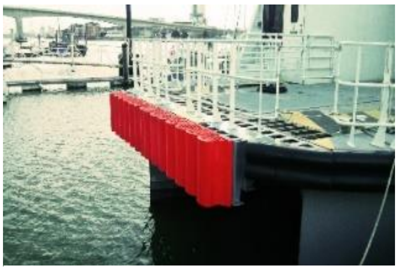


Figure 78: Fixed structure

9.3.3 Magnetic fenders

In chapter 4.1, the innovative magnetic fender system is described. The great advantage of this system is that it uses an active system which reduces the relative motions. Furthermore, the attachment and detachment is relatively fast. The fenders do need a powerpack and are relatively costly.

Figure 79: Magnetic fenders

9.3.4 Custom fenders

In chapter 7.1.3 the custom fender designs are illustrated. These fenders are portable and so designed that the umbilical can pass freely between the Fleet Cleaner support vessel and the seagoing vessel.

Figure 80: Custom fenders

9.3.5 Spud poles

Some inland vessels use spud poles to moor the vessel at a specific area. With this principle, a safe working distance can also be created. The advantage of this system is that the support vessel can berth very quickly. However, at some locations in the Port the use of spud poles is not allowed, or it is too deep.

Figure 81: Vessel with spud poles

9.4 LAUNCH AND RETRIEVE ROBOT

When the support vessel is next to the seagoing vessel, the Fleet Cleaner R.O.V. needs to be attached and retrieved. To do so, multiple principles are investigated and elaborated in the following chapters.

9.4.1 A-frame

A widely used principle of deploying an R.O.V. is by using an A Frame. The frame can rotate, which places the point of engagement further out of the support vessel. With this principle, the R.O.V. can be attached to the seagoing vessel. Furthermore, it can be combined with a sheave.

Figure 82: A-frame

9.4.2 Knuckle boom crane

The knuckle boom crane is often used onboard of transportable installations such as trucks. The advantage of this system is that it is flexible and foldable. However, this type of crane is complex as it has a lot of moving parts.

Figure 83: Knucle boom crane

9.4.3 Fixed boom crane

A fixed boom crane is the least complex crane available. It cannot be folded, and its usage is less flexible compared to the Knuckle boom crane.

Figure 84: Fixed boom crane

9.5 ACCOMMODATE THE OPERATIONAL CREW

The conceptual design for a hull cleaning support vessel in the ARAG area should be capable of operating 24/7, 365 days a week. To facilitate this, the operational crew needs an accommodation in which they can live. There are two possible concepts that can provide such accommodation.

9.5.1 TLQ

The temporary living quarters (TLQ) are accommodations build in containers. The units are mostly used in the offshore, oil and gas industry. The units are easily pilled, and they come with modern facilities. They are prefabricated and can be quickly installed on the support vessel

Figure 85: TLQ

9.5.2 Fixed accommodation

Almost all inland vessels have a fixed accommodation onboard. This accommodation is generically designed to facilitate a family with two adults and several children. In most cases a larger vessel has a larger accommodation.

Figure 86: Fixed accommodation

9.6 SUPPLY ELECTRICAL POWER FOR THE CLEANING INSTALLATION

As described in chapter 7.16, the Fleet Cleaner installation needs electricity to power the pumps, filters and computers. To provide this power, two possible concepts can be distinguished.

9.6.1 Transportable generator

Standard transportable generators come in all types, sizes and editions. They can easily be placed onboard of the support vessel to provide power. The main advantage is that whenever it breaks, it can be easily replaced. The disadvantage of a transportable generator is that is makes a lot of noise and vibrations.

Figure 87: Transportable generator

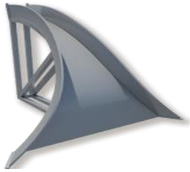
9.6.2 Build in generator

As all inland vessels need electricity, they all have a generator built within their engine room. If this generator has enough power, it could also power the Fleet Cleaner R.O.V. and her support system. Besides the advantage of having only one generator, it is also beneficial as the engine room is already isolated for vibrations and sounds.

Figure 88: Build in generator

9.7 OVERVIEW OF WORKING PRINCIPLES

In the next table an overview of the different working principles is presented.

PRINCIPLES	I	II	III	IV	V
Provide sufficient deck space	 *Tanker*	 *Dry Cargo vessel*	 *Inland barge*	 *Pontoon with push vessel*	 *Work vessel*
Guide the umbilical overboard	 *Chute*	 *Roller chute*	 *Sheave*	 *Roller Sheave*	
Provide a safe working distance	 *Pneumatic fenders*	 *Fixed structure att. to vessel*	 *Magnetic fenders*	 *Custom fenders*	 *Spud poles*
Launch and retrieve robot	 *A-frame*	 *Knuckle boom crane*	 *Fixed boom crane*		
Accommodate the crew	 *TLQ*	 *Fixed accommodation*			
Supply electrical power	 *Transportable generator*	 *Build in generator*			

CHAPTER 10 - WORKING STRUCTURES

The next step in the conceptual design process is to combine the different working principles into a working structure that fulfills all the requirements. The working structure is an optimal combination of working principles. With the use of the functional requirements the morphological chart was filled in. The remaining principles combined into an optimal working structure, which is the basis for the design of a configuration of a hull cleaning support vessel.

10.1 EXCLUDING THE WORKING PRINCIPLES

The exclusion of the working principles is a qualitative process, which is done based on the given non-functional requirements described in chapter 7.2. There are many approaches which are involved by restricting certain principles from the morphological chart. The decision is made to briefly describe the main considerations and the final decision.

10.1.1 Provide sufficient deck space

There are multiple vessels that fulfill the given requirements. All the vessels must be refitted to become a dedicated hull cleaning support vessel.

Complexity

The conversion of a tanker or an inland barge is relatively complex. For both the vessels the unnecessary piping and pumps must be removed. Furthermore, a tanker also has to be rebuilt to create deck space for the equipment.

Flexibility

The pontoon and the work vessel both have less flexibility in scheduling as their operational sailing speed is low. As it showed that the shipping business is very ad hoc, it is beneficial to have a high mobilization speed.

Overview

The decision is made to convert a dry cargo vessel to a hull cleaning support vessel and exclude the other principles. The conversion of this type of vessel is the least complex and remains the most flexible in operations.

10.1.2 Guide the umbilical overboard

There are multiple principles that are capable of guiding the umbilical overboard. However, to make an optimal design, a selection is made of the following non-functional requirements.

Durability

The goal is to guide the umbilical overboard. When doing so, it must preserve the umbilical in the best way possible and therefore improve its durability. As rollers lower the friction on the umbilical, this principle is chosen to improve durability.

Scalability

The difference of a sheave and a chute is that a chute can better withstand forces perpendicular to the winding. As we look at the ARAG area, not rough sea state is expected due to its sheltering. However, considering that Fleet Cleaner has a global ambition, a design path should be chosen which is scalable for the future. Due to this reason, a roller chute is preferred over a roller sheave.

Overview

The normal chute and the normal chute are excluded from the morphological chart due their influence on the durability of the umbilical. Finally, a roller chute is chosen over a roller sheave due to the favorable scalability.

10.1.3 Provide a safe working distance

The support vessel must be a safe working place with minimal risks on accidents and which should conserve the Fleet Cleaner installation in the best way possible.

Durability

The requirement is to create a safe working distance. However, the used principle also needs to protect the Fleet Cleaner installation. The pneumatic fenders give an opportunity to get the umbilical squeezed between the fender and the vessel. This has a negative influence on the durability of the hull cleaning system.

Complexity

Both the fixed structure and the magnetic fenders are very complex to implement. If a fixed structure needs to exceed 5 meters of reach, it must have a foundation. This makes it not flexible anymore. Furthermore, the magnetic fenders need to have a separate operational powerpack, maintenance scheme etc.

Flexibility

If a vessel wants to use spud poles in the port, it must ask for permission to the authorities. Furthermore, at some area’s spud poles are even forbidden due to pipelines under the seabed. As concluded before, an optimal support vessel should be as flexible as possible to serve the ad hoc shipping industry.

Overview

The decision is made to use the costumer fenders to provide the safe working distance necessary. This design keeps the umbilical and the people safe with minimal complexity and maximum flexibility.

10.1.4 Launch and retrieve robot

As can been seen in the morphological chart, there are three principles to launch and retrieve the Fleet Cleaner R.O.V. The following non-functional requirements have guided the design process.

Complexity

An A-frame is a very complex system mostly used in offshore situations with rough sea-state. It has a lot of moving parts and is therefore unnecessary complex for the purpose of hull cleaning in the ARAG.

Flexibility

The fixed boom crane can only lift a weight and then rotate. After studying the behavior of the current crane usage, it seemed that the crane is used for a lot of more lifting operations that are not as easy. Furthermore, at some cleaning operations, the attachment of the R.O.V to the seagoing vessel is also not as straight forward. At special occasions, the R.O.V. is attached from the other side of the support vessel. The limitation of not being flexible with a fixed boom crane is therefore eliminated.

Overview

The knuckle boom crane provides the most operational flexibility without adding any extra unnecessary complexity. Therefore, all principles except the knuckle boom crane are excluded for the final design.

10.1.5 Accommodate the crew

To have a 24/7/365 occupation, the crew should have a decent accommodation to live in. There are two possible principles described in chapter 9.

Complexity

Almost all inland vessels that will be converted already have a fixed living accommodation. It is rather complex to design a TLQ solely for this purpose. Furthermore, the vessel also needs to be redesigned to be compatible with the TLQ, which adds even more to the complexity.

Overview

Using a TLQ in the design, would add unnecessary complexity. The design will be much easier if an inland vessel is used, which has a decent accommodation.

10.1.6 Supply electrical power

As described in chapter 7.1.6, the Fleet Cleaner R.O.V. needs electricity to power all its systems. Therefore, a generator is placed onboard. As can be seen in the morphological chart, two options are given.

Safety

It is not allowed to place a transportable generator which is designed to stand outside, inside a closed room. For safety reasons it is chosen to build the generator in the vessel to minimize exhaust, noise, vibration and safety issues.

Overview

The decision is made to implement a built-in generator in the design of the support vessel.

10.2 OVERVIEW OF CHOSEN WORKING PRINCIPLES

PRINCIPLES	CHOSEN
Provide sufficient deck space	 *Dry Cargo vessel*
Guide the umbilical overboard	 *Roller chute*
Provide a safe working distance	 *Custom fenders*
Launch and retrieve robot	 *Knuckle boom crane*
Accommodate the crew	 *Fixed accommodation*
Supply electrical power	 *Build in generator*

Table 26: Chosen principles

10.3 OPTIMAL WORKING STRUCTURE

The remaining working principles in chapter 10.2 are combined to find the optimal working structure for the conceptual design for a hull cleaning support vessel in the ARAG area. The combined principles are the input for the final conceptual design which is fully described in chapter 11.

10.4 (IN)DEPENDENCY OF CHOICES

Due to the hierarchy in the principles, only one optimum of working principles can be chosen. It is however valuable to establish the dependencies of the choices so that if the requirements or scope changes this can be easily adjusted. The dependencies are listed in the table below.

#	REQUIREMENTS	(IN)DEPENDENCY	RELATED TO
I	Provide sufficient deck space	Dependent	V, VI
II	Guide the umbilical overboard	Independent	-
III	Provide a safe working distance	Independent	-
IV	Launch and retrieve robot	Independent	-
V	Accommodate the crew	Dependent	I, VI
VI	Supply electrical power	Dependent	I, V

Table 27: (In)dependency table

As can be seen in table 27, three requirements are related. As the first one has a higher hierarchy, requirement V and VI must follow. However, when future studies are done and the area of work changes, this has to be reconsidered.

Part III – The developed model

The final part of this thesis presents the developed model. The model will show the embodiment of the conceptual design of a hull cleaning support vessel.

Furthermore, a technical feasibility study will be presented to see whether this model is realistic and can be used for future support vessels.

Finally, an overall conclusion and recommendation will be provided regarding the developed model.

MAIN OBJECTIVE	PART	SUB-OBJECTIVES	APPROACH
DEVELOP A CONCEPTUAL DESIGN OF A HULL CLEANING SUPPORT VESSEL	PART 1	Identify the main limitations of a hull cleaning support vessel	- Literature study on support systems - Literature study on support vessels - Literature study on limitations
	PART 2	Develop the optimal working principles for a hull cleaning support vessel	- Establish the constraints - Establish the requirements - Combine working principles
	PART 3	Present the developed model	- Present the embodiment of design - Provide conclusions and recommendations

Table 28: Overview of research structure (Part 3)

CHAPTER 11 – DEVELOPED CONCEPT

In this chapter the embodiment of the design is realized. The goal of this design is that it can be used as a guideline for the implementation and design of future hull cleaning support vessels for Fleet Cleaner.

11.1 THE THUNDERBIRD 1 IN TRANSIT MODE

As can be seen in the Morphological chart, the preference is given out to a dry cargo vessel. To create sufficient deck space, all the cleaning equipment is stored in a refitted dry cargo vessel. When there is no cleaning operation, the vessel seems to be a normal dry cargo vessel.

All the cleaning equipment is stored within the support vessel. The cargo hold provides the desired sufficient deck space for the cleaning installation, the spares storage and the maintenance floor. When the holds are closed, the old cargo hold is transformed to a full maintenance area. This new maintenance area protects workers from all weather conditions.

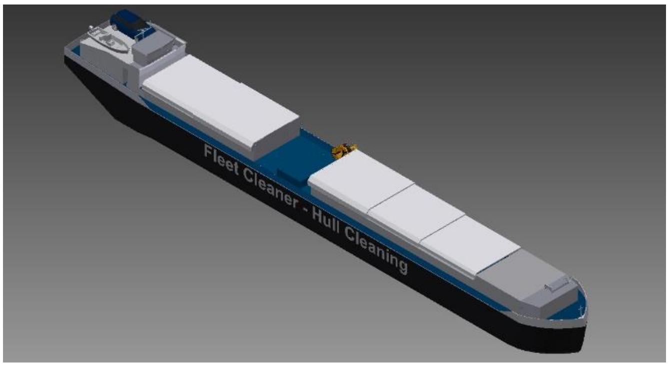


Figure 89: The Thunderbird 1

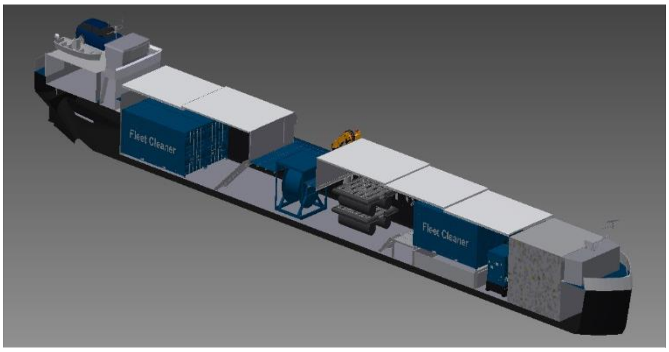


Figure 90: The Thunderbird 1

When a cleaning job is executed, all the necessary cleaning equipment is lifted out of the support vessel. As a normal dry cargo vessel is converted to a hull cleaning support vessel, it will be humorously named after the tv show; “The Thunderbirds”.

11.2 THE THUNDERBIRD 1 IN CLEANING MODE

When the Thunderbird 1 is arriving at the seagoing vessel that needs to be cleaned, she will transit to cleaning mode. For cleaning mode, the roller chute and the custom fenders are deployed.

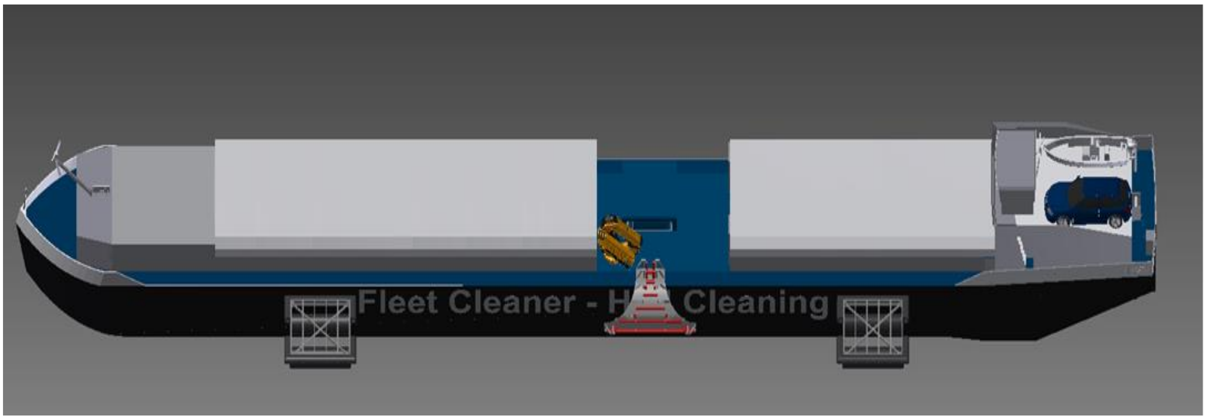


Figure 91: The Thunderbird 1

The support vessel is designed so that the vessel can moor normally when in transit mode. Therefore, both the fenders and the roller chute are fully demountable. With the use of the knuckle boom crane they are lifted from the cargo hold to the side of the support vessel.

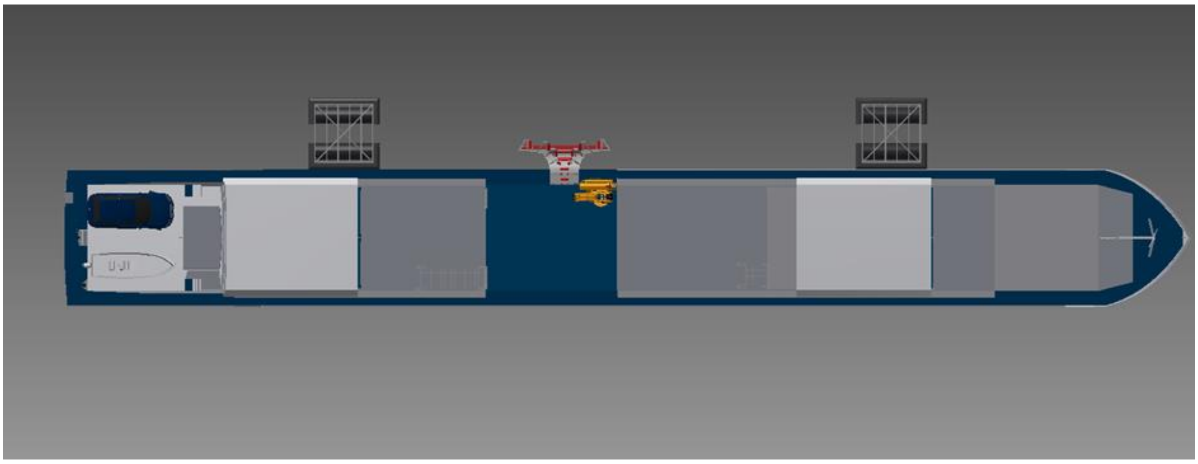


Figure 92: The Thunderbird 1

The support vessel has the following Dimensions presented to the right:

The chosen dry cargo vessel should also have an engine compliant with the CCR2 fase V restrictions.

With the dimensions and engine boundaries, the vessel is capable to operate in all the ARAG ports without the necessity of a deckhand.

Length:	54	M
Width:	7,25	M
Draught:	2,0	M
Freeboard	2,5	M
Height:	6,5	M

Table 29: Thunderbird 1 dimensions

11.3 IMPLEMENTATION OF THE DESIRED WORKING PRINCIPLES

In Chapter 7 the requirements of the conceptual design are clearly specified. After excluding the working principles in the Morphological chart, an optimum design is realized. All the desired working principles are implemented in the final design and fits the company's philosophy to have a modular setup.

11.3.1 Provide sufficient deck space

Chapter 7 describes that the required deck space is around 127,9 m^2. As can been seen in the below model, the complete cargo hold is transformed and therefore used as deck space. The criteria is easily achieved as the cargo hold is approximately 236 m^2.

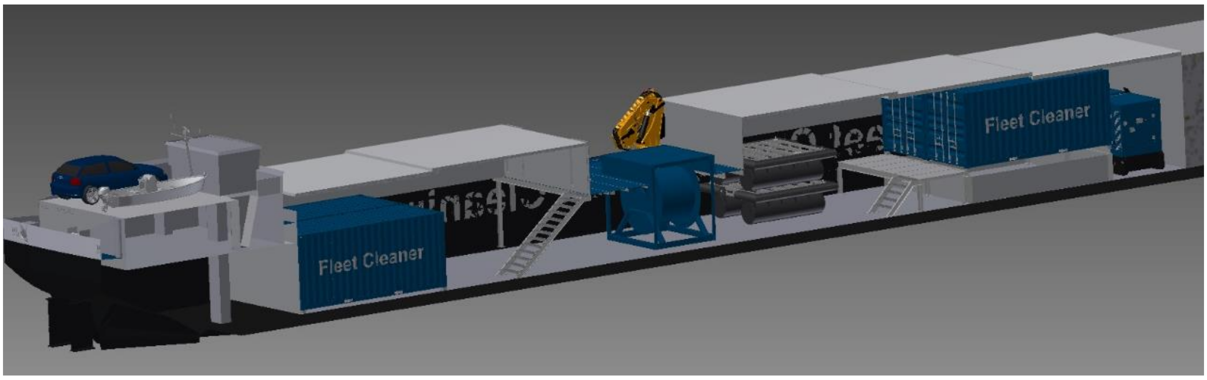


Figure 93: Deck space in the Thunderbird 1

11.3.2 Guide the umbilical overboard

As described in chapter 7.1.2, the umbilical is currently the most vulnerable part of the installation. The umbilical itself is not included in the scope of this Thesis, but the guidance system is.

As can be seen in the morphological chart, the roller chute has been chosen as a working principle for an optimal design. The difficulty with this is that the system is very vulnerable when its hanging overboard during transit.

Figure 94: Roller chute

To solve both the challenges, a detachable roller chute is chosen. In transit mode, the chute will be stored in the cargo hold. When the Thunderbird 1 transforms to cleaning mode, the roller chute is lifted by the crane and placed overboard.

11.3.3 Provide a safe working distance

The custom fenders described in chapter 7.1.3 are used to create a safe working distance. As can be seen in figure 93, the fenders are stored in the cargo hold when the vessel is in transit mode.

11.3.4 Launch and retrieve robot

The knuckle boom crane is also implemented in the design. The pillar is welded on to the side of the support vessel to provide sufficient stability. The strength calculation of this is not considered in this thesis.

Figure 95: Foldable knuckle boom crane

The knuckle boom crane with winch is foldable so that it does not obstruct the captains line of sight during transit. Furthermore, it has a reach that can lift every element in the cargo hold.

11.3.5 Accommodate the crew

To facilitate the crew, a fixed accommodation is chosen. When searching for an inland vessel it will be essential that the accommodation is good enough. As inland cargo vessels are designed to facilitate people over longer periods to transit through the inland waters, this seems to be feasible.

As the complete hold is now a working area, the crew is much better sheltered against all weather conditions. Furthermore, it will be provided with the necessary facilities and tools required.

11.3.6 Supply electrical power

The morphological chart shows that a built-in generator is preferred over a transportable generator. The generator is built in a separated chamber in the cargo hold. It is chosen to place this as far a front as possible so that it will disturb the operators and accommodation as little as possible. The separated chamber will be provided with all the necessary safety precautions similar to a conventional engine room.

11.4 EXPECTED TECHNICAL CHALLENGES

When constructing a vessel, many technical challenges are faced. A shipyard has a complete department that does the calculations for refitting a safe working vessel. The goal of this Thesis is to develop a conceptual design and therefore not go into much detail on these aspects. If the design will be implemented, the following minimal calculations should be done:

- Stability of the vessel when lifting and sailing
- Strength of the vessel, the crane, the umbilical guidance, fenders etc.
- The planning of constructing all the working principles and combining them
- Optimizing the hydrodynamics of the vessel for her specific draught

CHAPTER 12 – CONCLUSIONS AND RECOMMENDATIONS

The key conclusions and recommendations drawn from the research are elaborated in this chapter.

12.1 CONCLUSIONS

The conceptual design of a hull cleaning support vessel in the ARAG area is presented in this Thesis. This is the first vessel ever solely designed for hull cleaning and it is therefore unique in its requirements and design. This Thesis is divided into three parts.

In the first part of this Thesis a thorough analysis is made of the operation and the support systems used for hull cleaning and other similar maritime services. Each different maritime provider is assessed, and their principles are analyzed. Finally, the limitations of the current Fleet Cleaner support vessel are also described. The conceptual design should cover the limitations to improve efficiency, safety and durability of the Fleet Cleaner installation.

The second part of this Thesis describes the scope, the constraints and the requirements of the desired design. The scope of the conceptual design is limited to refitting an inland vessel and to support a modular system which is capable of cleaning seagoing vessels over 120 meters long in the ARAG area. Within this scope, the constraints outlined below are assessed:

TYPE	CONSTRAINT	SPECIFICATION
Environment	Operation in all the ARAG Ports	– Max length of 55 m – Max width of 10 m – Max draught of 6 m – Max height of 6.5 m – Min 5 m safe working distance – The engine should be CCR2 fase V certified
Modularity	The support system must be modular	– The support system should be interchangeable in less than 5 days.
Cleanable ships	To crane must be capable of reaching the waterline	– The freeboard of the vessel should not be too high. (5m)

Table 30: Constraints overview

Successively, the conceptual design also needs to fulfill the following requirements:

PROVIDE SUFFICIENT DECK SPACE	LAUNCH AND RETRIEVE ROBOT
GUIDE THE UMBILICAL OVERBOARD	ACCOMMODATE THE CREW
PROVIDE A SAFE WORKING DISTANCE	SUPPLY ELECTRICAL POWER

Table 31: Overview of requirements for the conceptual design

These requirements are covered by analyzing suitable working principles for each requirement and combining them to an optimum in a morphological chart.

Based on the findings in part 1 and part 2, the final conceptual design is presented in part 3. The conceptual support vessel is called Thunderbird One. This vessel is in transit, a normal dry cargo vessel. However, when a seagoing vessel needs to be cleaned, the cleaning robot comes out of the cargo hold and Thunderbird One transforms into a cleaning station.

Keeping an inland vessel normal for transit but making it capable of transforming for hull cleaning is an uncommon design-solution. With Thunderbird One, Fleet Cleaner will have sufficient deck space but also a very flexible and fast mobilization. For operations in the ARAG area, this will be key in achieving a high cleaning occupation rate.

The use of the cargo hold for maintenance and storage will improve the overall assembly quality and will stimulate workers onboard. The new inboard workplace creates a safe working environment which was one of the goals of this Thesis.

Not only will the quality of the assembly improve, the complete cleaning system will be much better preserved due to dry storage in the cargo hold.

Finally, it is concluded that Thunderbird One improves the overall quality, efficiency and safety of the cleaning operation. Fleet Cleaner is planning to implement the design within the upcoming year.

12.2 RECOMMENDATIONS

During the writing of this Thesis, much has been changed within Fleet Cleaner. At the starting phase the company did two cleanings every month. The cleaning installation was not reliable and the bottleneck for the occupation had nothing to do with the support vessel.

In the current phase, Fleet Cleaner cleans approximately 8-12 vessels a month. This means that not only the robot her speed needs to be optimized, but also the concurrent actions such as mobilization, cooperation with diving crews and the ability to work during the night.

To optimize speed and reduce costs, I would recommend Fleet Cleaner to try to implement diving equipment in the vessel. Currently, when divers are needed, they come with an own support vessel with equipment. It will be much more efficient and cost effective if such an operation takes place from the same vessel. To implement this recommendation, a thorough study must be made on safety, financial feasibility and the operational aspect of such a cooperation. This recommendation should be implemented, because Fleet Cleaner is often the main contractor also offering the diving services.

Furthermore, a follow-up study should be implemented when Fleet Cleaner decides to expand abroad. In other countries, different regulations may apply which can result in a more effective support vessel concept. For this concept, the minimal technical calculations have to be done listed in chapter 11.4.

Successively, it has been noticed that due to the shifting of the schedule of the seagoing vessels, it may be very interesting in combining Fleet Cleaner's service with another service which can be delivered during the waiting time. Further studies can be done on simultaneous bunkering, port maintenance, oil response service, garbage disposal, providing water or any other in port service.

Lastly, a big data analysis would be recommended on the operational aspect of the cleaning operation. It seems that Fleet Cleaner's downtime, traveling time and cleaning time is currently approached from their in-house experience. Equipping the vessel and the robot with a thorough time tracking system, will help them make more fundamental choices in their operation, maintenance and further developments.

CHAPTER 13 - LIST OF FIGURES

CHAPTER 14 - LIST OF TABLES

CHAPTER 15 – BIBLIOGRAPHY

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CHAPTER 16 – APPENDICES

This chapter consists out of the appendices used for this Thesis

16.1 APPENDIX A - FORCES ON THE UMBILICAL

Umbilical deployment/retrieval

The Fleet Cleaner R.O.V. is always connected through an umbilical. The force on the umbilical is accumulated through the weight of the R.O.V. and the Umbilical plus the forces accumulated on them both.

$$\boldsymbol{Ftotal} = Fd(rov) + Fw(rov) + Fd(umb) + Fw(umb)$$

Ftotal	Total Force accumulated (N)
Fd(rov)	Drag force caused by the R.O.V. (N)
Fw(rov)	Force caused by the weight of the R.O.V. (N)
Fd(umb)	Drag force caused by the umbilical (N)
Fw(umb)	Force caused by the weight of the umbilical (N)

Table 32: Overview of forces on the robot

The weight of the umbilical and the robot is neutral buoyant under water, which eliminates these two forces. Resulting that the force on the umbilical is caused by the drag caused by the tidal current on the robot and on the Umbilical.

$$\boldsymbol{Ftotal} = Fd\ (rov) + Fd(umb)$$

The largest force on the umbilical due to tidal streams will be developed when the umbilical is placed transverse to the tidal stream. The drag force is calculated using:

$$Fd\ (rov) + Fd(umb) = \frac{1}{2}A(rov)\rho C_{d1}v^2 + \frac{1}{2}A(umb)\rho C_{d2}v^2$$

Fd:	82	Drag Force (KN)
A(rov):	0.75	Area (m^2)
A(umb)	12	Surface umbilical (LxB)
ρ:	1025	Volumetric mass density of water ($\frac{kg}{m^3}$)
C_{d1}:	1.17	Drag coefficient R.O.V.
C_{d2}:	2.05	Drag coefficient R.O.V.
v:	2.5	Velocity ($\frac{m}{s}$)

Table 33: Table of drag forces

When the R.O.V. is hanging loose in the sea, all the above forces will accumulate on the support vessel. Applying a safety factor of 2, defines that deployment system should be capable of handling roughly 8.390 KG.

Excel to calculate max drag force on robot and umbilical perpendicular

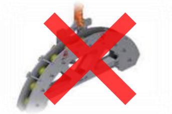
Place	v (m/s)	Source
Rotterdam (scheurkade)	2,5	http://mx-systems.nl/osr/

Situation perpendicular			0.5*A*ρ*Cd*v^2				
F robot	4924,805	N	502,0188	kg			
						Max force divided by 2	
F hose	44971,88	N	4584,289	kg			
					F haspel	2.292	kg
Ftotal	49896,68	N	5086,308	kg			
					With SF	4.584	kg
P robot	12312,01	W					
P hose	112429,7	W					
Ptotal	124741,7	W					

Umbilical concurrent with the current							
					F haspel	3.693	kg
F hose	36226,49	N	3692,812	kg			
With SF	72452,98	N	7385,625	kg	With SF	7.386	kg
			0				
Situation robot loose from ship	41151,29	N	4194,831	kg	F haspel	4.195	kg
Met SF	82302,59	N	8389,663	kg			
					With SF	8.390	kg

Parameters			
rho	1025	kg/m3	
A robot	0,75	m2	
d hose	0,15	m	
L hose	80	m	
A hose	12	m2	
Cd robot	2,05	-	
Cd hose	1,17	-	(circle)
Cf hose	0,3		
v	2,5	m/s	

16.2 APPENDIX B - MORPHOLOGICAL CHART EXCLUDED

Principles	I	II	III	IV	V
Provide sufficient deck space	 Tanker	 Dry Cargo vessel	 Inland barge	 Pontoon with push vessel	 Work vessel
Guide the umbilical overboard	 Chute	 Roller chute	 Sheave	 Roller Sheave	
Provide a safe working distance	 Pneumatic fenders	 Fixed structure attached to vessel	 Magnetic fenders	 Custom fenders	 Spud poles

Principles	I	II	III	IV	V
Launch and retrieve robot	 A-frame	 Knuckle boom crane	 Fixed boom crane		
Accommodate the crew	 TLQ	 Fixed accommodation			

16.3 APPENDIX C - LOAD GRAPH CRANE