‘Optimization of tug operations’

July, 1st, 2015
Hogeschool Rotterdam

Manager: Mrs. van de Drift
Principal: Ms. van den Berk

Wesley Looise 0890145 0890145@hr.nl
Marc Boot 0903020 0903020@hr.nl
Ferdie Krug 0889730 0889730@hr.nl
Jimmy Ettema 0889989 0889989@hr.nl
Bob Bouhof 0888350 0888350@hr.nl
Management summary

Introduction
For more than a hundred years tug-boats have been assisting sea ships while entering and leaving the port of Rotterdam. The towing methods and towing equipment have both been improved ever since. Also the safety on board of the tug-boats has been greatly enhanced. Nowadays research is taking place to look for further optimization regarding the use of tug-boats in the port of Rotterdam.

Conclusions and recommendations
Nowadays, big vessels are not assisted by conventional tug boats, but by azimuthal stern drive (ASD) tugs. Sometimes (for example in Rotterdam) tractor tugs will be used to assist vessels. For reasons of safety and efficiency conventional tugs are hardly used anymore to assist a big vessel.

In the future, new build tugboats will be fitted with either a Voith-Schneider propulsion system or a propulsion system using azimuth thrusters. Because these are the most efficient means that are at hand right now. Azimuth thrusters have the highest efficiency of them all. Current studies are now focussing on how to improve the efficiency on the electricity production and converting this energy to mechanical energy.

It is a hard job to come up with new ideas to improve the present towing methods and procedures. The reason behind this is that tug-boats have assisted large vessel for over hundreds of years and nowadays the tug boat captains work with all the techniques that were practically the same as 40 years ago. The towing nowadays is already very efficient.

Every day of every year, everyone involved is working on safety and it gets improved by determination and experience. As it is, safety is on everyone’s mind and this is certainly a good thing. Augmented reality is a state of the art technology that can be the solution for showing obstructed parts. However it is not known if it can be implemented and if the benefits are sufficient.

Problem solution
The TUC-system is the solution to address the communication problems between pilot and tugboat master. It is clear for everyone on the bridge and it is not possible for other ships to interfere when the system is in operation. This is a big problem while using the VHF. It is also a solution regarding the white-noise that is bothering the VHF-communication.

Conclusion
The answer to the question ‘How can tug operations be optimized?’:
Tug-boat operations can be optimized by implementing the TUC-system on board of the tug-boat and the vessel that is to be towed.

Recommendation
Based on the performed research it is recommended that more research should be done to make the TUC-system ready for operation. After the system has been tested and approved, it is ready for implementation.
Preface

This project was created to come up with new innovative methods and techniques to make towing more efficient. It was also created for students to gain more knowledge about how a research should be performed. This project group started to write down as much information as possible. After gathering enough information, the hardest part was yet to come. The hardest part was coming up with new technologies. In the end various concepts, effects and possible implications regarding the latest maritime technologies are included in this report.

This project group would like to thank mrs. van de Drift and ms. van den Berk for giving us a lot of helpful advice.

Rotterdam, 7th July 2015

Marc Boot, Bob Bouhof, Jimmy Ettema, Ferdie Krug and Wesley Looise.
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1. Introduction

Towing operations are critical operations in all the ports of the world. Therefore this branch of the industry is big and has many different aspects. Because this section of the maritime business world is so vast, there have to be new ways to improve the tug operations. The other advantage of a big branch is that there are a lot of stakeholders such as: the towing companies, the crew on board the tug boats and the merchant sailors who use tug assistance. Because this research team studies at the Rotterdam Mainport University this project will focus on tug operations in the port of Rotterdam. This will also give the advantage that a lot of towing companies are located in our vicinity.
1.1 Problem description

For more than a hundred years tug-boats have been assisting sea-going ships while entering and leaving the port of Rotterdam. The towing methods and towing equipment have both been improved ever since. Also the safety on board of the tug-boats has been greatly enhanced. Nowadays research is taking place to look for further optimization regarding the use of tug-boats in the port of Rotterdam. 

There are several different points describing the problems:

- The propulsion mainly delivers a low energy yield.
  - Fuel consumption and emission are too high compared to the operating hours. (Literature: P van Maanen, 2014)
- Inefficiency due to water thrust from the propeller against the hull of the towed ship.
  - In contradiction to pushing, towing delivers much lower efficiency. (physics laws)
- Tug operations can be time consuming.
  - Fixing the rope and getting in position according to current protocol can take time. Students in this group have experienced this in practice.
- Poor communication or lack of communication can compromise the operation.
  - Dangers will occur if communication is neglected or poorly interpreted. In 2014, a man lost his foot in a tug operation due to poor communication and wrongly interpreted instructions onboard the Julia N.
- Hazards to health and wellbeing can be endangered.
  - The enormous forces involved could lead to dangerous situations within seconds. If not neutralized, it could cause damage, injuries or even fatalities. (http://maritimeaccident.org/categories/tug/).
- Current technologies are outdated.
  - New technologies are available and not implemented, this decreases effectivity in towing. (Http://link.springer.com/article/10.1007/s11042-010-0660-6)

If one of the above points can be improved this will benefit not only the whole port of Rotterdam, but it could be implemented around the world. This could result in faster or safer towing methods. In order to find these innovations the present situation must be investigated thoroughly, with all its flaws that need to be addressed.

1.2 Problem definition

Towing operations are always critical, dangerous and time consuming. Some aspects of the operation can be optimized. In this project these aspects will be investigated and improved.

The objective of this project is to find a way to optimize the operation around or on board tug boats with the help of new innovative technology. This will be done for the benefit of both the towing companies and the crew of the tug boats.
1.3 Main question & sub questions
The main question, consisting of several sub questions, are guidelines for leading to solution to the problem. The problem is finding innovations leading to faster and/or safer towing methods

1.3.1 Main question
How can tug operations be optimized?

1.3.2 Sub questions
- What is the current situation regarding the use of tugs?
  - Combination of desk research and field research.

- How can a more efficient means of propulsion be achieved?
  - Quantitative research, a combination of desk research and field research.

- How can towing methods and procedures be improved?
  - Qualitative research, a combination of desk research and field research.

- How can the communication between tug and ship be improved?
  - Combination of desk research and field research.

- How can the safety be improved?
  - Quantitative desk research and field research.

- Which state of the art technology can be implemented in towing?
  - Mostly qualitative research, in a combination of desk research and field research.
1.4 Research methods

Research was carried out to get the sub questions answered. This can be done in different ways. There are two kinds of research to achieve this: desk research and field research. Both methods are used to find the information needed to deliver the final product.

Desk research is researching through certain methods, such as:
- Literature in books (towing manual)
- Articles on the internet (several websites)
- Outcomes of previous/other studies

Field research is researching through certain methods, such as:
- Interviewing of experts (pilots, Alphatron)
- Interviewing of a (towing) company (Smit, Fairplay)

Qualitative research was applied to both methods mentioned above. Qualitative research is an interpretative and subjective form of research, and will produce information on the particular cases studied. Another type of research is quantitative research. This method is aimed to numbers and is an objective research. Quantitative research is set out to be more of a method to produce empirical support for information gained through other methods. The outcomes of the committed research are measurable and can be found in the citation and is used for the efficiency question.

Following shows a list of the consisting of these research methods per question with their specific actions taken:

- **What is the current situation regarding the use of tugs?**
  - Desk research: Using internet, google scholar and other literature. Looking for existing researches.
  - Field research: Based on the experience of the project members (during internship). Interviewing of towing companies and pilots.
    - The information of the researches are in a qualitative form.

- **How can a more efficient means of propulsion be achieved?**
  - Desk research: Internet for inventorying types of propulsion. Researching in a variety of manuals.

- **How can towing methods and procedures be improved?**
  - Desk research: Using magazines, google scholar and literature for existing information.
  - Field research: Interviewing tug masters and pilots.

- **How can the communication between tug and ship be improved?**
  - Desk research: Using internet to collect several technical aspects regarding radio communication equipment.
  - Field research: Interviewing tug masters, pilots.
    - The results of the researches are qualitative.

- **How can the safety be improved?**
  - Desk research: Google scholar, internet and magazines. Researching statistics of casualties and injuries.
Field research: Questionnaire concerning safety in interviews with towing companies.

Which state of the art technology can be implemented in towing?

Desk research: Internet and technical magazines. In this way products of relevant suppliers and developers of modern equipment can be inventoried.

Field research: Contacting suppliers and developers of modern equipment. Alphatron will be contacted.

1.5 Project borders
During this project, research was carried out over several subjects. However, a number of subjects are ignored in this project. To provide understanding to what will be researched and what will not be researched, the project borders are explained below:

- The main question relates to harbour tugs, the same applies to the sub questions. Research to ocean going tugs is beside this project.
- All the results at the end of this project are not going to be tested in test centre with miniature tugboats. This project contains the theoretical approximation of the reality.
- At this project the exact reduction of the financial costs is not considered, only a very rough approximation is possible.
- At the subject how the communication between tugboat and vessel can be improved, it is about the communication between the vessel (with pilot) and the tugboat which is connected to the towed vessel.
- At the subject how the safety on board can be improved. For starters, it is about the safety during the making fast operation on board, but certainly not about a unsafe situation in the galley.
- At the subject: which state of the art technology can be implemented on board of the tugboats, it is about making fast and other procedures. Not how the navigational lights could be switched on with the aid of a smartphone.
- Concerning the subject, can tug methods be changed to secure a safer operation? In this case only the theoretical aspect will be recognized.
- At the subject what the most efficient ways of propulsion are there? It will practically not be tested. Only the theoretical most effective way will be researched and explained.
- The stability of the tugboats during towing will not be researched at this project.
2. Current situation regarding the use of tug

2.1 Introduction
In this chapter the sub question ‘what is the current situation regarding the use of tugs’ will be investigated by using internet and literature.

There are three main types of tugs, each with their own advantages and disadvantages. The types of tugs are strongly related to the way of propulsion. The type of the used tug is dependent on the assisting method.

The types of tugs:

2.2 Conventional tugs:
- Single screw tugs
- Twin screw tugs

2.3 Tractor type tugs
- Conventional tractor tugs
- ROTOR tugs

2.4 Azimuth stern drive tugs

For the different means of propulsion, see chapter three.
2.2 Conventional tugs

The largest number of tugs belong to this type of tug. These tugs can be found all over the world and are built in large numbers. Conventional tugs are used for push-pull assistance, in particular for towing on a line. The assisting methods will be described in chapter 4 (towing methods and procedures).

Single and twin screw tugs are mostly fitted with a single plate rudder. Mainly due to the location of the towing point (generally 0.45 x LWL from the aft) the tugs have limitations regarding performance and safety. When towing on a line, the main risk is capsizing (girting). To avoid girting, the tugs can be fitted with a quick release hook. When connecting at the stern of a vessel the tug uses in generally a gob-line (see figure 2.1 below). The use of a gob-line is very important in order to avoid girting of a tug. To see what is meant by a gob-line, below is an figure with a tug boat which use a gob-line. When using a gob-line, the towing point is moved further to the aft and reduces the manoeuvrability of the tug.

Figure 2.1

The astern power of conventional tugs is generally low. When making fast near the bow of a vessel, interaction forces between the ship and the tug makes it very difficult for a conventional tug to connect. A tug with side thrust is preferred in these situations.
2.3 Tractor type tugs
These types of tugs are fitted with two azimuthal thrusters or Voith Schneider thrusters at the bow (forward of the amidships). These tugs are fitted with a harbour towing winch which is located on the aft deck. The stern and bow is generally heavily protected by fenders so this makes it suitable for push and pull operations.

The large skeg is typical for tractor tugs and particular for Voith tractor tugs. It increases the course stability and brings the centre of the hydrodynamic pressure more to the aft. The last is a big advantage when towing on a line as an after tug, extreme high force can be originated.

The towing point lies about 0.1 – 0.2 x LWL from the aft (that is because the wire is leading through the big aft fairlead). The propulsion point is about 0.25 – 0.30 x LWL from forward (Henk Hensen, 2003).

Voith Schneider tractor tugs have great manoeuvring capabilities. They can turn on a place around their axis, deliver a lot of thrust in every direction and sail straight astern at high speeds. The amount of thrust astern is nearly the same as the available thrust ahead. A lot of disadvantages of the conventional (particularly single screw) tugs, such as no or low side thrust, does not apply to Voith Schneider tugs. Because the availability of thrust sideways makes it much safer to make fast when a vessel is sailing at high speeds. A tractor tug (Figure 2.2) does not require a lot of power to tow sideways, because the propulsion point is close to the turning point.

The azimuth tractor tugs have almost the same characteristics as the Voith Schneider tractor tugs. Only sometimes the skeg of the azimuth tractors are smaller than the Voith tractor tugs.

In figure 2.2 the layout of a Voith Schneider tug boat is shown. In this figure the tug boat is equipped with a skeg (aft ship) and two Voith Schneider propellers.
2.4 Azimuth stern drive (ASD) tugs
These tugs are fitted with two thrusters at the aft ship. The thrusters can each independently rotate at an angle of 360°. So the thruster can give thrust in every direction. Azimuth thrusters can be fitted with fixed pitch propellers or controllable pitch propellers (CPP). The advantage of having a CPP system is the possibility to have immediate reverse thrust and higher efficiency with different loads.

ASD tugs are fitted with a towing winch, which is located on the foredeck instead of the aft deck. An ASD tug is particularly towing over the bow. This means that as being a bow tug it is mostly sailing astern.

This type of propulsion system makes the tug highly manoeuvrable and very safe during making fast at the bow, because the thrust can be carried out to the side. The ASD tug can easily sail sideways but has to turn their rudder propellers in almost the opposite direction, to create sufficient power at the aft ship to drag the hull sideways through the water. This way of manoeuvring will reduce the towline force significantly (Captain Henk Hensen, 2003).

Figure 2.3 shows the layout of an ASD tug. This figure adds to the theory, to make it more clear to understand the principle of an ASD tug.

2.5 ROTOR tug
Nowadays there is a new type of tug: the ROTOR tug. It is similar to a tractor tug with a third rudder propeller at the stern of the tug. This makes this type of tug extremely manoeuvrable with an increased bollard pull when towing sideways.
2.6 Conclusion

Nowadays, big vessels are not assisted by conventional tug boats. These days the big vessels are assisted by ASD tugs. Sometimes (for example in Rotterdam) tractor tugs will be used to assist vessels. Several reasons (two of the reasons are unsafe and inefficient) have ensured that conventional tugs are not be used to assist a big vessel.

The use of ASD tugs is preferred because a tractor tug has a bigger draught than an ASD tug. Nevertheless, the tractor tug is a very efficient and high maneuverable type of tug boat.

A ROTOR tug is a better type of a tractor tug boat: extreme maneuverable, very much power during towing sideways.

<table>
<thead>
<tr>
<th>Type</th>
<th>Thrust</th>
<th>Safe during towing</th>
<th>Maneuvrability during towing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single screw, fitted in</td>
<td>Ahead: 100 %</td>
<td>Not safe, only when using gob line</td>
<td>Bad</td>
</tr>
<tr>
<td>nozzles, conventional</td>
<td>Astern: 60%</td>
<td>(what restricts the manoeuvrability</td>
<td></td>
</tr>
<tr>
<td>rudder flap</td>
<td>Sideways: 0%</td>
<td>extremely)</td>
<td></td>
</tr>
<tr>
<td>Conventional tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twin screw, fitted in</td>
<td>Ahead: 100%</td>
<td>Not safe, only when using gob line</td>
<td>Better than a</td>
</tr>
<tr>
<td>nozzles, conventional</td>
<td>Astern: 60%</td>
<td>(what restricts the manoeuvrability</td>
<td>conventional single</td>
</tr>
<tr>
<td>rudder flap</td>
<td>Sideways: ± 10%</td>
<td>extremely)</td>
<td>screw tug, but responds not fast.</td>
</tr>
<tr>
<td>Tractor tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional tractor</td>
<td>Ahead: 100%</td>
<td>Very safe, especially during making</td>
<td>Very good</td>
</tr>
<tr>
<td></td>
<td>Astern: 95%</td>
<td>fast</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sideways: 80%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractor tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROTOR tug</td>
<td>Ahead: 100%</td>
<td>Very safe during all operations</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Astern: 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sideways: 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azimuth stern drive</td>
<td>Ahead: 100%</td>
<td>Safe</td>
<td>Very good</td>
</tr>
<tr>
<td></td>
<td>Astern: 98%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sideways: 60%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Efficient means of propulsion

3.1 Introduction

This chapter shall be answering the question: What is the most efficient type of propulsion for a tugboat? There are several kinds of propulsion available for ships. Each type of propulsion has its own characteristics, making it perfectly suitable for some types of vessels, but very unsuitable for other types of vessels. This project is only aiming for the optimization of tugs, so the best types of propulsion for other types of vessels are left out of consideration.

The biggest part of the information, gathered while carrying out desk research, is coming from the internet. The second source of information is coming from literature, mostly educational books.
3.2 The conventional propeller
There are two different types of conventional propellers. The first type is the propeller with a fixed pitch, which is called an FPP propeller. FPP stands for ‘fixed pitch propeller.’ The second type of propeller is the propeller with a controllable pitch, which is abbreviated to CPP.

3.3 The fixed pitch propeller
Fixed pitch propellers are particularly installed on ocean going vessels, such as bulk carriers, tankers and large container vessels. (www.Wärtsilä.com)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Simple construction and less maintenance than CPPs</td>
<td>- Performance degrades rapidly at off-design conditions, where the vessel may operate majority of the time</td>
</tr>
<tr>
<td>- No support system needed</td>
<td>- Not able to provide reverse thrust without stopping the engine, unless a reduction gear is installed</td>
</tr>
<tr>
<td>- Smaller propeller leading to increased open water efficiency</td>
<td>- Potential cavitation, strength &amp; stability issues at highly loaded off-design conditions</td>
</tr>
</tbody>
</table>

(University of Michigan propeller study)

3.4 The controllable pitch propeller
Controllable pitch propellers are especially suitable for vessels that require variable propulsion power in terms of speed, bollard pull and maneuverability as is the case with fishing boats, tug boats, supply vessels and other utility ships.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Pitch schedule can be optimized over operational range</td>
<td>- Requires a support system to operate properly which will entail more electrical power and maintenance</td>
</tr>
<tr>
<td>- Ability to mitigate cavitation and reduce blade stress as well as increase overall efficiency</td>
<td>- More complex and expensive than a FPP</td>
</tr>
<tr>
<td>- Ability to produce forward or reverse thrust while continuing to rotate in the same direction</td>
<td>- Larger propeller hub leading to decreased open water efficiency</td>
</tr>
</tbody>
</table>

(University of Michigan propeller study)

Maintenance and reliability issues of the two propeller types need to be taken into consideration when determining which propeller to integrate. FPPs are relatively low maintenance, while it’s not uncommon to have an expensive systems overhaul of a hydraulically actuated CPP every couple of years requiring dry docking.
3.5 Ducted propellers

A ducted propeller is also known as a ‘Kort nozzle.’ This is a propeller fitted with a non-rotating nozzle. The tube is mounted to improve the efficiency of the propeller. It is especially used on heavily loaded propellers or propellers with limited diameter.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| - Increases thrust per kW, higher efficiency  
- Better course stability | - Costs more than a single conventional screw  
- More chance on cavitation (Can be adjusted by adding more blades)  
- Efficiency loss while sailing astern. However this is not a problem when speaking about azimuth thrusters, because they will rotate $180^\circ$ |

(www.propellerpages.com)
Ducted propellers are mostly used in tug-boats and fishing trawlers. There is a clear reason for this. Kort nozzles or ducted propellers are more efficient than unducted propellers at low speeds while under high load producing lots of thrust in a small package. At high speeds (balancing point 10 knots) the shrouding creates more drag so it outweighs the gained efficiency. The Kort nozzle loses the advantage over unducted propellers.

3.6 Voith-Schneider (VSP, cycloidal drive)

The Voith-Schneider principal was invented prior to WWI. It is an old means of propulsion, but it is still used all over the world, because of its great maneuvering capabilities. It is a unique type of propulsion, the system generates stepless thrust in all directions with precision and speed. Propulsion and steering are combined in one unit.

The Voith-Schneider Propeller works as follows: it consists of a circular disk with movable and controllable blades. These blades are installed at a 90 degree angle on the disk that rotates at the vessel bottom. Below (Figure 3.1) is shown a figure of the cycloidal drive.

The thrust force is determined by the speed of the rotation of the disk. The controllable angle of the blades determine the direction of the thrust. This means that there is no need for a rudder. It provides the vessel with very precise maneuvering, even in difficult conditions. Because of its maneuverable capabilities it is primarily used on tug-boats and ferries.

Figure 3.1: cycloidal drive
3.7 Azimuth thrusters

Azimuth thrusters were invented in the late 50s. These thrusters are sometimes also called Z-drives. There are two different types of thrusters to choose from. There is the mechanical driven version and the alternative is the electrical driven version.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Good maneuverability due to 360° turning propellers</td>
<td>- The blades are fixed</td>
</tr>
<tr>
<td>- Low maintenance costs</td>
<td>- Installing thrusters costs more than installing a</td>
</tr>
<tr>
<td>- They do not require a lot of space in the engine room</td>
<td>conventional propeller</td>
</tr>
<tr>
<td>- Excellent in combination with diesel generators, making a main engine redundant</td>
<td></td>
</tr>
</tbody>
</table>

One of the disadvantages are the fixed blades. However this is not necessary because the propeller is driven by an electric motor. Because of the latest technology in frequency controllers it is now possible to reduce an electro-motor its power delivery without losing efficiency (Uitleg over Frequentieregelaars)

Azimuth thrusters are used mostly for ship docking and marine construction. Conventional propellers and rudders are more efficient for port to port towing.

3.8 Bow thrusters

Bow thrusters are used for steering the bow of the vessel. Basically it is a duct in the bow of the vessel. In the duct there is a propeller, driven by an electro-motor. Some vessels require extreme maneuverable capabilities have two or even three bow thrusters. See figure 3.2.

![Figure 3.2: The bow of a vessel with three bow thrusters](image)
3.9 Conclusion, how can a more efficient means of propulsion be achieved?

There are several types of tugs, all of which have been built to fulfil a specific task. This makes it very hard to determine the best type of propulsion, since every tugboat is designed for distinct tasks. For example, tractor tugs are very efficient with the propulsion placed at the front of the vessel. While ASD tugs have azimuthal thrusters fitted on the aft of the vessel, giving them excellent manoeuvring characteristics for towing over the bow. Conventional propellers, with or without duct, are being used fewer than before, and this trend will go on for the coming years. This is because of their limited manoeuvring capabilities and efficiency.

In the future, new build tugboats will be fitted with either a Voith-Schneider propulsion system or a propulsion system using azimuth thrusters. Because these are the most efficient means that are at hand right now. Azimuth thrusters have the highest efficiency of them all. Current studies are now focussing on how to improve the efficiency on the electricity production and converting this energy to mechanical energy.

<table>
<thead>
<tr>
<th>Type of propulsion</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Fixed pitch propeller | - Simple construction and less maintenance than CPP’s  
- No support system needed  
- Smaller propeller leading to increased open water efficiency | - Performance degrades rapidly at off-design conditions, where the vessel may operate majority of the time  
- Not able to provide reverse thrust without stopping the engine, unless a reduction gear is installed  
- Potential cavitation, strength & stability issues at highly loaded off-design conditions |
| Controllable pitch propeller | - Pitch schedule can be optimized over operational range  
- Ability to mitigate cavitation and reduce blade stress as well as increase overall efficiency  
- Ability to produce forward or reverse thrust while continuing to rotate in the same direction | - Requires a support system to operate properly which will entail more electrical power and maintenance  
- More complex and expensive than a FPP  
- Larger propeller hub leading to decreased open water efficiency |
| Ducted propeller | - Increases thrust per kW, higher efficiency  
- Better course stability | - Costs more than a single conventional screw  
- More chance on cavitation (Can be adjusted by adding more blades)  
- Efficiency loss while sailing astern. However this is not a problem when speaking about azimuth thrusters, because they will rotate 180° |
| Voith-Schneider | - Performs extremely well and fast at maneuvering | - Complexity  
- Expense |
| Azimuth thrusters | - Good maneuverability due to 360° turning propellers  
- Low maintenance costs  
- They do not require a lot of space in the engine room  
- Excellent in combination with diesel generators, making a main engine redundant | - The blades are fixed  
- Installing thrusters costs more than installing a conventional propeller |
4. Towing methods and procedures

4.1 Introduction
In the world of tugs and towing there is not one exact and perfect method. Every vessel is different, the weather is not one day the same and every situation is different. So there are more ways to assist a vessel in harbour operations. Many of the used assisting method depend on the type of used tug. For example: a conventional tug uses a totally different towing method than an ASD tug. In this chapter the question "How can towing methods and procedures be improved" will be answered.

Most of the towing companies have towing procedures. But towing is based on experience and cannot be done by following steps in a handbook or a guideline. The difference between towing methods and procedures is that the procedure is made up by the company and is actually a guideline. The method is how the towing will actually be carried out.

Desk research is carried out to give more insight in the towing methods. The findings of this research can be found in the appendix in the chapters with the interviews.

- 4.2 Direct/indirect towing
- 4.3 Tug wash effects
- 4.4 New type of thruster
- 4.5 Procedure
4.2 Direct/indirect towing method
The direct towing method is a method whereby the tug is pulling the assisted vessel directly with its direction of propulsion. The indirect towing method is a method whereby the tug is making use of the flow of water. So this method can be used only when there is a sufficient flow of water, for example: assist a vessel in a swing when sailing ahead with a speed of 6 knots. When the assisted vessel does not make speed through the water this method is useless. In these kind of situations there has to be used the direct towing method.

Because of the extremely high hydrodynamic forces the indirect towing method is a simple but very effective method. At this method the risk of girting exists.

The tractor tug is more effective than an ASD tug because an ASD tug needs more crosswise power and so less effective power on the towline (HenkHensen, 2003).

4.3 Tug wash effects
When a tug has to assist a vessel, the tug’s propeller wash hits the hull of the assisted vessel (figure 2). This is called: the Coanda effect. The larger the hull underwater, the larger the negative effects of the propeller wash. When the thrust is increasing, the negative effect is increasing as well. Proper towline length and towing angle reduces this negative effect. The bigger the underwater hull and the more power required, the longer a towline should be.

Using a different assisting method can minimalize these tug wash effects: instead of towing on a line, pushing against the hull of the assisted vessel (figure 1). So at this method there is not any propeller wash, which hits the hull.

Figure 1 and figure 2 are providing clear pictures of the tug wash effect to make it clear what is meant by text.

Figure 1: push against the hull, propeller wash not towards the vessel
Figure 2: towing on the towline, propeller wash against the hull
4.4 New type of thruster
Nowadays there is a thruster which has a small angle downside, so the thruster is tilted. This means that all of the propeller wash is pressed astern with a little angle downside (figure 3). This means that when the under keel clearance of the assisted vessel is a few meters, the propeller wash will go under the vessel and not hitting the hull. The angle of the thruster is 97° and so is this thruster 7° lifted compared to other thrusters. To give a clear overview of this, figure 3 is a schematic view of the tug boat with a thruster which is lifted and the flow of the propeller water. The thruster can deliver an increased thrust up to 25% compared to 90° mounted thrusters. This new type of thruster is invented by Pleuger azimuthing systems.

![Figure 3](image)

4.5 Procedure
There are many rules and procedures for towing operations. To sketch an example of these procedures an up to date procedure can be found in the appendix (Appendix: “4. tug movements in port” and “5. Mooring”). In general the procedures contain the following:

- Tug movements in port, including standard phrases and maximum speeds.
- Mooring Procedure, including general principles and mooring plans.
- Emergency communication procedures, including communication between pilot and tugboat and procedures in case of communication malfunction, signals and channels.
4.6 Conclusion

It is hard to come up with new ideas on the subject of: "How can towing methods and procedures be improved".

The reason behind this is that tug-boats have assisted large vessel for over hundreds of years and nowadays the tug boat captains work with all the techniques that were practically the same as 40 years ago. The towing nowadays is already very efficient. Improvements over the years are visible in the procedures.
5. Communication

5.1 Introduction

In this chapter the sub question: “How can the communication between tug and ship be improved?” is researched. During tug operations the communication between tug boat and vessel is very important. Therefore research is conducted to improve the communication. During the desk research phase most of the information has been gathered on the internet. During the field research several experts are contacted. There have been some new developments in the radio communication technologies which can be implied in towing operations.
5.2 Present means of communication.

Nowadays most of the communication is done by means of portable VHF radios. This technique has been used for decades and works! Some of the communication is done by hand signals, but the portable VHF has almost entirely replaced this way of communication. However due to the white noise which can disturb the conversations it doesn’t work perfectly.

VHF stands for “Very High Frequency”, which indicates the frequency range of the transmitter/receiver. The Portable VHF uses radio waves to send or receive the spoken word. Because these radios uses a very high frequency the distance covered is relatively small, but the interference is limited. Still the white noise cannot be ruled out.

Another problem with the portable VHF radios is that signals cannot go through steel very well, unfortunately every merchant vessel is built entirely out of steel.

Towing companies have standardised procedures for communication failures. In the appendix a procedure can be found of this procedure (Appendix: “6. Procedure: emergency procedure communication”.)

5.3 New ways of communication

New technology which is already implemented in the commercial radio industry is the so called “Digital Audio Broadcasting” (DAB). When a person listens to this audio broadcasting it will no longer come with any form of white noise. This is because this system uses another form of radio signals. Because of the fact that this form of broadcasting eliminates the white noise there could be great potential in this technology.

During the research it has come to light that this technology won’t improve the communication. This because of the fact that when the signal is interrupted, instead of white noise it won’t produce any sound. (Marcom Algemene radio communicatie, schrijverscollectief marcom docenten)
Towing Universal Commands (TUC)

Tugboats have assisted large vessels for over a hundred years now, and these operations have been optimized ever since. The stress on the environment has been greatly reduced, the safety has been enhanced and the navigational equipment has been upgraded. One part of the operation that hasn’t been modernized for a very long time is the communication. The lion’s share of the communication takes place by VHF. The biggest problem using a VHF is the white noise and the fact that people can’t talk to each other at the same time. When people press the PTT-switch at the same time and start talking, they are not listening to what the other person has to say. This could cause very big problems. The TUC is the solution to all the old VHF-related problems. Loodswezen supports this idea provided that for the sake of safety it has to work in 100% of the times.

The Towing Universal Commands System

It is an application which should be used on a mobile platform, preferably a mobile platform equipped with a touchscreen. The Tug Universal Commands (TUC) should be fitted on the tugboat and on the ship that is to be towed. Via this application the pilot and the captain are able to monitor and overview the situation. The tug boats are able to connect through this application with their tow, so the officers on board the tow can monitor in real time what actions are taken. It will show the following parameters for the tow: Speed over ground, rate of turn, pitch of the bow thruster and heading. The parameters of the tug boat will show: angle of the tow line, tension in the line. This will ensure that all parties concerned know what is happening.

The application must be installed on the ship and tug boats in order to make it work. This is to determine the angle of the tow line. This can be calculated by means of the GPS-positions and the position of the hawse pipe. The application is able to exchange data with the tugboat.

TUC can be installed on new-built vessels, but can also be fitted on existing vessels by means of retrofitting.

When installing the TUC application it is required to fill in some of the ships particulars. The required particulars consist of the exact position of the GPS-antenna, the exact position of the hawse pipes. The tug-boat also needs to fill in the exact position of the GPS-antenna and the position of the drum.

Using the TUC to enhance safety

Using this application will enhance safety. It provides a clear overview of the situation for all the vessel participating in the maneuver.

What can the TUC-system add to the VHF communication?

Adding the TUC to the bridge equipment can give more redundancy for the communication.

Possible extra features on the TUC

A possible feature of the TUC-application is sending and receiving of information regarding both of the vessels. Information such as owner, address, company, etc. This could reduce the amount of paperwork that needs to be filled in, because you can read all the needed information from the screen.
In the following figure, figure no. 1, is an overview of the tablet with the standard commands. This overview gives an indication of how the application is designed. Depending on the (part of) the harbor or the towing company there can be a slight change in the interface or theme, because they may have to work with different commands. This can easily be adjusted.

Starting the system
At first the connection between pilot and tug has to be made before the second part (the tug commands) can be developed. The most difficult part is not to sending the commands, but to establish a proper connection with the tugs which should be working at all time.

Communication by internet connection
The data communication in the TUC-system can be done via the internet, using the 3G or 4G network.

Working with an internet connection
When the pilot sends the desired command from the tablet to the tug boat, the signal will go from the tablet, using the 4G network, to the Virtual Particular Network (VPN) of the Loodswezen. From here the internet signal is going to the server, this is a separate server which is paid by the tug boat company and the Loodswezen. The signal will now go from the server to the tug-boat its network. The server on the tug-boat transports the signal to the VPN part and from there the signal will go to the antenna of the tugboat. The antenna will transport the signal to the router and finally it will reach the screen by the tugboat captain. The time between sending the command and receiving the command on the screen on the tugboat is a few seconds. It is a little slower than the communication by VHF.

When the tugboat sends a commands back (in example for an acknowledgement) the signal will follow the same track, but the other way around.

On the next page is a schematic overview (figure 2) of the 4G-LAN-VPN network. It is a clear picture that helps to clarify the whole system.
Why using the internet as network

The advantage of using an internet connection is that the internet is growing fast and developing all around the world. The connections are getting more reliable and companies such as Google (project Google Global) are investing in internet connections all over the world. So when looking at the future perspective, using TUC on the internet is strongly recommended.

The Wi-Fi connections are getting better, more reliable and the global coverage is getting larger.

Due to the relatively small data bundles the transfer of data will be fast. There has to be more development in the future to ensure reliably all the time. (see figure 2).

Figure 2
Communication by AIS connection

Another way to making the system communicate is by making use of the AIS of the assisted vessel and the involved tugs. Nowadays the pilots have a small transponder which is connected to the AIS pilot plug. This transponder sends all the AIS information to the pilot his computer while using Bluetooth.

Sending commands by the AIS system is very practicable, so the commands from vessel to vessel is solved. But how are these commands going to reach the AIS-system by using a tablet.

Bluetooth seems to be an option because it is already in use. It is an instable, weak and unreliable signal. The best option to communicate between tablet and the AIS system is via a Wi-Fi connection.

In that case the small AIS transponder must be provided with a small Wi-Fi connection modem. Independent of the Wi-Fi from the assisted vessel.

This is an easy system what is facile to implement in the current system.

In figure 3 there is the flow diagram from the communication by AIS. The communication from the tablet to tug transponder is by an Wi-Fi signal.

Figure 3
Working with the AIS signal

In this chapter there is a short summary of how the AIS-system is operating. This is to clarify why using the AIS-system could be an option for the TUC-system.

The AIS sends dynamic information like the course over ground, speed over ground, rate of turn and much more data. Besides dynamic information the AIS also sends static information like name of the vessel, IMO number call sign and more data like this.

The signal which should be sent is not directly going to every AIS station. Therefore uses the AIS system a slot system.

Each AIS station determines its transmission slots by initially ‘listening’ to the existing traffic to establish which slots are free. It then uses defined algorithms to choose suitable slots. This method of selecting the transmission slots is known as self-organising TDMA (Time Division Multiple Access). The self-organising TDMA is known as SOTDMA (RADAR and AIS, Dr Andy Norris 2009).

Figure 4 shows the timeslots of the AIS system.

Because two VHF channels are used for the AIS system, the number of slots can be doubled. Instead of 2250 slots per minute, the whole AIS system works with 4500 slots per minute. See Figure 5 for the working of a timeslot.
Signal in the time slot

Depending on the ships condition, the AIS sends the conditions faster to other AIS stations. So the dynamic conditions of a vessel that sails with a speed of 25 knots or more, the reporting interval is 2 seconds. So every 2 seconds the ships dynamic conditions is sent. While reducing speed (without changing course) within a the range of 0 - 14 knots the reporting interval is 10 seconds.

In figure 6 is a table with the reporting intervals versus the ships dynamic conditions.

Figure 6

<table>
<thead>
<tr>
<th>Ship's Dynamic Conditions</th>
<th>Reporting Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship at anchor or moored and not moving faster than 3 knots</td>
<td>3 Minutes</td>
</tr>
<tr>
<td>Ship at anchor or moored and moving faster than 3 knots</td>
<td>10 Seconds</td>
</tr>
<tr>
<td>Ship 0 - 14 knots</td>
<td>10 Seconds</td>
</tr>
<tr>
<td>Ship 0 - 14 knots and changing course</td>
<td>3 1/3 Seconds</td>
</tr>
<tr>
<td>Ship 14 - 23 knots</td>
<td>6 Seconds</td>
</tr>
<tr>
<td>Ship 14 - 23 knots and changing course</td>
<td>2 Seconds</td>
</tr>
<tr>
<td>Ship &gt; 23 knots</td>
<td>2 Seconds</td>
</tr>
<tr>
<td>Ship &gt; 23 knots and changing course</td>
<td>2 Seconds</td>
</tr>
</tbody>
</table>

This table shows that the orders will take a while before the tug will receive this order.

The problem can be solved by adding a special ‘towing mode’ in the AIS. For example: when the tug is connected, both vessels select the towing mode in the AIS. Now all the commands have first priority. Another solution could be that the commands will be placed in an apart (spare) slot.

When this problem is solved, the AIS is a good way to bring over the commands to the tug.

Conclusion.

The lion’s share of communication nowadays is by VHF. White-noise and interference from other ships are bothering this type of communication. Added to these problems is the language-barrier. Pilots are often communicating in their own language, leaving the captain on the side, not knowing what the communication is about. Today, there is no alternative to VHF communication that brings satisfactory. To answer the sub question: “How can the communication between tug an ship be improved?” the TUC-system can is a way to improve the internal and external communication during towing operations. The TUC-system needs no implementation, because it is using already implemented technologies, such as the internet network, the AIS receiver/transponder and the pilot plug on the bridge. The TUC-system provides a clear overview for everyone on the bridge, in English language that can be understood by everybody.
6. Safety

6.1 Introduction

How can the safety be improved? is a question which will be answered in this chapter by doing desk and field research. Desk research consists of usage of literature and field research consists of questions in interviews.

The cause of an accident is seldom just bad luck. In general, an accident is the sum of a series of events and factors which finally leads to such misfortune. Therefore, safety is of great importance during the handling of tugboat operations. Additionally, it is important to investigate the reasons behind an accident, the so-called root causes, in order to improve safety onboard and be able to prevent such accidents happening again in the future.

6.2 Safety procedures during tug operations

There are currently no written international minimum safety standards for towing in port. The reason behind this is because every port and every ship is different. Because of this difference there can be no specific minimum standards for all ships and tugboats. Procedures deviate by length and speed per ship, set up of the port and the navigation limitations. This makes it hard to standardize said procedures. Although what mentioned above is not internationally standard, towing companies have their own safety procedures implied in their own systems for captains to use. A few of those procedures are implied in the appendix (Appendix: “Procedures 4, 5 and 6”).

However, just because there are no legally set regulations about this matter, recommendations to make towing operations safer still exist. In this chapter the matter of safety onboard and safety during towing operations will be explained, discussed and the possibilities of improvement will be outlined.
6.2.1. Safety during towing operations

From a towed vessel viewpoint, there are several ways to ensure a safe operation prior and during towing encounters. For starters, it is wise to prepare for a towing encounter with clearing a checklist and check all relevant factors prior to the encounter. This is just a way of assessing possible risks and checking the equipment. After checking certain factors prior to the operation it is wise to continue doing checks throughout the operation to keep ensuring the safety during such event. These checks can just be implemented in the preparation checklist as an extended checklist for the whole operation.

In the appendix a copy of such checklist (British Tug owners Association) can be found. ([www.britishtug.com](http://www.britishtug.com))

To guarantee an overall view of safety, these checks should at least include the following:

- **Condition of the towing arrangements**
  - Checking the condition of the towing arrangements includes:
    - The state of the ropes (damages)
    - The lining of the ropes (are they secured?)
    - Condition of the bollards or/and the winches (are they well maintained?)

- **Condition of anchoring equipment**
  - The condition of anchoring equipment must be checked in order to be able to let go anchor in emergency situations. This includes:
    - Condition of the anchor chain
    - Preparing the anchor winches for possibly immediate use

- **Drafts, to ensure a stable tow (Depending on the situation, keeping in mind the tow is more stable if slightly trimmed by the stern)**

- **Electrical Power**
  - Making sure there is enough power available for the winches to guarantee a safe mooring operation while towing (as well as the propulsion)

- **Life-saving and fire-fighting equipment in good condition and ready to use in case of fire**

- **Condition of tow (after making fast)**
  - Checking the condition of the tow includes:
    - Is the tow well secured?
    - Check for damages on the tow
    - Making sure the crew is clear of the tow (snapback safety)

- **Identify signs of damages**
  - Checking signs of damages in general includes:
    - Damages on the tow during towing
    - Damages on bollards
    - Damages on winches

- **Establishing a good means of communication between the bridge and forward/aft mooring team, and between the bridge and tugboat.**

In the appendix a safety checklist can be found which is actually used for tug operations and all that is relative in practice. (Appendix: safe towage operation checklist)
6.2.2 Interview “Smit”
Concerning this matter an interview with Smit was held to acquire more information about towing in general. This interview is enclosed to this report in the appendix named “Interview Smit”. In this interview questions were asked about the safety onboard of tugs and how to improve it. As it turns out, the managers at the tug company gave the same answer as found in researching this matter. Improving safety is a continuous process. Safety has always been, and will always be a major issue. But just keeping in mind that dangers may occur, people are already improving it. Keeping in mind what happened in the past makes a person think about what can happen in the near future.

6.3 Conclusion
Improving safety is a continuous process. To answer the sub-question: “How can the safety be improved?” it can be concluded that this is being done every day. Every day of every year, everyone involved is working on safety and it gets improved by determination and experience by means of updating checklists and procedures. As it is, safety is on everyone’s mind and this is certainly a good thing. To keep in mind that there will be a chance that dangerous situations may occur, safety is already improved.
7. New technologies and innovations

7.1 Introduction
To answer the sub question: “Which state of the art technology can be implemented in towing?” research has been done. Nowadays new technologies and innovations are fast developing. This desk research will focus on the available new technologies.

7.2 Research methods
By means of a desk research information can be gathered concerning the availability of new technologies. The field research is effective for asking the question: ‘Which state of the art technologies can be implemented in towing?’
7.3 Augmented reality

The augmented reality innovations are fast developing. The maritime symposium has already researched this.

"It is also possible that the bridge view is obstructed by parts of the vessel. So that a certain part close to the vessel is blocked from view (see figure). The black line is the line of view of the OOW. The red marked area is the area where the line of sight of the OOW is blocked by his own vessel."

Citation from: http://www.maritimesymposium-rotterdam.nl/uploads/Route/Augmented%20Reality%20On%20The%20Bridge.pdf

The ‘obstructed parts’ could be assisting tugboats.

Figure 6

For example:

A bulk carrier assisted by eight tugboats.

Figure 7 All eight tugboats are in the area blocked from view.
Augmented reality can show these tugboats virtually which will improve the overall view. There is only no indication that this will increase efficiency. Because most of the towing operations are done by two tugs.

7.5 Conclusion
Augmented reality is a state of the art technology that can be the solution for showing obstructed parts. However it is not known how it can be implemented and if the benefits are sufficient. At this time this will not be a profitable operation, because of the fact that most of the towing operations are done by two tug boats there is no gain in efficiency.
8. Conclusion

This project has six sub-questions. Every sub-question is covering a specific subject that is directly related to towing. Every sub-question is created while aiming to improve the efficiency of the tug-boat operations.

What is the current situation regarding the use of tugs

The first sub-question served to gain more information about the current use of tugs. Main subjects are the different types of tugs and the different utilizations. The conclusion is that conventional tugs are inefficient while towing large vessels. ASD tugs and tractor tugs have large advantages over conventional tugs because they are safer and working more efficient. The ASD tugs have an advantage over the tractor tugs because they have fewer draught. The advantage of the tractor tug is the efficient method of tugging, while being highly manoeuvrable. The ROTOR-tug is an improved tractor tug, yet they are still in development and more expensive.

<table>
<thead>
<tr>
<th>Type</th>
<th>Thrust</th>
<th>Safe during towing</th>
<th>Maneuvrability during towing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single screw, fitted in</td>
<td>Ahead: 100 %</td>
<td>Not safe, only when using gob line (what restricts the</td>
<td>Bad</td>
</tr>
<tr>
<td>nozzles, conventional</td>
<td>Astern: 60%</td>
<td>manoeuvrability extremely)</td>
<td></td>
</tr>
<tr>
<td>rudder flap</td>
<td>Sideways: 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twin screw, fitted in</td>
<td>Ahead: 100%</td>
<td>Not safe, only when using gob line (what restricts the</td>
<td>Better than a</td>
</tr>
<tr>
<td>nozzles, conventional</td>
<td>Astern: 60%</td>
<td>manoeuvrability extremely)</td>
<td>conventional single screw tug, but</td>
</tr>
<tr>
<td>rudder flap</td>
<td>Sideways: ±10%</td>
<td></td>
<td>responds not fast.</td>
</tr>
<tr>
<td>Tractor tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional tractor</td>
<td>Ahead: 100%</td>
<td>Very safe, especially during making fast</td>
<td>Very good</td>
</tr>
<tr>
<td></td>
<td>Astern: 95%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sideways: 80%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractor tug</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROTOR tug</td>
<td>Ahead: 100%</td>
<td>Very safe during all operations</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Astern: 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sideways: 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azimuth stern drive</td>
<td>Ahead: 100%</td>
<td>Safe</td>
<td>Very good</td>
</tr>
<tr>
<td></td>
<td>Astern: 98%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sideways: 60%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Efficient means of propulsion
This sub-question is focussing on the pros and cons of all the different types of propulsion. The conclusion is clear. It is not possible to name one type of propulsion that is the most efficient. This is because there are different types of tug-boat operations. Some have to take place in shallow waters, others have to take place in ports where there is only limited space for manœuvreing. Every situation requires a different tug-boat with different characteristics. The answer to this sub-question is:
Different situations require different types of propulsion.

<table>
<thead>
<tr>
<th>Type of propulsion</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed pitch propeller</td>
<td>- Simple construction and less maintenance than CPPs</td>
<td>- Performance degrades rapidly at off-design conditions, where the vessel may operate majority of the time</td>
</tr>
<tr>
<td></td>
<td>- No support system needed</td>
<td>- Not able to provide reverse thrust without stopping the engine, unless a reduction gear is installed</td>
</tr>
<tr>
<td></td>
<td>- Smaller propeller leading to increased open water efficiency</td>
<td>- Potential cavitation, strength &amp; stability issues at highly loaded off-design conditions</td>
</tr>
<tr>
<td>Controllable pitch propeller</td>
<td>- Pitch schedule can be optimized over operational range</td>
<td>- Requires a support system to operate properly which will entail more electrical power and maintenance</td>
</tr>
<tr>
<td></td>
<td>- Ability to mitigate cavitation and reduce blade stress as well as increase overall efficiency</td>
<td>- More complex and expensive than a FPP</td>
</tr>
<tr>
<td></td>
<td>- Ability to produce forward or reverse thrust while continuing to rotate in the same direction</td>
<td>- Larger propeller hub leading to decreased open water efficiency</td>
</tr>
<tr>
<td>Ducted propeller</td>
<td>- Increases thrust per kW, higher efficiency</td>
<td>- Costs more than a single conventional screw</td>
</tr>
<tr>
<td></td>
<td>- Better course stability</td>
<td>- More chance on cavitation (Can be adjusted by adding more blades)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Efficiency loss while sailing astern. However this is not a problem when speaking about azimuth thrusters, because they will rotate 180°</td>
</tr>
<tr>
<td>Voith-Schneider</td>
<td>- Performs extremely well and fast at maneuvering</td>
<td>- Complexity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Expense</td>
</tr>
<tr>
<td>Azimuth thrusters</td>
<td>- Good maneuverability due to 360° turning propellers</td>
<td>- The blades are fixed</td>
</tr>
<tr>
<td></td>
<td>- Low maintenance costs</td>
<td>- Installing thrusters costs more than installing a conventional propeller</td>
</tr>
<tr>
<td></td>
<td>- They do not require a lot of space in the engine room</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Excellent in combination with diesel generators, making a main engine redundant</td>
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What are the current towing methods and procedures
This sub-question is created to find new towing methods that could be more efficient. After several interviews with tug-boat companies there is one conclusion. It is not possible to improve the current towing methods and procedures. Tug-boats are working in ports all over the world for over a hundred years now. All these methods have been improved to reach maximum efficiency. Now that this point has been achieved, development has been stopped.

Communication procedures
The lion’s share of communication nowadays is by VHF. White-noise and interference from other ships are bothering this type of communication. Added to these problems is the language-barrier. Pilots are often communicating in their own language, leaving the captain on the side, not knowing what the communication is about. Today, there is no alternative to VHF communication that brings satisfactory. That is why the TUC-system was created, to address to this problem. The TUC-system needs no implementation, because it is using already implemented technologies, such as the internet network, the AIS receiver/transponder and the pilot plug on the bridge. The TUC-system provides a clear overview for everyone on the bridge, in English language that can be understood by everybody.
A simplified model of the TUC system is shown in figure 1 below.

figure 1.

How can the safety be improved
The improvement of safety takes place every day. Every day people are making risk-assessments. Writing more procedures makes people more conscious and aware of the dangers at work. It is unthinkable to create an work environment where it is impossible for accidents to happen. Most of the accidents are happening because of human factors. The only way to bring the number of accidents to a minimum is to keep making the people aware of the dangers at work.

New technologies and innovations
Augmented reality can be a great assistant for the bridge-team. It can be used for showing obstructed parts and invisible tug-boats. However this is still in its infancy. This subject requires much more development. At this time this will not be a profitable operation.
9. Recommendations

The TUC-system could be the answer to improve the efficiency of tug-operations. Communication is a big problem nowadays, with the ever growing amount of ship in ports all over the world. The TUC-system could erase the problem of other vessels interfering with each other. This system needs more development though. There are two main points that require thorough investigation:

- Research should be carried out to find problems while communicating using the AIS. A problem could be that the slots system is unable to withstand the TUC communication because it is too demanding.
- Research should also be done to see how the internet coverage develops around the world, because a stable internet connection could well be the best network for communication between different TUC devices.

When the TUC systems have been tested without any further problems, it is ready for implementation on tug-boats.
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