Laura Himanen

ALTERNATIVE MOORING SYSTEMS

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Opinnäytetyön nimi Vaihtoehtoiset kiinnitysjärjestelmät	57 sivua 12 liitesivua
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Tiivistelmä

Opinnäytetyön aiheena oli löytää vaihtoehtoisia järjestelmiä alusten kiinnittämiseen ja irrottamisiin satamissa. Tavoitteena oli löytää mahdollisimman turvallinen ja taloudellisesti järkevin ratkaisu. Tarkoituksena oli tarkastella erilaisia vaihtoehtoja mahdollisimman monelta kannalta, jotta paras mahdollinen vaihtoehto löytyisi.

Työssä esitellään laajasti aiheen teoria ja sen pohjalta tehtiin haastattelu suurimmille vaihtoehtoisten järjestelmien valmistajille. Haastatteluiden tarkoituksena oli selvittää vaihtoehtoisten järjestelmien tekninen toimivuus ja järjestelmien ylläpitoon ja huoltoon liittyvät asiat. Lisäksi haastatteluiden yhteydessä otettiin huomioon järjestelmien hinnat sekä omistajille koituvat taloudelliset hyödyt ja haitat.

Tulokset pohjautuvat teoreettiseen osuuteen sekä aihetta käsiteltävillä luennoilla ja haastatteluissa saatuihin tietoihin. Opinnäytetyön päätelmät ovat niin kriittisiä ja rohkeita kuin mahdollista, huolimatta kunnollisesta tutkimusmateriaalista. Parempiin tuloksiin olisi mahdollista päästä, mikäli olisi voitu haastatella järjestelmien omistajia sekä kuulla käyttäjien kokemuksia.

Varsinaisia uusia järjestelmiä, jotka toimivat ilman köysiä tai ketjuja, löytyi kaksi. Tästä huolimatta opinnäytetyössä on otettu huomioon myös kolmas järjestelmä, joka on nykyisiä toimintatapoja turvallisempi, vaikka se toimiikin köysin ja ketjuin. Järjestelmien huoltosuunnitelmien lisäksi opinnäytetyössä on esitetty myös taloudellinen näkökulma.

Asiasanat

kiinnitys, irrotus, logistiikka, satama, huolto, ylläpito, sidosryhmät, TCO, RAMSSS

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Abstract

The objective of the study was to find alternative mooring systems. The aim was to find new systems for mooring and unmooring. The new methods could reduce mooring costs significantly, make the mooring process safer and, faster, and reduce maintenance costs.

A survey based on theoretical information and interviews which have been done with the most important alternative mooring systems producers. The aim of the interviews was to obtain technological and financial information about the new systems. It also take into account the maintenance aspect and aims to identify risks and limits of the alternative systems.

The results are based on the theoretical part, interviews and lectures of this issue. The solutions presented are as bold and critical as possible within the scope of the limited research material. More accurate conclusions could have been drawn with interviews of system owners and system users.

Actual two new system has been found which operate without ropes or lines. This thesis also consider one system which uses ropes and lines but is more safe than the current systems. Maintenance plans are also explained and financial results are presented on this thesis.

Keywords

moor, unmoor, logistics, maintenance, port, stakeholders, TCO, RAMSSS

TABLE OF CONTENT

1 INTRODUCTION

The aim of this study is to find alternative mooring systems to make the mooring processes faster and safer. Nowadays mooring and unmooring on board vessels is done by lines and ropes. In a normal situation it is necessary to use around two to six people from the vessel, according to the size of the vessel, and another six to ten people from the shore. These amounts of people make mooring and unmooring a very labor-intensive and time-consuming job. During long voyages all ropes and springs are kept inside the forecastle to protect them from weather conditions. Before the vessel approaches the berth after a long voyage, the ropes and lines need to be taken out the forecastle to the mooring deck. Once all ropes and lines are ready it takes about half an hour to moor the vessel completely this also according to the size of the vessel. This makes the processes very time-consuming.

Another issue is the high accident risk during mooring and unmooring. In 2012, four people died because of a broken line or ropes. (EMSA, 2015.) When the tension becomes too high the line or spring can snap with deadly consequences. Because of the labor-intensive job, the high risk and the current technology there are justifiable reasons to consider a safer system for the future.

The main goal is to examine both technical and logistical knowledge on mooring systems. The logistical aspects will contain maintenance and RAMSSS analysis. Financial aspects have also been described.

This study also compares the risks of the alternative systems. The major part of the information needed in this project based on literary and internet sources, but information on mooring has been obtained from the external experts, such as system producers.

The main question is: How to do mooring and unmooring without the use of lines and springs to make this job safer, less labor-intensive and less time-consuming? This question is answered with five sub questions which are: What kinds of alternative berthing systems are there? What are the benefits, limits and risks of these alternative berthing systems? What are the logistics aspects behind the alternative berthing systems? How extensive investments are needed for the commissioning of the alternative berthing system? What is the safest and less labor-intensive and less time-consuming way to moor different kind of vessels? The purpose of this thesis is to answers these questions.

2 THE ROLE OF PORTS

Before familiarization with the topic, it is important to define the environment where these systems will work. Ports are important in the transport system because they work as a connection between sea and land. Ports are geographical areas and they have several important operations. (Stopford 2009, 81). Ports are major components of the maritime industry and they play an important role in world trade, in the global supply chain and international logistics. (ICS 2013, 37). Their main purpose is to provide a location where ships can berth safely. Ports need to improve mooring systems to respond on that demand by doing investments to new technology. (Stopford 2009, 81–83.)

The European Sea Ports Organization (ESPO) defines the port as an area of land and water including facilities, destined mainly for receiving vessels, loading, discharging and storing cargoes, receiving and delivering the cargoes to land transport. Ports may also include activities of sea trade business. The facilities associated with the port include the arrival and departure of vessels and areas of loading and discharging. (ICS 2013, 36.) Ownership of ports will determine who will make and pay investments in port area.

3 PORT OWNERSHIP

Earlier, ports were usually publicly owned. Public ownership protected port users from the misuse of monopoly situation. In countries with poor capital markets, port development work could be paid with public money. Public ownership made sense because their ports were service to all the users. In a private business profits were distributed to shareholders and arguably this happens often at the expense of trade and economy. (ICS 2013, 11.)

In the late twentieth century, there was a process of port privatization occurring in the United Kingdom. The state of the United Kingdom owned ports and forced privatization of previous trust ports took place. This kind of privatization may not occur anywhere else, still the concept of private operations and venture capital investment in the port area has been recognized. The main idea of privatization is to increase port efficiency and reduce the size of public sector obligation. The aim of privatization is that the port can free raise money in the capital market. (ICS 2013, 11.)

There is no standard model for which kind of ownership model world ports use. While sea transport has developed internationally, the development of the port usually takes place at the local or national level. This is one of the main reasons why port ownership cannot be determined for the all ports around the world. Another reason is rules and requirements of local public authority. (Meersman, et al., 2014, 15.) The presence of the public authority in ports is usually evidenced by the presence of statutory bodies who supervise maritime activities such as coast guards, vessel traffic services and marine safety services to ensure compliance with national and international regulations of ships calling at the port, and goods and passengers passing through it. This involves port state control customs clearance and health control. (Bichou 2009, 20.)

Apart from the functions carried out by the public authorities, the other port activities can be performed by commercial operators. Industrial investment, can be undertaken either by the public or private sector. (ICS 2013, 39.) As stated before there are no rules concerning ownership of the port but theoretically different ownership models can be divided into four categories. The ownership model also shows who owns port equipment and who is responsible for maintenance issues and similar.

	Infrastructure	Superstructure	Workforce
Landlord	YES	NO	NO
Tool	YES	YES	NO
Service	YES	YES	YES
Private	All totally owned and operated by the private sector		

Table 1. Port ownership

Table 1 of above is a summary of different port ownership models. These will be discussed in further detail in the following chapters. In the table the ´yes´ mark means that the port authority, while ´no´ means that private ownership.

3.1 Landlord port

A landlord port is a port where the infrastructure is owned by the port authority, usually a municipal or state body. In this case infrastructure includes wet and dry areas. Private firms own superstructure which includes warehouses, buildings and handling equipment. These private firms lease the quay and its adjacent area. (Alderton 2008, 75.) Private firms also provide stevedoring and may provide services including pilotage. The landlord port also develops and maintains the infrastructure. The port leases infrastructure to the private sector. (ICS 2013, 11.)

In landlord ports, private firms hand the cargo with their own equipment. Investments by the private sector ensure strong market leadership and a long-term relationship. These facts are some of strengths of the landlord port. It is clear, however, that this kind of port ownership has weaknesses. A landlord port may sometimes have a conflict between private sector ambitions and general public interest. Over capacity can be a general problem in a landlord port. There could be also possibilities for uncontrolled operations. (ICS 2013, 39.)

3.2 Service port

In a service port the port authority owns and maintains all facilities. Port management offers necessary services. A complete range of services is important for the port to be able to carry out all operations. Most ports in the developing world are service ports. (ICS 2013, 12.)

Service ports have tended to be inefficient, often through the use of excessive labor. These ports have responded to political, rather than commercial pressure. (ICS 2013, 12.). In the developing global economy there are competitive pressures in the port sector. Private ownership provides ports with the discipline and flexibility to be able to compete in a competitive market situation. (ICS 2013, 12.)

A service port owns, maintains and develops both infrastructure and superstructure. It also owns and operates handling equipment. The port operates all port functions and the services to customers' by itself. The unity of command and management could be one of the strengths of this type of port ownership, while weaknesses may include handling operations not compatible with administrative duties and the strong power of trade unions. (ICS 2013, 39.)

3.3 Private port

The entire port is controlled and managed by the private sector subject to the regulatory and statutory functions of the respective government. This is the main idea how of private ports work. (ICS 2013, 12.) Everything is owned and operated by the private sector. The public authority performs regulatory and statutory functions. (ICS 2013, 39.)

The strengths of this kind of port type is that management is less influenced by political decisions. Moreover higher efficiency in asset and human resources management are positive aspects of this kind of port type. There is, however, a risk of monopoly and possible deviation from core business and more profitable activities. (ICS 2013, 39.)

3.4 Tool port

In a tool port, the port authority provides both the infrastructure and the superstructure. A tool ports does not offer stevedoring facilities. (ICS 2013, 11.) A tool port also develops and maintains the infrastructure. Superstructure means for example shore cranes, sheds and warehouses. Private sector provides handling operations and other marine services. (ICS 2013, 39.)

A tool port needs considerable investment by the public authority. (ICS 2013, 39.) The port is not dependent on one or more private investor and economic downturns do not affect the operation of the port as quickly. (Stopford 2009, 69.) A tool port has similar problems similar to these of landlord port. There is a possibility of conflict regarding equipment assignment and operational efficiency. In addition double entry (public, and private) undertaking cargo operations and management could cause problems. (ICS 2013, 39.)

4 THE PORT COMMUNITY AND CONCEPT OF STAKEHOLDERS

The port is not only determined by infrastructure, superstructure and the related workforce. In the developing world it is more important that the port manager has a good relation-ship to stakeholders and hand these relations as effectively as possible. The main goal as a manager is to keep to the interactions between different stakeholders towards a common objective. (Henesey et al., 2008, 3.) This chapter will describe different stakeholders and explain the relationship between them. This stakeholder analysis is based on a presentation by Mr. Notteboom and Mr. Winkelmans, in Panama 2012.

The internal stakeholders

Groups inside the port authority are called internal stakeholders. (Dooms 2010, 142.) This group includes for example port managers, employees, board members, unions and shareholders.

The external stakeholders

Groups which are not a part of the port authority are called external stakeholders. This group includes economic players. (Dooms 2010, 142.) This group consists of the different port companies and supporting industries that invest directly in the port area and who generate value-added and employment by doing so. Some of these companies are mainly involved in physical transport operations linked to cargo flows for example terminal operators and stevedoring companies and the carrier- and terminal operator in case of dedicated terminals. There are also industrial companies in the port area, supporting industries companies and port labor pools also belong to the group of the first order economic stakeholders. Other economic stakeholder groups include the port`s customers, trading companies, importers and exporters. (Port Perform Tool Kit 2015.)

Legislation and public policy stakeholders

This group includes government departments responsible for economic and transport affairs. There are different departments which operate on a local, regional, national and supranational level. This group also includes environmental departments and spatial planning authorities on the many geographical decision levels. (Henesey et al., 2008.)

Community stakeholders

This stakeholder group includes community groups or civil society organizations, the general public, the press, and other non-market players. There are possibilities that some community stakeholders can be ignorant of their relationship to the port until a specific event gets their attention. (Henesey et al., 2008.)

5 SUPPORT SERVICES

As the previous chapter explained, a port has many stakeholders. In this chapter the focused is one main support services. As stated, these services are provided by external stakeholders. It is important to explain these three, because they plays an important role in the mooring processes now-a-days. In the future the role of these services can be different or non-existent

5.1 Pilots

The mission of pilot services is to provide reliable, safe and efficient pilotage. Pilots board arriving vessels in the vicinity to guide incoming ships to dock. They also provide assistance to outbound ships. (LA the port of Los Angeles, 2012.)

The most challenging part of any ship's voyage is the passage through the narrow waterways that lead to port and the final docking. The pilot gets to the ship expertise in handling large vessels in confined waterways and knowledge of the local port. The pilot is isolated from economic pressures, while the captain usually has these kind of pressures and these can compromise safety. (IMPA and ICS 2012.)

5.2 Tug boat

Tug boats plays as significant role in the berthing processes. Tugs put that power to good use, pushing or towing vessels into their berths in a port. Large ships would never be able to make it into the berth without the help of tugs, since they are not able to turn as quickly as a tugboat. Typically tugboat operations are carried out by private firms. (Port a Transportation system 2009.)

5.3 Mooring service

In larger ports, a mooring service is usually performed by a private firm, especially in a complicated nautical situation. For example single point mooring buoys, specialized piers for chemicals or gases, or ports with large tidal differences mooring activities require expert skills and equipment. (Fejfer, 2013, 82.)

Ports are an important link in the supply chain solutions offered by the port. They provide logistics services and ensure an operational integration between foreland and hinterland allowing correct planning and high efficiency. (Song & Panayides, 2015, 57.) Ports can stand out from its competitors by better port equipment. As stated the new systems are uniformly better than the old ones.

6 BERTH PLANNING

Berth planning is an important process in a port. Planning requires knowledge of berth configuration, including length, available draught, alongside capacity. It also requires information about every individual ship such as its length service pattern and estimated time of departure. (ICS 2013, 95.) Beth planning also has an economic effect. Successful planning is when one vessel is going away while another is ready to come to the berth. Vessels do not need to wait for available berth and the port has no empty places. As generally known, time is money. Better mooring systems mean saving time so ports can call more vessel per year.

6.1 Berth performance indicators

Berth performance indicators essentially concern the calculation of a ship`s waiting time and its time in port. A challenge for port managers is to secure optimum use of berths in the port. Insufficient berth capacity planning will result in delays to the ship and overblown berth capacity will be a wasted use of port capital and resource. (Bichou, 2009, 71.) The main indicators used to assess berth performance are explained below.

- *Berth throughput indicator* is the total tonnage or number of units handled on one berth in a given period of time. This indicator is a measure of berth activity. When the throughput amount of a port is higher than competitor`s, the port has a good market place. Units of berth throughput include, teu, tons and number of vehicles handled. Some port operations, for example transshipment and re-stowage need double handling, meaning this amount needs to be counted twice. (ICS 2013, 42)

Beth throughput (BT) = Total units handled in a period of time

- *Waiting time* is defined as the time a vessel needs to wait for an available berth, in other words it is delay between a ship's arrival in the port and it's trying up at the berth. The port works better in this business part when the time is as short as possible. This performance indicator is made for the port managers. (ICS 2013, 42) They can calculate waiting time for individual vessel by using this formula:

$$\text{Waiting ratio} = \frac{\text{Time waiting a berth}}{\text{Service time}}$$

- *Service time* can be defined as the time the vessel stays at a berth. It does not depend on service time if a vessel is working or not. The service time is established from first line fastening to last line release. (ICS 2013, 42) By using better mooring systems the service time ratio can be established for a berth. Ports can calculate the service time by using the below formula.

$$\text{Service time ratio} = \frac{\text{Cumulated service time}}{\text{Total number of vessels}}$$

- *Time in port or turnaround time* is the total time the vessel spends in the port from arrival at the port to final departure. By using alternative mooring systems this time can also be reduced. As will be discussed in chapter 9 those systems really save time and that way it is also possible to save money. This indicator, time in port ratio can be established for a port situation in the developing world. (ICS 2013, 42)

$$\text{Time in port ratio} = \frac{\text{Cumulated waiting time + Service time}}{\text{Total number of vessels}}$$

- Calculation a *grade of waiting ratio*, has usual a financial reason. The comparison of the waiting time with the service time provides a good indicator of what is acceptable by ship-owners. Ship-owners often accept is 10 % grade of waiting ratio. Over above mentioned percentage level the port is considered to operating inefficient with low quality. (ICS 2013, 43)

$$\text{Grade of waiting ratio} = \frac{\text{Cumulated waiting time}}{\text{Cumulated service time}}$$

- *Berth occupancy ratio* can be determined by the time a berth has been occupied (in hours per year) divided by the total number of hours in a year (8760). This calculation formula shows port services level of demand. (ICS 2013, 43)

$$\text{Berth occupancy ratio} = \frac{\text{Total service time (per berth)}}{\text{Hours in year (8760)}}$$

- *Berth working time ratio* can be determined by hours which a vessel is operating in port during the total time of stay on the berth. Beth working time ratio informs whether or not there is a long idle time within operations of berth. For example a berth working time ratio of 75 % means that the port works only 18 hours per day and the ship is idle for 6 hours. (ICS 2013, 43)

$$\text{Berth working time ratio} = \frac{\text{Total time worked}}{\text{Total service time}}$$

6.2 Berth capacity

Number of berths in the port determines port physical limitations. Every factor will be in connection with another. These influence the performance of port. (ICS 2013, 98.) Better handling equipment affects the berthing time, because they allow for faster loading and unloading processes. In addition, better mooring systems will have same effect as better handling equipment.

To estimate the capacity of a berth can be calculated used these formulas:

$$\text{Tons/ship-worked hour} = \frac{\text{tons}}{\text{gang-hour x average number of ship}}$$

$$\text{Annual maximum berth capacity} = \frac{\text{tons}}{\text{Service hour x 24 hrs x 365 days x maximum occupancy ratio x number of berths}}$$

$$\text{Tons/service hour} = \frac{\text{tons}}{\text{Ship-worked hour x service time}}$$

Cargo type and packing methods also influence a berth`s capacity. (ICS 2013, 98)

7 MAINTENANCE MODELS

Maintenance can be defined: “All those activities that aim to keep sustainable (production-)means in or return them to a condition deemed necessary for them to properly fulfil their function. “ (Business Dictionary 2016)

This concept not only includes all of the implementation activities, it includes all of the necessary and associated preparatory and conceiving activities. Consequently, the definition also cover inspective, preventive and corrective maintenance. (Service Logistics 2015, B-4)

For the classification of maintenance activities there is no determination who these activities carried out. They could be carried out by production personnel, by maintenance specialists who may or may not belong to the technical services or maintenance services, or that it has been contracted out. A port can influence maintenance costs by using the correct maintenance models. If the maintenance has been planned correctly its influences financial and also minimize problems. (Service Logistics 2015, B-5.) Next, different maintenance models will be discussed.

7.1 Predictive maintenance

Predictive maintenance refers to the activities that establish the maintenance condition or reliability. These also include establishing which parts or constructions require periodic inspection. Predictive maintenance should therefore be seen as a part of preventive maintenance. (Service Logistics 2015, B-4.)

Predictive maintenance can be divided into two stages. Firstly, predicting the failure occurring and secondly preventing that occurrence by required amount of maintenance. The used technique of maintenance has to be effective for failure predicting and it also has to provide the needed warning time. When predictive maintenance has been done effectively, maintenance is done only when it's required. A common pitfall of predictive maintenance is that there's used too much maintenance. Over maintenance leads to higher maintenance costs and it might also lead, paradoxically, to higher failure rates. That is because of incorrect re-assembly or other errors made in maintenance. Even 70% of equipment failures happen soon after initial installation or preventive maintenance. (Reducing operation and maintenance costs 2013.)

7.2 Preventive maintenance

Preventive maintenance refers to the implementation of activities intended to improve what is known as the maintenance condition, before the product or production means actually stop fulfilling their function. (Service Logistics 2013, B-4.)

This attempts to eliminate or reduce the chances of failure by serving the facilities at pre-planned intervals. The consequences of failure while in service are considerably more serious however. The principle is also applied to facilities with less catastrophic, consequences of failure. The regular cleaning and lubricating of machines, even the period painting of a building, could be considered preventive maintenance. (Slack et al, 2010, 627.)

Preventive maintenance is regularly performed maintenance that is done to equipment to reduce the likelihood of failure. Preventive maintenance should be planned with the intention to get the required resources available at desired time. (Preventative maintenance 2016.)

7.3 Corrective maintenance

Corrective maintenance refers to repair activities that are performed when the product or production means no longer function. (Service Logistics 2015, B-4.) The goal of corrective maintenance is to restore the equipment to proper working order after a failure. Corrective maintenance is mostly unplanned. It can be also a part of run-to-failure maintenance plan. The unplanned corrective maintenance is much more costly than planned maintenance. The possibility of failures can be reduced to a minimum by preventive actions. Furthermore, if the risks were realized, the operating company might be forced to close its whole activity, so the probability of using corrective maintenance can be seen as 0%. (Reactive Maintenance 2016.)

8 TOTAL COST OF OWNERSHIP

The total cost of ownership (TCO) determines how much the new system costs during the entire life cycle. The owners are always interested to know the financial site of the new investment. Capital goods have a life cycle consisting of 5 phases. In the first phase there are defined needs and requirements based on the market and technical possibilities. Then the system is designed. After this multiple units of the system are produced. Then the systems are used. This phase is called exploitation phase. Finally, the system is disposed of. (Dingemans, 2014.)

The costs during the first three phases of the life cycle are reflected in the sales price of new systems. In this thesis these costs are referred to as the acquisition costs, which are the highest cost in many cases. The acquisition costs consists of the project costs, sales charges, initial spare parts costs and costs of capital. The rest of the TCO occurs after the purchase of the new system. During the exploitation phase, costs of multiple types arise, with maintenance and downtime accounting for the largest proportion. Maintenance costs consist of all the resources needed for maintenance, which may be executed by the user itself or by the manufacturer or a third party. In other words, it consists of the labor costs, RMR costs, helpdesk costs and spare parts costs. (Dingemans, 2014.) In any case, the items that have to be paid for include spare parts, service/maintenance engineers, infrastructure and management. Downtime costs may consist of direct costs, such as those caused by a reduction in the output of a factory, and indirect costs, such as those caused by loss of reputation and resulting loss of future revenues. Finally, in the disposal phase, there will be disposal costs. (Houtum, 2010.)

9 ALTERNATIVE MOORING SYSTEMS

In this chapter alternative mooring systems are described. Two of them work without ropes and lines so they are the systems that this study focus on. The third one is explained because it is less expensive than these others, but also safer than current systems. All benefits have been taken into account and limits and risks are explained. Most of the information is based on interviews, available in Appendix 1.

9.1 Magnetic mooring system

A magnetic mooring system is an important step to use automation in shipping. In magnetic mooring systems, there are used piers, wharfs and mooring buoys to secure the ships. This magnetic mooring system includes the electrical cables, fenders to protect the quay and vessel, the magnetic pads connected to the hydraulic arms and the power supply that provides the magnetism. Using electrical power that produces electromagnetic fields turns on the magnets. The electromagnetic fields are used for mooring the ship.

An electric current is used to turn temporary magnet act like electromagnets. The electromagnet works as a magnet as long as the current flows in the solenoid. When the current is switched off, the solenoid is no more magnetized. An interview with a company specialized in magnetic mooring (Mampaey) gave some important information. The interview with questions and answers is available in Appendix 1.

9.1.1 Advantages of the magnetic mooring system

With a magnetic system securing, the ship is easier than with ropes. Loading and unloading can be started earlier with the magnetic system because the mooring process takes less time. A magnetic system is much safer than a traditional system, which includes high casualty risks. When using magnetic mooring there is no more need for ropes so the risk of snapping and slipping ropes is eliminated. A magnetic mooring system enables more efficient and faster working. The magnetic mooring process takes no more than a minute and the whole system can be released in only 20 seconds. (Reenen 2013.) The average calling time can be reduced by 40 minutes. Mooring with a magnet system, there is no need for such a large working team as a with rope mooring system. Only the control room, where electromagnetic shields are activated, has to be operated. (Keulemans 2003).

With magnetic systems there no need to invest in expensive mooring ropes. When the vessel will enter a port without the magnetic mooring system the expensive mooring ropes have to be used again, but the condition of the ropes will be better because the vessel will use them less. Mooring costs can be cut by millions of euros per year with magnetic mooring systems. This conclusion is based on calculations available in the chapter on Voyage estimate. Rowers, who catch the cluster, are not needed when using a magnetic system. This generates savings for ship owners because they do not need rowers' services anymore.

9.1.2 Disadvantages of the magnetic mooring system

It is not possible for this system to move in a lateral way. In a port with a lot of ebb and flood current this system cannot be used yet. Consequently, some improvements have to be made to the system. The investments will be higher relative to the common system with ropes, but the magnetic mooring system can be used for twenty years and the ropes only for a few years. The way to moor and unmoor a vessel will become very exact, there will only be a few ways to moor and unmoor the vessel. This is because of the possible damage to the system. There will always be a need for people who are familiar with monitoring the system – the users need long education and enough knowledge to use this system safely. Relative to the current mooring system with ropes, all crew-members are familiar with the rope system. In northern countries, hulls of the ships are covered with thick ice in the winter, it has to be solved how the magnets are working with the ice.

Dr. Eng. Martin Verwij, electrician on the TU Delft has conducted research on magnetic mooring. One of the most significant disadvantages with magnets and mooring is the magnetic field, which can harm the electrical installation on board of the vessel and the magnetic field can even be that strong that it is impossible to load and unload containers on a container vessel. Another disadvantage related to a permanent magnet is the constant force produced by the magnet. With this constant force it is impossible to unmoor the vessel; mooring can be done by a permanent magnet but unmooring is impossible. One solution is the electromagnet. An electromagnet is an iron core with a copper wire wrapped. When an electrical current runs through the wire the iron kern gets a magnetic nature: when the current is turned on there is a magnet, and if it is turned off, the magnetic fields are gone. An electrical magnet is ideal for magnetic mooring. (van Reenen-Hak, 2003.)

For the harmful magnetic field Dr. Martin Verwij discovered a new kind of magnet. He made one magnetic together with thirteen oblong magnets. With these thirteen small magnets the magnetic field became flat and is even strong enough to moor and unmoor a vessel. An example is given: normally it is enough to open a cabinet door magnet with one finger. Dr. Verwij put two metal plates on both ends of the magnet and after that the force increased. This is because the plates will push the magnetic field lines to each other. The area that is covered by the magnetic decreased, but the force increased quadratic, so the total force will increase considerably. With a row of thirteen magnets the effect will ingeminate constantly. (van Reenen-Hak, 2003.)

A small but powerful magnetic field is ideal for mooring. The magnetic field lines passed through the ship’s hull from one magnetic pole to the other magnetic pole without any harmful magnetic field on the other side of the ship’s hull. (van Reenen-Hak, 2003.)

9.1.3 Limits and risks

The system has no real limits according to Mampaey. It is possible to add some hydraulic arms and pads to increase the force; this is also shown with the calculations. This will decrease the risk possibility. There are always two pads that will work together. When the vessels draft or the tide will change the two pads have to work together. Mampaey calls it "walking" of the pads. When the tide or the draft of the vessel change the pads will disconnect, move and connect again to the ship's hull, fully automatically. For example: when the ship is unloading the draft of the vessel will de-crease. When the force on the arms and or pads will increase above a certain level the lowest pad of the two pads will disconnect, move up and connect again to the ships' hull. The system is flexible; when the force needs to be stronger, the amount of pads or the size of the pad can be changed.

At the moment, it is only possible to use this system in ports with only slack water, because the arms cannot move in a lateral way. The arms can be made more flexible with some other connections between arm and quay. A solution can be a ball joint. A ball joint has the disadvantage that a lot of power and strength of the arm will be lost.

Almost every kind of vessel can be moored with the magnetic mooring system. According to, Mampaey, when the vessel is larger it will be better because the total area will increase. Of course when the vessel's length is larger the wind area will also increase. It is not possible to connect the pads at the ship's bow and stern because the area needs to be flat.

Mooring tanker vessels can be challenging because the system can cause an electrical spark. Most of the time when the tanker is being moored there are no dangerous gasses around the tanker vessel so it does not usually present a significant risk. It is even forbidden for tankers to blow off the high pressure inside the cargo tanks in the port. When the tanker is sailing in different areas the pressure can increase due to the change of air temperature. Tankers will blow off the high pressure because it can damage the cargo tanks.

The thickness of the vessel's hull can be a problem. When the thickness of the ship's hull will be less than eight millimeters it is possible that the magnetic force can bend the ships' hull during mooring an unmooring. If the ship is moored there is no change of bending anymore. Every ship nowadays has a hull of over eight millimeters, so it is not a real limit.

Between the moored vessel and the quay fenders are placed. Fenders can be compared to balls and are usually made from rubber. The purpose of fenders is to protect the ship’s hull and the quay from damage and this will be a limit for the magnetic mooring system. The total force of the magnetic mooring system has to be less than the maximum force working on the fenders. If the force will be more the fenders can be damaged or the fender can even snap.

The pads and hydraulic arms of the magnetic mooring system are fixed on the quay and it is not possible to move them without disassembling. When the quay is used for one kind of vessel, with the same length and draft like ferries, the fixed system is not a limit. If the quay will be used for different kind of vessels the fixed system is a limit. Normally when the quay is used to moor lager vessels it is not a problem when a smaller vessel will be moored, because it is possible to use a portion of pads. This, however is not possible vice versa. Maintenance will also be less if the arms and pads can move and be stored in a barrack.

An electrical blackout can be a risk of the magnetic mooring system. After an electrical blackout the current will not run through the copper wire anymore so the magnetism will be gone. There are some solutions like an emergency-generator, connect the magnetic mooring system to the vessels’ diesel-generators and some backup ropes and springs. These three solutions can be combined and have to be automate.

The safety limits of Mampaey are always higher than the limits of the customer. Mampaey has a good name and they want to retain that good name. The safety limit used by Mampaey is 1.5 times the maximal external force. During the first phase of the installation of the magnetic mooring system, Mampaey will observe the different kind of vessels and the way they moor and unmoor. This phase takes about three weeks. After these three weeks an analysis will be made and the discussion with the customer will start. After an agreement with the customer the production will start.

9.2 Vacuum mooring system

The vacuum mooring system is a really innovative berthing system for sea vessels nowadays. When the vessel is a few meters away from the quay the vacuum pump will be started up. The vacuum pads will suck the ship to the quay in a gentle way. The vacuum pads will produce a constant force on the vessel during the mooring operation. After the vessel is moored the safety system will keep the vessel connected, even when there is a blackout. The system will not lose its vacuum for two hours so there is enough time to work on a leak in the system or to get the power back on. When a leak does happen, the repair crew should be informed that the leak should be solved. When it has a leak of 60%, it should give a signal to the repair crew so they can immediately immediately with the repair so the vessel will not lose its vacuum. A power generator is also a possible solution to prevent a black out of electricity. The vacuum system makes use of a vacuum pump, hydraulic system, steel, monitors and power supply to control the whole system.

The vacuum pads are connected to a hydraulic arm. These arms cannot move in a vertical direction. This is why they need to walk on the ship when there are changes in the tides or displacement of the ship. They can move 0.5 meters in horizontal direction.

The system has monitors to control all sensors. When there is something wrong with the system the bridge of the vessel will get an alarm and the system on the shore will get an alarm as well. This will kick in when the vacuum drops to 60%. The vacuum pad sensors measure the vacuum constantly and translate this into forces, which are working on the ship's hull. The sensors in the hydraulic parts will measure the ship movements. This is monitored on screens. As a back-up a small emergency generator is added to the system on the quay.

The vacuum system is fixed on the quay and will not move for different ships. It will stay in that position and the amount of pads will determine which ship will berth along that quay.

9.2.1 Advantages of the vacuum mooring system

Vacuum mooring is safety solution for mooring, because the system does not need for a shore gang or mooring deck crew. It is also easier to secure a vessel to the quay according to the system with ropes. The system is also more time efficiency, the vacuum mooring system can moor the vessel in between 30 sec. – 2 min. The forces can be calculated easily by making use of the sensors and software installed on the monitor. Less fuel consumption because it is less time consuming to connect the vessel to berth. Compared to the magnetic system the pads of the vacuum mooring system can reduce or increase the pressure gently.

9.2.2 Disadvantages of the vacuum mooring system

It is not possible for this system to move in a lateral way. In a port with a lot of ebb- and flood current this system cannot be used yet. Some improvements have to be made. The investment costs depend on the size of vessels to be handled. The hydraulic arms of the hydraulic system cannot move in vertical direction. The pads can only connect to a flat surface. The pads cannot connect in an angle, which makes it impossible to connect on the bow or stern of the vessel. The system will be ship-specific. If there is a significant difference between ships it cannot handle the forces of the ship movements of a lager ship when the system is made for a smaller ship.

9.2.3 Limits and risks

The system does not have a lot of limits according to Cavotec. If a large vessel needs to be se-cured to the quay then it is easy to add more vacuum systems with their pads. The thickness of the vessel’s hull can be a problem. When the thickness is under the 9.8 mm then the system can bend the ship’s hull. Besides that, it is not allowed to connect a pad to glass inside the ship’s hull. It can damage the glass.

A limit on the quay can be the fenders, which are made from rubber. The total force of the vacuum mooring system needs to be less than the maximum force working on the fenders. If the force will be more the fenders can be damaged or the fender can even snap. Each vacuum pad can handle 20 tons before it brakes. This is important for determining the amount of vacuum pads according to the wind area and lateral area of the vessel. Each pad can move in horizontal way for only 0.5 meter, besides of that there are no vertical movements possible with the vacuum mooring system. One vacuum pad needs to be at least 2.5 m² to get a vacuum of 80%.

The pad needs to be connected to a flat surface and cannot be connected in an angle to the bow or stern of the vessel. The vessel has to be totally flat, otherwise there will be a loss of vacuum. This can even happen after one dent in the ship's hull. A solution is a flat plate welded on the ship's hull. The ship's speed needs to be low when approaching the fenders. The fenders need to get out all the ship's movements before assembling the vacuum pads.

9.3 Shore Tension system

The Shore Tension is shaped cylindrically and it exercises the same constant pressure to the ships mooring lines. The lines are fixed to the bollards on the quay. No electricity is used, only for the hydraulic system that will make sure the Shore Tension will stay at the right tension. When this is done, the cylinder will move along with the forces that are working on the mooring line. This will work constantly without the need of extra energy. The mooring lines will have the same tension constantly, even when the weather conditions change or there are more waves. This will be crucial to keep the mooring stable and safe. When the tension in the different mooring lines varies, then this can cause the ship to move in the water and the possibility to snap the mooring lines.

The Shore Tension gives a high tension to the line and the line can deal with peak loads without exceeding the minimum breaking load of the line. The system will reduce the ship's movement and will absorb the energy the ship is producing. When the peak loads are over, the system will store the energy and will return to its original position. Shore Tension is CO_2 neutral because it does not need an external energy source. Environmentally friendly companies can use the shore tension and the maintenance due to the power pack will be less.

The Shore Tension will be better secured with the combination of the use with high quality mooring line made of HMPE. This is a very strong synthetic fiber.

These mooring lines are issued to the ship from the shore. (Port technology 2015.)

Between two bollards, the Shore Tension is positioned on the quay. At one end of the Shore Tension it is attached to the quay bollard while the ship's mooring line is connected to the moveable part of the device. The other quay bollard is used for guiding the ship's mooring line.

With a hydraulic system the Shore Tension only has to be activated once. It can function afterwards without external energy. This means the system can easily move to the different positions on the quay. It will be possible to integrate the Shore Tension vertically in quay walls in the future.

There are two to four Shore Tension system's needed, depending on the weather conditions and the size of the ship, to make sure that the vessels can be moored in a safe and stable way. With all kinds of loads the Shore Tension will perform optimally. The Lloyds Register in London has the Shore Tension certified with a safe working load of 150 tons.

With the use of solar energy, the wireless controller on the Shore Tension can work. This makes sure that the captain of the ship or the terminal operator can monitor the tension on the lines in real time. All parties will be notified automatically when the mooring line approaches the predetermined limits. When this happens, new measures are required. This system will help to control the vessel and its mooring lines. The control unit settings can be adjusted remotely.

The pressure of the Shore Tension, the battery power and the displacement of the rod of the Shore Tension are other information that can be available by using the wireless control unit. The system will log the data history.

Marine terminals are built more in exposed areas these days and berthing a ship will be more difficult because of climate change. Furthermore the increasing demands of the terminals will require more from the mooring facilities. To make sure environmental conditions do not have a significant impact a number of measures have to be implemented that are expensive such as breakwaters or wind screens. The vessel movement and the down times of the terminal will be reduced because of the high pre-tension and the reducing of the loads in the mooring line in combination with the fender system.

Ships are growing a lot and this gives some challenges for the safety. The lateral wind areas of vessels will increase and the mooring lines will be exposed to high loads be-cause of this wind. A solution would be to buy extra storm lines but for many berths, the number of bollards and the available space are limited. The Shore Tension can enhance the mooring capabilities of large vessels. It provides high tension and is making sure that it can handle the peak loads without exceeding the minimum breaking load of the line.

To prevent the mooring lines from snapping, there are conventional tension winches on the deck. This system can cope with wind, tidal elevations and loading a vessel. A disadvantage is that this system is engine-driven so it requires a lot of energy. When the ship berths and the Shore Tension puts the right tension on the mooring lines then it requires external energy. This is the only time when Shore Tension is using external energy.

9.4 Advantages and disadvantages of the Shore Tension system

One of the advantages of the Shore Tension system is that it prevents lines from breaking (fewer personal injuries). Fewer mooring accidents could theoretically result in lower insurance premiums. It also improves the stability of the ship while being moored and increases the safety and speed of on- and offloading. It is versatile and can be installed on almost every quay or jetty. It is able to provide a constant (high) tension up to 60 metric tons of force (600kN). It has a safe working load of up to 150 metric tons (1,500kN). It has sensors that register the loads in the ropes. This data will be available for the ship’s master, port and terminal operators. Data will be logged for review of berth. A warning system can be set for when exceeding limits in force as well as displacement. GPS data provides an overview of where warnings are issued across the globe.

The disadvantage for this system is that it takes a lot of space on the quay. For now it is still a horizontal system but a new placed in vertical direction is currently being developed. (Shore Tension 2015.)

10 MAINTENANCE OF SYSTEMS

It can be summarized that the most used type of maintenance in alternative mooring systems is predictive maintenance. Monitors in magnetic and vacuum mooring are used to perform the predictive stage. The vacuum systems are monitored continuously by the sensors in hydraulic system and vacuum pads. The sensors within the vacuum pads measure the vacuum and translate this into forces that are directed on the ship's hull. The sensors in the hydraulic part are used for measuring the movements of the ship. The monitors used in magnetic mooring enable very quick reaction for the identified errors. All possible errors can be monitored and the alarms can be seen on the monitor. There is also a possibility to connect the alarm system to smart watches.

Some regular measures like keeping the systems clean and oil checking can be classified as preventive maintenance. The magnets have to be replaced approximately every three years because of the corrosion on the magnets. The hydraulic systems also need preventive maintenance. The mooring systems are very quick, the whole process takes no more than minutes so the utilization of the systems is very low. That is why the deterioration is very slow in these systems, for example the hydraulic arms have never had maintenance and they are still totally operable.

11 MAINTENANCE STRATEGY

The sensors are very important so the maintenance on these sensors has a high priority. When the sensors do not work anymore, they cannot give a signal to the monitors that a leak is occurring in the system. Movement of the ship will happen, which can result in dangerous situations, and one of the goals is that the system is safer than ropes. To prevent such a failure, the sensors must be checked every time before a ship moors. Preventing the breakdowns of the sensors is crucial because safety is key and time can be saved.

A standard LCD monitor has a lifetime of 35,000 hours. (ICT loket 2015.) This means it will break down in about 4 years. This is predictive so to make sure that the failures of the monitors would not happen, they should be replaced every 3.5 years. However, when a monitor breaks down before that time, there must be new monitors available by the supplier. The supplier should have spare parts in stock, allowing quick repairs and continuation of the process.

The pads are in use all the time when a ship has been moored, and it is important that they works the whole time. Replacements of these pads can be calculated when the lifetime is known but corrective maintenance would be better because the pads can break down prior to reaching the end of their lifetime.

As a whole, this means that the sensors are so important that preventive maintenance should be applied. Sensors must not be allowed to fail; otherwise the safety will be at risk for the personnel and the ship. For the others parts there should be corrective maintenance. The supplier of all the different parts should have the spare parts in stock so the avail-ability of these spare parts is high and less time will be spent on replacing the different parts.

12 RAMSSS-ANALYSIS

The RAMSSS model consists of six different factors, which are sustainability, reliability, maintainability, safety, supportability and availability. This chapter analyzes the effect that the magnetic, vacuum and Shore Tension mooring systems have on these factors. This analysis based on Mr. Langstraat Power point presentation in Mainport University of Applied Sciences in Rotterdam.

12.1 Reliability

Reliability describes the probability that a system performs its intended functions with-out failures during a specified length of time. Reliability can be expressed as a sum of the following factors (Ngeru 2015)

- Probability: Number of times a failure occurs/number of trials
- Satisfactory performance: Mooring/unmooring completed without technical problems and other failures
- Desirable time: Succeeded mooring time can be set to 2 minutes for alternative systems

- Specified operating condition: Tidal movements, electricity failures, harmful magnetic field, and extremely harsh weather conditions.

According to the given information from Mampaey and Cavotec, both magnetic and vacuum systems are extremely reliable; the reliability is over 99% in these systems. Compared to traditional rope mooring, the reliability has improved considerably in magnetic and vacuum mooring. The most significant and common failure in traditional mooring, snapped ropes, can be tackled almost entirely by these new systems.

In magnetic mooring there is a theoretical risk that the arms are not connected when the ship is swaying. Another theoretical risk in magnetic mooring are electricity failures. Electricity failure might cause magnetic loose and therefore massive accidents in the port. Magnet stop plates can be used to prevent magnetic fields from influencing other systems. These stop plates consist of thick magnetic alloy. Despite the risk of electricity failures, they have never occurred in magnetic mooring so the risk of breakdowns can be considered unrealistic. Although the risk is very small, the emergency measures have to be included in the system.

Generating a magnetic field with considerable forces might damage the hull of the ship. This risk, however, is not realistic because it can be avoided by forming a flat magnetic field, where small electromagnets are located side-by-side. Tidal movements can be controlled by the system itself, so they should not effect on the reliability level.

Following aspects below related to reliability should be identified with every ship. Can the ship sail with its own power or is there need for a tug? In the magnetic mooring the need for tug services is significantly smaller than in rope mooring.

In vacuum mooring there are no great risks either. The system gives a warning signal most of the time when the risk of a breakdown occur. The warning system reduces the risk level to minimum. In cases of breakdown, the company might be forced to close its operation due to the claims the failure would cause.

In the Shore Tension system, there is still a need for ropes. However, the reliability of the Shore Tension system is very high compared to a traditional system. The snapping of the lines can be prevented even in extreme conditions. The Shore Tension has been developed to improve the mooring possibilities of large ships. Especially strong ropes have also been developed for the Shore Tension system, made of Dyneema®. It is said that Dyneema fiber is 7 times stronger than steel which enables taking the highest loads. It is also smooth and easy to handle. (Dyneema 2014.)

12.2 Availability

Availability means the probability that the system is working at a certain moment of time. The availability of systems can be calculated with two factors, Mean Time Be-tween Failures (MTBF) and Mean Time to Repair (MTTR). (Slack et al., 2010, 620.) The formula is the following:

$$\text{Availability} = \frac{\text{MTBF}}{(\text{MTBF} + \text{MTTR})}$$

Availability of the Vacuum Mooring system is more than 99%. For power back up, there is a small generator added to the vacuum system.

The magnetic mooring system enables more efficient and faster mooring than traditional rope mooring. Repairing a broken arm might take from 1 to 2 days, so the availability is very high also in magnetic mooring. The broken arms are the only measurable element for describing the availability of magnetic mooring.

One negative aspect that might have an influence on the availability of magnetic and vacuum systems is that there is always need for personnel that are competent to handle the monitors. There must be a certain amount of people that have been educated to use the monitors. Otherwise the availability may decrease.

12.3 Maintainability

Maintainability describes the probability that the failed system can be restored to the specified level during a certain amount of time by using defined resources. Failures in these systems are very unlikely and maintaining from the failures takes rarely more than two days. Overall the maintenance does not have significant impact on the systems and there is are notable maintenance costs. In vacuum mooring the maintenance costs are 2% of procurement costs. The magnetic mooring system also needs some maintenance. Spare parts of magnetic system need to be cleaned at regular intervals. These cleaning operations lengthen the lifetime of the system. The vacuum system works with hydraulic technique so those components need lubrication. The lubricant should be changed several times a year to keep the availability and reliability high. This also has a positive effect on the lifetime of the system. The vacuum pumps work only 30 seconds per half an hour. To keep the system clean, the oils must be checked and the oil used must be eco-friendly.

12.4 Safety

Compared to the rope mooring, where the ropes are broken occasionally and therefore causing personal injuries at times, both the magnetic and vacuum systems are extremely safe.

In a magnetic mooring system, securing the ship is easier than in rope mooring. In magnetic mooring the theoretical personal harm may be related to electricity failures, which might cause massive accidents. In both magnetic and vacuum systems there is always a possibility that ropes are as a backup system. When using the backup-system, personal risks might be higher because the workers do not have the needed experience of handling the ropes.

The vacuum system contains a safety system that keeps the vessel connected even after a black-out. The vacuum pads are connected to a hydraulic arm that follows the ship's motions during loading, unloading and tide changes. The system is monitored constantly by sensors within the vacuum pads and the hydraulic system.

In the Shore Tension system, two to four Shore Tensions are used, depending on the ship size, weather conditions and local conditions to keep the mooring process safe and stable. Every Shore Tension has its own wireless controller which enables the captain of the ship, terminal operator and other parties to follow the tension on the mooring lines in real-time. GPS - data provides an overview of the locations of the warnings across the globe. All involved parties in the mooring process can be automatically notified if the safe working load (SWL) approaches the set limits. Sometimes additional measures are required. The Shore Tension system allows safe working up to 150 metric tons (1,500kN)

The continuous growth of the ship sizes presents significant challenges for the safety decrees of mooring operations. One proposed solution is to introduce new long breast lines or extra storm lines.

With the Shore Tension system the risk of personal injuries can be notably reduced com-pared to traditional mooring. Dyneema ropes are much safer and more durable compared to steel ropes

12.5 Supportability

Supportability means the degree to which the system can be supported effectively. It describes how the system is supported with the purpose of making the system last longer, reduce costs and increase the Return on Investment. The support planning is intended not only for acquisition but also for the whole operational life cycle of the system.

Supportability can be divided into three levels, organizational level, intermediate level and depot level. For the alternative mooring systems, the supportability can be seen to be at intermediate level. In vacuum mooring systems, the monitors are included in a package deal within the whole system. After purchasing the whole system is supplied to the operator, including the monitors. The updates for the software can be received. When making supportability analysis for alternative mooring systems, the following is-sues can be taken account.

12.5.1 Reliability and maintenance predictions

The users aim is to get the reliability and availability to as high a level as possible and to eliminate all corrective maintenance. With properly executed predictive and preventive maintenance the maintenance costs can be minimized.

12.5.2 Personnel training requirement analysis

In magnetic and vacuum mooring there is a need to arrange training for using monitors so that there is always personnel available who have full competence to operate with monitors. Because mooring has to be very precise and there are only few a ways to moor and unmoor the vessel, the training has to thorough. Because rope mooring is still needed for back-up, the personnel also has to be educated for rope mooring. Because the probability that ropes are needed is very low, the training should be executed regularly to ensure that the staff has the needed competence when a failure occurs.

12.5.3 Back-up system analysis

In magnetic mooring emergency generators are already used as a back-up system. It might also be possible to introduce those emergency generators in vacuum mooring systems. In vacuum mooring there is already a safety system to keep the vessel connected after being moored. The vacuum mooring system might need software which can calculate the needed forces for each ship. This is because the forces are different due to their various sizes. For the Shore Tension system breakwaters and windscreens can be implemented to ensure that harsh environmental conditions are not affecting to the system negatively. Extra storm lines can also be acquired for back-up. If the magnetic or vacuum mooring system fails and ropes are needed to perform the mooring process, the ordinary amount of workforce is not enough to moor the vessel. There should be a back-up team of 6-8 employees available for those situations.

If the alternative mooring system fails and ropes are needed quickly, there has to be the needed workforce available to perform the mooring.

12.5.4 Maintenance task analysis

In magnetic and vacuum mooring, the maintenance can be divided into two stages, predictive stage and preventive stage. In the predictive stage the errors are controlled by monitors. In the preventive stage the operations differ depending on the system. In magnetic mooring preventive maintenance consists of cleaning and replacing the mag-nets and regular oil checking. The hydraulic system used in magnetic and vacuum mooring needs the following maintenance: changing the hydraulic filters, obtaining hydraulic fluid, filtering hydraulic fluid, checking hydraulic actuators, cleaning hydraulic reservoir checking and recording hydraulic pressures and pump flow and checking machine cycle time and record. The predictive stage requires only one employee. Daily cleaning and oil checking can be also implemented by one employee. It might take 10 minutes per day. (Reliability Web 2016.)

12.5.5 Purchasing cost analysis

The procurement costs of alternative mooring systems are high and it takes years to cover all the procurement costs. A magnetic mooring system, in particular, could be very expensive due to the high need of magnetic pads. That is why it makes sense to consider leasing instead of buying the whole mooring system at once. There are two leasing options, which are discussed below.

12.5.6 Lease

By using financial lease, the user will be the owner of the system at the end of the contract. The reparation costs are for the company. Financial lease offers a clear sight on the monthly costs, because the costs are calculated in advance and they do not vary.

With operational lease the user does not get the ownership of the system, they are only renting it. Therefore the reparation and insurance costs are for the company which offers the lease. With operational lease the usage of the system might be limited per certain period.

Because of the high procurement costs, the optimal option would be taking financial lease because of the ownership and good insight in costs. As already stated those system producers are Dutch so if the systems work the in Port of

Rotterdam, operational lease must be the chosen leasing type because the port is a landlord port. (Streetfleet 2013.)

12.5.7 Warehousing analysis

Magnetic arms and pads could be stored in a warehouse. Back-up pads can be used in case of extreme circumstances. Inventory management might be challenging due to varying the need of pads.

12.6 Sustainability

A sustainable system uses materials that meet the demand while maintaining the environmental-friendliness. Both magnetic and vacuum systems are very sustainable. A significant benefit of these systems is the increased speed of the mooring process, which enables lower emissions of the ships. In magnetic mooring lower energy levels can be used when a vessel is connected. The low energy mode is taken on by automatic signal.

Vacuum mooring requires a maximum 20 kW per day. A vacuum system causes less exhaust waste in the port and less erosion, in addition to which its fuel saving is a considerable sustainable advantage. In magnetic and vacuum mooring, there is no need for ropes. In traditional systems the rope expenses are high, causing major impact on the environment.

The Shore Tension system is CO_2 neutral. The only needed electricity in the Shore Tension system is for the external hydraulic system, which needs to be used only once to get the Shore Tension at the right tension. The drawback of the Short 69Tension system is that its tension winches are engine-driven requiring a lot of extra energy. However, the only time that external energy is needed is when the ship berths.

12.7 Priorities

In this subchapter the RAMSSS-elements have been prioritized. Afterwards all the elements have been categorized depending on the difficulty and costs of implementing those elements.

12.7.1 Magnetic mooring

1. Failure preventing (preventing electricity failures with magnet plate, preventing damages on the hull of the ships by using flat magnetic field)
2. Decision of ownership
3. Tug services
4. Regular cleaning
5. Daily oil checking
6. Back-up team for rope mooring
7. Warehouse facilities
8. Low-energy-mode

12.7.2 Vacuum mooring

1. Warning system
2. Power generator
3. Decision of ownership
4. Tug services
5. Regular cleaning
6. Lubricant changing
7. Daily oil checking
8. Back-up team for rope mooring
9. Warehouse facilities

12.7.3 Shore Tension

1. Dyneema ropes
2. External hydraulic system
3. Breakwaters and windscreens
4. Decision of ownership
5. Warehouse facilities

Failure preventing including all functions is still relatively expensive to procure and maintain in alternative mooring systems. The difficulty of the back-up team is keeping the team always available for action. It’s also expensive to find the needed premises and resources for new warehouses. The decision of ownership is easy to make among little amount of options. Tug services, cleaning of the systems and oil checking are necessary but easy and cheap to implement. Warning systems, power generators, external hydraulic systems and low-energy modes need to be implemented only once. Once they have been implemented, they are easy to maintain.

Hard to implement:

- Failure preventing
- Back-up team for rope mooring
- Warehouse facilities

Easier to implement:

- Decision of ownership
- Tug services
- Regular cleaning
- Lubricant changing
- Daily oil checking

- Dyneema ropes
- External hydraulic system
- Warning system
- Power generator
- Low-energy model

13 COMPARISONS

In this study Magnetic mooring, Vacuum mooring and Shore Tension have been examined. After the interviews the conclusion was that these systems can be used for every kind of ship with different dimensions and tonnage. This comparison does not take into account the financial aspect because only the price of vacuum system is available. This is because other companies wish to keep the price a secret.

There is major difference between Magnetic mooring and Vacuum mooring as regards time efficiency. Both systems will work in a timeframe of 30 sec. – 2 min. Compared with the current rope systems this is considerably less. Mooring with the current rope system it takes approximate 30 min. – 60 min. Making use of the Shore Tension system, it still will take the same time to moor the vessel as with the conventional system with ropes, but during loading and unloading of the vessel the crew doesn’t have to check the tension on the ropes. This is a time efficiency compared to the conventional system with ropes. During loading and unloading the draft of the vessel will change. The crew has to check the winches because the tension of the ropes will change. With magnetic- and vacuum mooring there is no need to check the winches so the crew has time to do other jobs.

There is not major difference between Magnetic mooring and vacuum mooring as regards labor intensity. During mooring and unmooring there is no need for a shore gang to attach the ropes to the bollards. Both systems can be operated by one person who is familiar with the system and monitor/touchscreen. During the lay time of a vessel somebody needs to keep an eye on the system and monitor/touchscreen because the weather conditions can change and the systems can have a failure. Normally there are officers on the bridge of that particular vessel during the lay time. It is not necessary to check the tension of the ropes on the winches. Shore Tension still needs a shore gang to put the ropes on the bollards. The only advantage as regards labor intensity is that there is no need to check the ropes' tension.

The key difference between Magnetic mooring and Vacuum mooring is safety. Even when there is a leak in the Vacuum mooring system or a black out of the entire system, the system can hold its vacuum for two hours before the ship will disassemble from the quay. When there is a blackout in the Magnetic mooring system, the magnetic field will be gone and the ship will disassemble in a short time. A solution to this problem is an emergency-generator, which is not necessary with vacuum mooring. This emergency generator will cost extra money. Compared to the current rope system, broken ropes, will no longer cause injuries. Most of the time the accidents with ropes happen during mooring and unmooring, especially mooring. During mooring the acceleration forces will be high, which can cause a snapped rope. The chance of a snapping rope still exists when the shore gang is making use of the Shore Tension system. It will be safer only when the vessel is loading and unloading because winches system automatically changes the tension of ropes during the operations.

For the purposes of comparison, a matrix with the above three criteria is used: safety, less labor intensity and time efficiency. Every berthing system inclusive the conventional rope system will get an appreciation. A distinction will be made between the different criteria. This distinction is necessary because one criterion is more important than the other one. Safety is the most important, because every year some crewmembers are injured or even killed during mooring and unmooring procedures. This cannot be expressed in money. After safety the most important criterion for the customer is time efficiency. When a terminal can handle more ships in the same time the sales volume of that terminal will increase. Finally, labor intensity is considered because the saving will be less than time efficiency.

With this distinction the calculation will be as follows: When a system gets one plus for all the three criteria the safety criteria will be multiplied by three, time efficiency with two and less labour intensity with one.

	Characteristics			
	Safety (x3)	Time efficiency (x2)	Less labour intensity	Total
Magnetic mooring	+ (x3)	++ (x2)	++	+9
Vacuum mooring	++ (x3)	++ (x2)	++	+12
Shore Tension	- (x3)	- (x2)	-	-6
Conventional rope system	-- (x3)	-- (x2)	--	-12

++ = very good
+ = good
+ / - = average
- = poor
-- = very poor

13.1 Magnetic mooring

- Safety, one plus. This system will not get two plusses because of the possible blackout. After the blackout it will cost some time to start up the emergency generator.
- Less labour intensity. The magnetic mooring system gets two plusses for less labour intensity because there is no need for a shore gang anymore. This system can be operated by one person.
- Time efficiency. Two plusses for time efficiency, this because of the short timeframe of 30 sec – 2 minutes. With the conventional system it will take much more time. During the loading and discharge operation there is no need for checking the winches, this is also one big asset.

13.2 Vacuum mooring

- Safety, two plusses. This system will get two plusses because during a blackout the sys-tem can keeps its vacuum for two hours.

- Less labour intensity. The magnetic mooring system gets two plusses for less labour intensity because there is no need for a shore gang anymore. This system can be operated by one person.
- Time efficiency. Two plusses for time efficiency, this because of the short timeframe of 30 sec – 2 minutes. With the conventional system it will take much more time. During the loading and discharge operation there is no need for checking the winches, this is also one big asset.

13.3 Shore Tension

- Safety, one minus. The shore tension system gets one minus because the system still works with ropes. The chance of a snapping rope still exist during mooring and un-mooring
- Less labor intensity, one minus. For this system a shore gang is necessary to connect the ropes to the bollards. During loading and unloading the crew does not have to check the tension on the ropes, so one minus.
- Time efficiency, one minus. The same comment as less labor intensity.

The matrix above shows the comparisons for the different characteristics of the mooring systems. Vacuum mooring has the best results because of safety, which is essential for the customers. Vacuum mooring is safer than magnetic mooring because of the safety margin of two hours. This is not the case with Magnetic mooring and an emergency generator is necessary. In practice both systems need an emergency/back-up system in case of failures. During a blackout an emergency/back-up generator will not start up immediately, there will always be a few seconds that the magnetic and vacuum mooring system is without power. In these seconds the vessel can float away due to the current or wind forces.

14 COST OF SYSTEMS

This chapter discusses cost of the new system. Cavotec provided more details of the system cost than Mampaey. Encrypting the data is understandable because the companies always think about competition. This chapter summarize financial information obtained from interviews with the companies. Of course better and truer studies could be able to do if all the necessary information could be given.

Estimated lifetime for the vacuum system is 20 years. The price for the new system is around 250 000 to 300 000 euros. It depends on the situation how many systems and how many pads are needed. Maintenance costs are 2% of value of the system and labor costs are 140 000 euros per year. Operation costs of the system are electric power costs. One system use 20 kWh/day. There are no downtime costs for the owners because the availability is more than 99 percent. Disposal costs are low, because the lifetime is 20 years and the system is built by using environmentally friendly material, which, can be recycled. (Cavotec, 2015)

Total costs of ownership are difficult to determine because the exact data rates of systems are not available. In addition, how many pads owners need depends on the situations so the price of the system is not known. However, the above formula can be used, if all the necessary information, which the formula needs, is known.

Formula: TCO = AC + MC + OC + DC

Investments in new systems are expensive, but as is apparent from Mampaey interview, the owner will make positive ROI (return of investment) by using magnetic system in five years after the investment. This information is based on an interview with manufacturing company Mampaey. ROI is a performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments. Return on investment is a very popular metric because of its versatility and simplicity. That is, if an investment does not have a positive ROI, or if there are other opportunities with a higher ROI, then the investment should be not be undertaken. (Return on investment 2015.)

The return of investment (ROI) can be calculated with the DuPont model. This model has adjusted factors which have to be filled in to get the ROI percent-age. The result of this model can be seen as a bank interest. It is important to have a ROI as high as possible. (Dupont Analysis 2015.)

15 FINANCIAL BENEFITS

As already stated time is money. This chapter explain how new systems can financially influence effect to system owners and also ship owners.

15.1 Voyage estimates

Faster mooring will have a positive effect on the voyage estimate and this way will decrease costs of ship owners. A voyage estimate is a calculation of the profitability of a prospective voyage of a ship using estimated figures. In the case of a tramp ship owners, the estimate is used to compare two or more possible voyages in order to determine which is the most profitable. Mooring is part of voyage and this way ship owners are interested in knowing which kind of mooring systems ports are using. Faster mooring means faster voyage and will decrease costs. Other voyage costs for owners are running cost of the ship, bunker costs, port charges and canal dues together with the ship's agency fee and any cargo handling costs; the revenue is the daily hire, in the case of a time charter, or the freight, less any commission in the case of a voyage char-ter. (Shipbroker, 2009.) Result based on an example which tries to describe a real situation as well as possible. The voyage estimate can be presented to potential customers and convince them with that. This might be one way to save money for the owner of the ship.

Cargo details:

14 700 TEU

Load: Rotterdam, Netherlands

Discharge: Shanghai China

Laycan 1-10 December

Load speed: 20,000 t

Discharge Speed: 10,000 t

2.5 percent adcom + 1.25 brokerage

Vessel details:

M/S Emma Mærsk – Open Copenhagen November

156,907 DWT SDBC on Draft 16.02 meter ssw

Speed and Consumptions:

IFO (Fuel oil) 25.0 knots / 25mt (laden)

25.5 knots / 21mt (ballast)

MDO (Diesel Oil) 2.5mt at sea 1 mt in port

Other details:

- Vessel delivery will take place on Shanghai.
- Vessels intake will be 14 700 TEU
- Price of Bunkers: Spot Singapore prices IFO 405.00 USD pmt / MDO USD 596.50 USD pmt (Fuel prices, 2015)
- Port Costs: Rotterdam USD 98783,77 (see appendix 2), Shanghai USD 30,000
- Miscellaneous expenses: USD 5,000
- Net Daily Hire of the Ship (cost in the open market to charter a ship on a Time charter basis): USD 10,000 per day prorate.
- Loading will take: 4 days
- Discharging will take: 5 days
- Ballast Distance Copenhagen to Load port 865 NM
- Laden Distance Rotterdam to Shanghai 7.307 NM
- Repositioning leg distance 583 NM (reposition to Yangshanin)
- Extra Sailing Time allowed for bad weather: 1 day
- Turn Time 12 hours both ends

Voyage duration

Ballast leg = 865 nm/612 (25.5 x 24 hours) = 1.41 days

Laden Leg = 7307 nm/600 (25 knots x 24 hours) = 12,178 days

Repositioning Leg = 583 nm/612 (25.5 x 24 hours) = 0,95 days

Total Sailing days = 14,538

Plus days in port = 10 days (9 loading and discharging plus 1 day in total turn time)

Plus Bad weather = 1 day

Total estimated voyage duration = 25,538 days

Bunker / Fuel Costs

1) IFO (Fuel oil) at sea

Ballast leg 21mt IFO per day x 1.41 days = 29.61mt

Laden leg 25 mt IFO per day x 12.178 days = 304.45 mt

Repo leg 21 mt IFO per day x 0.95 days = 19.95 mt

Total cost: 354,01 mt x USD 405 = USD 143 374

2) MDO (Diesel oil) at sea 1.5 mt per day x 14.538 days = 21.807 mt

Total Cost: 21.807 x USD 596.50 = USD 13 007

3) In Port Consumption

10 days x 1 mt MDO = 10 Mt MDO x USD 596.50

Total Cost = USD 5 965

Total Bunker cost= USD 162 346

TC in Costs (Chartered in Vessel Costs)
USD 10,000 per day x 25.538 days = USD 255 380

Total Voyage Costs

1. Total Bunker cost USD 162 346

2. Port Costs USD 128 783.77

3. TC in Costs USD 255 380

4. Miscellaneous USD 5,000

Costs USD 551 509

Plus Commission of 3.75 percent of Total Cost USD 20 681

Total Voyage Cost USD 572 190

The mooring process takes no more than a minute by using a magnetic system or a vacuum system. Both systems can be released in only 20 seconds. The average calling time can be reduced by 40 minutes. Based on this information the voyage estimate has been made again. The calculations will show how much the ship owner can save if the vessel will choose the port of Rotterdam which might have one of these systems in the future. Below is an available result which is based on information that systems can be reduced 40 x 2 = 80 min, which means 0.05554 days of total voyage estimate.

1) IFO (Fuel oil) at sea

Ballast leg 21mt IFO per day x 1.41 days = 29.61mt

Laden leg 25 mt IFO per day x 12.122 days = 303.05 mt

Repo leg 21 mt IFO per day x 0.95 days = 19.95 mt

Total cost: 354,01 mt x USD 405 = USD 142 807,05

2) MDO (Diesel oil) at sea 1.5 mt per day x 14.4824 days = 21.7236 mt

Total Cost: 21.7236 x USD 596.50 = USD 12 958

3) In Port Consumption

10 days x 1 mt MDO = 10 Mt MDO x USD 596.50

Total Cost = USD 5 965

Total Bunker cost= USD 161 730,05

TC in Costs (Chartered in Vessel Costs)
USD 10,000 per day x 25.482 days = USD 254 824

Total Voyage Costs

1. Total Bunker cost USD 161 730.05

2. Port Costs USD 128 783.77

3. TC in Costs USD 254 824

4. Miscellaneous USD 5,000

Costs USD 550 338

Plus Commission of 3.75 percent of Total Cost USD 20 637

Total Voyage Cost USD 570 974

Savings of voyage: USD 572 190 - USD 570 974 = 1 216 USD

This example shows that the savings of the ship owner are possible. However, this ex-ample is not reliable, but this formula can be applied when the exact specifications and consumptions of the ship are known. The most important point is to note that the savings will be generated because of mooring and un-mooring occurs faster, how realistic the savings are, is difficult to assess.

Laytime is the time allowed by the owner of the ship to a ship for loading or unloading cargo without demurrage. Laytime can be expressed as consecu-tive days including weekends and holidays, as working days excluding week-ends and holidays or as weather working days which excludes additionally days when operations are prevented by bad weather. (Dictionary of Interna-tional Trade.) Laytime starts when a vessel is berthed or when a vessel's arri-val is recorded. To make a proper laytime calculation, the following documents are needed: recap of fixture, which describes how much time have been agreed for loading and unloading, notice of readiness from load- and unload-port, statement of facts from load- and unload port and copy of relevant charter party. With alternative mooring systems the laytime can be reduced significantly compared to traditional rope mooring. (Zwarte 2015)

15.2 Salary savings

Nowadays on board of vessels the mooring and unmooring is done to use around six to ten people from the vessel and another two to six people from the shore. This means the mooring process usually requires 12 to 20 people. A magnetic system and a vacuum system will reduce labor force. A magnetic system needs four people on the mooring process. One of these people will observe monitors. The vacuum system needs a maximum of two people on the shore and one for the monitors. Owners of these systems and owners of vessels will save salary costs by using these systems. The salary savings calculation is based on current salaries in the Netherlands because these systems providers are from the Netherlands and that is why the Netherlands could be the first place where these systems could be tested. The current average salary of the deckhand is 46 000 USD per year (Deckhand Salary in Netherlands, MO 2016) and 50 000 USD per year (Terminal employee Salary in Netherlands, MO 2016) for the terminal employee.

Vacuum system

In the shore:

Current: salaries for the 10 people per year 500 000 USD

Future: salaries for the 3 people per year 150 000 USD

Savings: 350 000 USD per year

For the ship owners:

Owners can easily save 46 000 USD. When there is less people to doing the mooring and unmooring those people can do for example maintenance and repairs work on that moment on the ship. Deckhand is a worker on a ship who does work that does not re-quire special training. (Deckhand, 2015) They can for example cleaning a deck and help other worker with most challenging tasks.

Magnetic system

In the shore:

Current: salaries for the 10 people per year 500 000 USD

Future: salaries for the 4 people per year 200 000 USD

Savings: 300 000 USD per year

For the ship owners:

Owners can easily save 46 000 USD. When there is less people to doing the mooring and unmooring those people can do for example maintenance and repairs work on that moment on the ship. Same explanation as savings of vacuum system.

There is no unequivocal answer to how much each party can save the wages because this example describe only estimated savings. Similarly, it is not clear whether the half to cut staff as much as the example states. However, the example is it clear how many workers receive income for a year, so for instance, the calculation shows how much the reduction of even one worker can produce salary savings. As has been presented in these mooring systems not requiring workers unmooring mooring and processes as much as the current practice, so there is possibility to save money, but it is hard to estimate how much real numbers can be.

16 CONCLUSION

The traditional, thousands of years used rope mooring system has kept its position as the most commonly mooring method. Mooring with ropes can, however, be considered too old, dangerous, expensive, unsustainable and labor intensive to be used nowadays. Considerable improvements are required to change these aspects to fulfil the modern standards. In traditional mooring, injuries and even deaths occur. The alternative systems, magnetic, vacuum and Shore Tension systems would be a suitable solution to largely replace the old-fashioned traditional mooring largely in the near future. The alternative methods require only a small amount of labor compared to the traditional method.

Maintenance is needed for these systems to work efficiently and effectively. There are three different strategies of maintenance: predictive, preventive and corrective. For the most important parts preventive maintenance is applicable. For example sensors are critical in the mooring systems because they give signals when something is not working well or has a leak. This can prevent dangerous situations and ensures safe mooring. For other parts corrective maintenance would be the best solution. When something breaks down the supplier should be able to deliver quickly any spare parts to fix the problems directly. The supplier should have a high availability of the spare parts so an agreement between supplier and buyer should be made.

Regular training should be arranged for mooring personnel to ensure that they have the needed competence to perform back-up mooring. Training with monitors should be arranged precisely so that the personnel can complete all the requirements. The most crucial support that could be arranged for magnetic and vacuum is back-up teams of 6-8 persons. Instead of buying the whole system, the most appropriate solution might be taking operational lease, when the ownership doesn’t belong to the user of the system. Extra warehouse facilities are needed to optimize the availability of the spare parts and back-up parts. On the whole, the most important goal that needs support is preventing the sys-tem failures.

These alternative systems are significant investments for the owners. On the other hand the maintenance-, down time- and disposal costs are low, so the total cost of the ownership over the long term is reasonable. Because these systems make mooring faster, this is useful for both parties, users and owners. Ship owners save time and money if the port is available for any of these systems. The owners stand out from their competitors in dedicating this kind of system because time is money.

Vacuum mooring has the best results because of safety, which is crucial for the customers. Vacuum mooring is safer then magnetic mooring because of the safety margin of two hours. This is not the case with Magnetic mooring and an emergency generator is necessary. In practice both systems need an emergency/back-up system in case of failures. During a blackout an emergency/back-up generator will not start up immediately, there will always be a few seconds that the magnetic and vacuum mooring system is without power. In these seconds the vessel can float away due to the current or wind forces.

Both the magnetic mooring system and the vacuum mooring system have one enormous significant disadvantage: lateral movement. At the moment it is only possible to use this sys-tem in ports with only slack water, because the arms cannot move in a lateral way. The arms can be made more flexible with some other connections between arm and quay. A solution can be a ball joint. How-ever a ball joint has the disadvantage that a lot of power and strength of the arm will be lost. As a result more research should be conducted in the future on how the ball joint can keep its power and strength.

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APPENDICES

Appendix 1. Interviews

Mampaey

1. What are the advantages and disadvantages of the alternative berthing system relative to the additional system with ropes?

There will be more safety during mooring and unmooring when the magnetic mooring system is used. Less crew is necessary for mooring and unmooring. There will be more efficiency, the mooring process will cost only a few minutes. The investments will be higher relative to the common system with ropes. The magnetic mooring system can be used for twenty years. The way to moor and unmoor are vessel will become very exactly, there only will be a few ways to moor and unmoor the vessel. This is because of the possible damage to the system.

2. What are the limits and risks of the alternative berthing system?

There are no limits, it is possible to add some hydraulic arms and pads to increase the force. This will decrease the risk possibility. There are always two pads that will work together. When the vessels draft or the tide will change the two pads have to work together. Mampaey call it “walking” of the pads. The walking of the pads is fully automatic. The system is real flexible, when the force needs to be bigger, the size of the pad can be changed.

3. How are the calculations done and what kinds of calculation methods are used? Calculations about wind and current forces and keeping the vessel connected to the shore.

The calculations are done by external companies, they have more knowledge about the forces. Mampaey paid them to do the calculations. The calculations method is one of the secrets of Mampaey.

4. What kinds of safety limits are used?

The safety limits of Mampaey are always higher than the limits of the customer. Mampaey has a good name and they want to retain that good name. The safety limit used by Mampaey is 1,5 times the maximal external force. During the first phase of the installation of the magnetic mooring sys-tem, Mampaey will observe the different kind of vessels and the way they moor and unmoor. This phase is about three weeks. After these three weeks an analyses will made and the discussion with the customer will start. After agree with the customer the production will start. Another limits are the fenders. The total force of the pads have to be less than the maximum force the fender can handle. Mampaey will nog damage the fenders. The pads together with the hydraulic arms are fixed on the quay, you can say that this is a limit.

5. What kinds of ships (length, tonnage, kind of cargo) are potential for the alternative berthing sys-tem?

Lager vessels are better. When the total surface of the vessel will be more, more pads can be connected. Of course when the vessel is smaller less pads are needed, so all kind of vessels can be used for the magnetic mooring.

6. Are there any kinds of ships (length, tonnage, kind of cargo) that cannot be moored with the alternative berthing system? And why?

-See question number five

7. What are the different parts of the alternative berthing system?

The system contains permanent magnets, hydraulic arms, a power pack is needed and a touchscreen to monitor the system and to lock and unlock the system. All values, like forces, magnetism and the ships freeboard are monitoring all the time. When one of the values will below a set value an alarm on the touchscreen will ring.

8. Do you think that the alternative berthing system will replace the additional system in the future?

Mampaey thinks that magnetic mooring will be the future because of the enormous advantages and especially the safety. But the world is always shivery with a new kind of system, this is also the case with magnetic mooring. Mampaey think that magnetic mooring is better than vacuum mooring be-cause that system needs a constant power supply.

9. How much faster are Magnetic systems compared to mooring with ropes? Which costs can be saved with a quicker magnetic mooring system?

The magnetic mooring process can be done in two minutes. Compared to rope mooring, there can be saved an hour.

10. There is no need any more for ropes and therefore no need to invest for those. How big costs can be saved with that?

The costs of the ropes should be taken into account because there has to be ropes available when the system fails. Everything will be logged into the system so it is better for the authorities. A possible limit is that the ship cannot be fixed to the pad because the skin of the ship is not flat enough. The skin of a ship has to have a certain thickness. The flux of the magnets will not go furthere than the thickness of the skin.

11. How many people need to participate when using the Magnetic mooring system?

Rope mooring system requires using 15 people in the ship. There are too many people involved and too much communication so errors will be made quicker because the communication with all the people have to be good. With magnetic mooring there is need for only three. In addition one employee is needed with monitors.

12. How serious the consequences would be and how big losses of profit the failures can cause by using the Magnetic mooring system?

The system is extremely reliable. When the ship gravitates, there is possibility that the arms cannot connect the ship

13. The magnetic mooring system makes use of monitors. What are the working principles of the monitors and what kind of costs are included to those monitors? How much people are needed to work with monitors? What kind of competence you need to use those monitors?

The monitor system is completely automated. Using monitors allows quicker reactions for possible errors. The errors can be recognized well in advance with the monitors, this allows effective preventive maintenance. The system has 2000 different errors. Everything is monitored and alarms can be seen on the monitor. There is a possibility to connect this to smart watches.

14. Acquisition costs of alternative systems and what acquisition costs include?

When the system is used for 10 years, after 5 years the investment is recovered. ROI is very high

15. How much and how often the Magnetic system needs maintenance? What are the maintenance costs? What kind of maintenance the system needs (preventive, corrective etc.?)

System needs maintenance as all hydraulic systems. Corrosion can be resulted on the pad but this can be replaced very easily every 3 years. Even still maintenance is not needed very often. The extra costs are low and the daily costs barley.

This august the law will be changed with regard to the mooring with alternative berthing systems. At this time it is only allowed to berth with ropes.

16. What are Day-to-day expenses of these systems?

The daily costs are almost nothing.

17. How big is the probability of breakdowns? What are the breakdown costs for the owner?

There is always theoretical breakdown risk. Everything can be recorded in the fleet manual. Electrical failures has never happened. In cases of breakdowns, the shipyard personnel takes the responsibility. There is always a way to disconnect the ship manually.

18. What are the availabilities of the systems? Mean time between failures?

Usually failures need 1 to 2 day repair.

19. How about reliability of the whole system? (This consist different components which together has direct relationship with the failure).

The system is extremely reliable, over 99%.

20. Sustainability: how the system effect to environment? What kind of materials are used on the system?

Compared to Cavotec, Mampaey can save environment with lower energy consumption. When the vessels are connected, the signal is given and the engine is switched to use lower energy. The lower energy system is also money saving function. Hydraulics are used as well as steel and an automation system. There is little energy consumption to connect the ship. When the temperature is going down the permanent magnets will work better.

21. Is there solutions available how to use magnetic mooring in the northern countries where the ice is thick?

There can be used to break the ice allowing the use of magnetic mooring

Other relevant information:

• In Mampaey outsources their functions to low-cost production countries like Dubai, China and Singapore.

• The making of these systems will probably be moved to Singapore. At this point everything is done In Europe. In Singapore are a lot more grants made possible by the government.

• Magnetics may leave black tracks on the hull of the ship

Cavotec

1. What are the advantages and disadvantages of the alternative berthing system relative to the additional system with ropes?

The biggest advantage of the vacuum system is the safety and time efficiency. As well for the shore gang as the crew it is much safer to moor with the vacuum system then with the ropes. Another big advantage is that the forces can be calculated when the ship is alongside. With ropes it is not possible to calculate the forces. Another advantage is less fuel consumption when the vessel is coming to the quay. It is more time efficient and therefore it will cost less fuel. Therefore the voyage speed can be lower for the same ETA.

An advantage compared to the magnetic mooring system is the pads. With magnets it is fast or loose and not something in between. With the vacuum pads you can reduce or increase the pressure gently.

A big disadvantage is the Investment but still that depends on the situation. It can be a small or big system. Another disadvantage is that the vacuum system cannot move in vertical way. It needs to walk in steps on the ship hull during loading or unloading otherwise the ship will get a list. Another disadvantage is the ship's hull, when there is not enough flat surface then the vacuum pad cannot connect. This will make it impossible to connect it on the bow or stern of the vessel.

2. What are the limits and risks of the alternative berthing system?

Limits are glass in the ship's hull or the steel surface of the ship. This needs to be at least 9,8 mm. The limits in forces are 20 tons for each vacuum pad. Pads can move horizontal for 0.5 metres. The pad needs at least 2.5 m2 to get a vacuum of 80%. The ship needs to have a flat surface to attach the pads, because they cannot connect in an angle. The pads need to handle the forces of the fenders. If the forces coming from the fenders are more than the pads then the ship cannot moor to the quay. The fenders need to deal with the ship movements. Before using the vacuum system the ship's speed need to be low.

3. How are the calculations done and what kinds of calculation methods are used?

Calculations about wind and current forces and keeping the vessel connected to the shore. Besides of that the waves will influence the forces on the pads as well. They didn't gave the correct formula's but I think we can get far with the 20 Tons that one pad can hold. Cavotec will calculate the pads that need to be used for a particular quay. Off course when the forces are higher an extra pad need to be installed on the quay.

4. What kinds of safety limits are used?

Ship can be hold to the quay for another two hours when a failure or leak in the vacuum system has been found. The system will give an alarm when the vacuum drops to 60%. The leaks will give an alarm on the bridge so that the Officer of the Watch can decide what to do. On the shore there is as well somebody, which is keeping an eye on the system. On the bridge of a vessel the mooring sys-tem can be controlled. The shore has these controls as well. In case something goes wrong the sys-tem can be activated or deactivated.

5. What kinds of ships (length, tonnage, kind of cargo) are potential for the alternative berthing sys-tem?

There are no limits in that way. If the ship has enough flat surface to connect the pads then it is no problem to connect the ship to the quay. For now they use it for Ferries, LNG tankers or containers vessels.

6. Are there any kinds of ships (length, tonnage, kind of cargo) that cannot be moored with the alternative berthing system? And why?

It is not easy to moor vessels with a lot of glass windows in the ship's hull. Think about cruise ships.

7. What are the different parts of the alternative berthing system?

The system makes use of a vacuum pump, hydraulic system, steel, monitors and a power supply to control the whole system.

8. Do you think that the alternative berthing system will replace the additional system in the future?

Now they are developing with the Moor Master 200, which is the latest version. According to the company CAVOTEC this mooring system can be used on lager scales but still not a lot of people want to choose this system prior to the conventional system. Especially the boatmen don't want to change their operations because it is working now. In the opinion of CAVOTEC it will be a lot safer to do it with the vacuum pads.

When they do a test the system will be tested to 30 ton instead of 20 ton. If it can hold for at least 10 minutes then the system will be approved for use. Currently the US Navy is developing ship to ship mooring. This is a secret innovative project which will come out when it is done and ready to use.

9. How much faster are vacuum systems compared to mooring with ropes? Which costs can be saved with a quicker vacuum mooring system?

The vacuum systems can moor a ship in about 30 sec – 2 min. If you use the conventional rope system then it will cost 25-30 min so it is a lot quicker. They were not sure about the costs that will be saved by using the vacuum mooring system instead of the conventional system.

10. Vacuum systems allow less labour workforces. What is the salary costs compared to rope mooring systems?

They need somebody on the bridge of a vessel at the berth and they need somebody on the shore, which is watching different monitors to control the system. The costs will be a lot lower than the conventional operation but they are not sure of the costs.

11. How many people need to participate when using the vacuum mooring system?

Only one person on the shore. To keep an eye on the entire operation and system you also need an Officer of the watch of that particular vessel.

12. The vacuum mooring system makes use of monitors. What are the working principles of the monitors and what kind of costs are included to those monitors? How much people are needed to work with monitors? What kind of competence you need to use those monitors?

From the monitors the entire system can be controlled. The costs of these monitors are includes in the total price. You will also get the updates for free for the software. There is one person needed for watching the monitor on the bridge.

13. Acquisition costs of alternative systems and what acquisition costs include?

The two systems in Den Helder costs €500.000-€600.000. It depends on the situation how big the costs are.

14. How much and how often the vacuum system needs maintenance? What are the maintenance costs? What kind of maintenance the system needs (preventive, corrective etc.?)

The system doesn’t need a lot of maintenance. Only the Hydraulic system needs some maintenance. Besides of that the vacuum system needs to control the vacuum every hour for 30 sec by making use of the vacuum pump.

15. What are Day-to-day expenses of these systems?

When the system is installed there will not be any costs anymore. The only costs will be the power supply. This is 20 kW for the entire system.

16. How big is the probability of breakdowns? What are the breakdown costs for the owner?

There are no breakdowns known. When there will be a breakdown CAVOTEC will have big problems and can close their company. They will not place a system that is not working how it should be. First they will do a lot of tests.

Appendix 2. Port costs

Port costs are consisting of different factors; taxes and surcharge, which apply to a ship and/or the cargo on board the ship once it, has reached port. The rise in these charges may reduce the number of goods arriving at that port, or otherwise impact the price of doing business. Basic port charges include tonnage dues, lighthouse dues, dock fees, anchorage dues, canal dues, berth dues, pilotage, river dues, tugboat fees, customs duties, sanitation dues, and freight dues. Port Charges fees collected from ship owners and cargo owners to defray the cost and Port charges may be collected by state or local authorities. At our case they are local authorities. All costs numbers based on information, which can be found port of Rotterdam and Loodswezen websites. Because these are just examples these calculations don't describe correctly real situation but these may be help to under-stand how huge these numbers can be.

On this calculation is used the same example vessel than in the voyage estimate example. There are several things which are needed to make port costs calculations. Type of vessel, transhipped weight, draft of vessel and gross tonnage of vessel. GT is the volume of space within the hull and enclosed space above the deck of a merchant ship, which are available for cargo, stores, fuel, passengers and crew. On the below is able to found calculations of M/S Emma Mærsk from Sea to Maasvlakte II. These calculations consist port dues and pilotage costs.

Details:

Type of vessel	Container
Gross Tonnage	170794
Transhipped	Containers of 90 000t
Draft	16.02 meter (160.2 dm)

Port dues (Port of Rotterdam 2016)

GT-size x GT-tariff

170794 x 0.239 € = 40819,766 €

Transshipped weight x Cargo traffic

90000 x 0.475 = 42750 €

Payable dues = 40819,766 € + 42750 € = 83569.77 €

Pilotage costs (Loodswezen 2016)

From Sea to Maasvlakte II

Draft 16.02 meter means:

1544 T-tariff (route-dependent tariff) in €

6063 S-tariff (starting tariff) in €

Pilotage costs: 1544 € + 6063 € = 7607 €

Our example vessel needs pilotage services also to going to back to Sea

Together these services are 15214 €

Total port costs **98783.77 €**