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Exploring the barriers and opportunities of the trend towards autonomous shipping

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TABLE OF CONTENTS

List of figures

List of tables

List of abbreviations

AAWA ______ ***A**dvanced **A**utonomous **W**aterborne **A**pplications initiative*

ASV ______ ***A**utonomous **S**urface **V**ehicles*

BSH ______ ***B**undesamt für **S**eeschifffahrt und **H**ydrographie*

CML ______ *Fraunhofer-**C**enter für **M**aritime **L**ogistik und Dienstleistungen*

DMA ______ ***D**anish **M**aritime **A**uthority*

Dwt ______ ***d**ead-**w**eight **t**ons*

HPA ______ ***H**amburg **P**ort **A**uthority*

ICS ______ ***I**nternational **C**hamber of **S**hipping*

IMO ______ ***I**nternational **M**aritime **O**rganisation*

ITU ______ ***I**nternational **T**elecommunications **U**nion*

MASS ______ ***M**aritime **A**utonomous **S**urface **S**hip*

MLP ______ ***M**ulti-**l**evel **p**erspective*

MUNIN ______ ***M**aritime **U**nmanned **N**avigation through **I**ntelligence in **N**etworks*

SOLAS ______ *International Convention for the **S**afety **o**f **L**ife **a**t **S**ea*

TUHH ______ ***T**echnische **U**niversität **H**amburg-**H**arburg*

UNCTAD ______ ***U**nited **N**ations **C**onference **O**n **T**rade **A**nd **D**evelopment*

USV ______ ***U**nmanned **S**urface **V**ehicles*

UUV ______ ***U**nmanned **U**nderwater **V**ehicles*

Abstract

Following new technological possibilities, autonomous vehicles have received their starting shot in transportation. This novel trend has also reached the shipping sector, leading to an increasingly gaining momentum for the concept of unmanned and autonomous vessels. This study specifically explores the barriers and opportunities of the trend towards autonomous shipping for two points of view: the general shipping sector and a port environment (case study port of Hamburg). The insights are additionally examined under the umbrella of transition theory to arrive at an understanding about the trend's current trajectory and associated factors. Initial research reveals four distinct cornerstones with individual barriers and opportunities each: *technology and infrastructure*; *safety, security and insurance*; *societal, legal and regulatory acceptance* as well as *economical attractiveness and feasibility*. While the possibility to improve navigational safety is the most prominent opportunity, dismal social prospects (e.g. demise of seafaring profession and extensive job losses) and the constrained compatibility of the existing legal and regulatory framework (e.g. conventions tailored to manned shipping) stand out as barriers. Notwithstanding that issues yet need to be resolved, the introduction of autonomously operating vessels is consensually foreseen within a timeframe of 10 to 15 years for long-distance, deep-sea navigation. Conversely, the port of Hamburg is currently more difficult to be envisaged being sailed by autonomous vessels within a comparable timeframe (e.g. because of the interaction of various ship types in a spatially constrained environment). The results of this thesis are aimed at contributing a new perspective to the yet emerging body of knowledge on the concept of autonomous shipping to aid shipping stakeholders in future decision making and support planners in preparing shipping environments respectively.

Keywords: Autonomous shipping, barriers and opportunities, transition theory, shipping sector, port environments, port of Hamburg

1 Introduction

Especially nowadays, technological development is progressing at an exceptional rate and thus seems to bring novel, disruptive innovations day by day, altering the way of living (Schwab, 2016). Not least information and communication technology (ICT) is considered such an accomplishment with enormous influence on economy and human life (Sendov, 1997). With the large spectrum of new possibilities arising from technological progress, the *era of digitalisation* has been heralded (Bao & Xiang, 2006; Hylving, 2015; Portilla, 2015; Sendov, 1997). While until now there have been three industrial revolutions referred to (Bauernhansl et al., 2014; Li et al., 2017), the rise of digitalisation and its prospects is now launching the 'fourth industrial revolution' (Schwab, 2016).

This most recent revolution is strongly interconnected with the term *Industry 4.0 (*Bauernhansl et al., 2014; Li et al., 2017; Meudt et al., 2017; Schroeder, 2016; Schuh et al., 2017; Weber, 2016). which implies the "widespread integration of information and communication technology in industrial manufacturing" (Schuh et al., 2017, p. 7). Coined by the German government in 2011 (Li et al., 2017), *Industry 4.0* equates to the digitalisation of industry (BMBF, n. y.). While on the one hand the vast opportunities to enhance efficiency in production are compelling (Meudt et al., 2017; Weber, 2016), worries about possibly associated extensive job losses due to human redundancy loom large on the other hand (Bonekamp & Sure, 2015; Weber, 2016). *Industry 4.0* thus comes as a global mega trend with potentially far-reaching societal impacts (Schroeder, 2016).

An industrial sector particularly influenced by digitalisation is the one of transportation (Brooks et al., 2016; Giannopoulos, 2004; Leviäkangas, 2016). Following new technological possibilities, autonomous vehicles have received their starting shot in transportation. Especially the last year's extensive research and pilot testing concerning areas of practical application of such vehicles enabled these concepts to mature significantly, bringing them close to implementation. While the automotive industry appears to stand out in its efforts to pave the way for autonomous driving (Fagnant & Kockelmann, 2015; Hars, 2015; Le Vine et al., 2015), also the shipping industry is past the point of sole envisioning more autonomy in vehicles. Being considered "a key element of a competitive and sustainable European shipping industry in future" (Kretschmann et al., 2017, p. 76), the concept of unmanned and autonomous shipping is now increasingly gaining momentum (Burmeister et al., 2014; Liu et al., 2016; NorthSEE, 2019; Kiencke et al., 2006; Kretschmann et al., 2017; Schwab, 2016; Wróbel et al., 2017).

The idea of larger autonomous vessels keeps maturing and appears less and less like a distant prospect. Some scholars refer to a timeframe of 10 to 15 years until the first unmanned and autonomous vessels are expected to go into service (Wróbel et al., 2017; cf. HSBA, 2018). Conversely, others express that "Visions of massive container ships ploughing across the ocean with nobody on board are still a while off" (Ship Technology, 2018). In the pursuit of realizing large-scale autonomous shipping, it thus seems a number of obstacles still need to be overcome and answers to different questions be found. Among the purported issues demanding further inquiry are the effects on navigational safety (Wróbel et al., 2017, p. 2; cf. Laurinen, 2016; Jokioinen, 2016), legal and regulatory aspects (DMA, 2017; IMO, 2018a; Karlis, 2018; Kobyliński, 2018; Komianos, 2018), the social and human element (e.g. employment) (HSBA, 2018; Kobyliński, 2018) as well as economic use and consequences (DMA, 2017; Kretschmann et al., 2017; Willumsen, 2018). Only technology is presently said to already have considerable maturity (Jokioinen, 2016; Kobyliński, 2018).

1.1 Problem statement and research question

The pursuit of unmanned and autonomous shipping seems to progress significantly. However, knowledge about this topic is still considered scarce (Wróbel, 2017) which indicates that demand for further research exists. This conforms with the considerations from above which point to yet unresolved issues. While studies dealing with autonomous shipping are increasingly been done for the shipping sector as a whole, such investigations for port environments have so far received little to no attention. This may also be a reason why ports are said to so far hardly recognize and embrace their role within the idea of autonomous shipping (Ship Technology, 2018). However, there is no indication for assuming that autonomous vessels will no longer have ports as their pivotal hubs (Kavirathna et al., 2018; Zheng et al., 2017) from where they begin and end their voyages. Bearing in mind that port environments come with significantly different characteristics compared to, for example, shipping on the high seas, there are clear limitations for drawing inferences only from general shipping as an umbrella. These aspects make studies for the concept of autonomous shipping in ports equally important to investigations in the general shipping sector. It can therefore be expected that a comprehensive perspective demands explicit research into both the interfaces *shipping sector – autonomous shipping* as well as *port environments – autonomous shipping*. Still, since the shipping industry has built its system on the long-lasting tradition of manned ship operation, the potential realization of the concept of autonomous shipping will likely come as a major challenge.

In order to contribute to the groundwork for accepting this challenge, this study is concerned with the following centric research question: "*What are the barriers and opportunities of the trend towards autonomous shipping, concerning the general shipping sector on the one hand and port environments on the other?*"

The research question necessitates defining both a barrier and an opportunity. In this study, a barrier is defined as an obstacle and/or impeding condition to and thus a drawback for the implementation of the concept of autonomous shipping. An opportunity is here defined as an asset and/or supporting condition to and thus an advantage for the implementation of the concept of autonomous shipping.

1.2 Scientific and societal relevance

The shipping sector is well advised to harness the technological and digitalisation advancements at its doorstep. Since autonomously operating vessels are linked to different advantages, further inquiry into the potentials of autonomous shipping and its options for realization can be expected to be beneficial. Another driver for more research is the possibility to contribute to various domains of sustainability and hence to help achieve the United Nations' 2030 Agenda for Sustainable Development in terms of its economic, ecological and social aspects (Kretschmann et al., 2017; United Nations, 2019b; cf. Burmeister, Bruhn, & Rødseth, 2014; HSBA, 2018; Rødseth & Burmeister, 2012). Nevertheless, different legal and regulatory obstacles as well as possibly adverse societal impacts such as significant personnel cutbacks also demand a critical investigation of the new concept design (Bruhn, 2017; Komianos, 2018; Sriwijaya, 2016).
The opportunities of digitalisation as well as the relevance of a thriving shipping industry are also recognized by Germany in its *Maritime Agenda 2025*:

> "It is essential to maintain what has already been achieved, to expand on this and at the same time to guide maritime transport into the digital age. The digital transformation amounts to an efficiency revolution in the maritime transport sector and can make a substantial contribution to Germany keeping its leading position in terms of its business environment" (BMWI, 2017, p. 29)

Consistent with above considerations, German government has announced plans to disclose certain test fields for autonomous ships. Resulting from a dialogue with economic actors, especially "urban areas with a branched network of waterways such as in Berlin, the area of the Unterelbe and large-scale harbours" (Deutscher Bundestag, 2018) are considered attractive for respective studies (ibid.). Since the latter two conditions coincide with the characteristics of Germany's biggest seaport (Hafen Hamburg Marketing, 2019a), this study investigates the port of Hamburg as an example for the interface *port environments – autonomous shipping* (case study, see chapter three).

Altogether, this study aims to contribute a perspective specifically dealing with the barriers and opportunities to the yet emerging body of knowledge on autonomous shipping. While different

purported benefits may incite one to only indulge in endorsement of the concept, there certainly are also drawbacks that need to be acknowledged. The respective investigation thus is intended to cast light on the concept of autonomous shipping in a way that it provides guidance and support to various players involved in shipping that are faced with a yet unclear future. Since an era of autonomously operating vessels would indicate a holistic shift in how shipping takes place, the target audience of this paper is wide-ranging. To only mention a few: Shipowners and -builders would encounter nothing less than a totally new design and operation of vessels, coming with both incentives and risks for investment. Legal and regulatory shipping authorities would be required to address and enable the safe operation of ship types that long have never been foreseen in documents and frameworks. This points at a considerable challenge. The same would apply for ports and their respective authorities. Moreover, with significantly less or no crew onboard ships, especially the future of seafarers would be threatened. Above considerations are certainly also relevant for the planning domain, as the groundwork for facilitating autonomous shipping cannot be expected to naturally emerge. Instead, paths with tools to move from theory into practice are demanded. These stakeholders are only examples of the vast variety of this study's addressee's.
Taking possibly fundamental changes in the shipping industry into account, the barriers and opportunities of autonomous shipping are additionally shed light on from the angle of transitions (see chapter 3). In sum, the value of this study is threefold as it

- gives insights into issues linked specifically to the general shipping sector, thereby providing additional soil for attention and debate on the topic (both internationally and in Germany);
- gives insights into issues linked specifically to a port environment (port of Hamburg), thereby helping to close the current knowledge gap concerning ports and allowing to start drawing inferences for other ports alike;
- and informs players in shipping and planners alike (transitions perspective) with a basis for future decision-making in the potential pursuit of autonomous shipping.

1.3 Theoretical approach

The theoretical research for this thesis was conducted in three steps. In the *first step* the centric characteristics of the shipping sector and port environments as the areas for investigation were identified and introduced. This was followed by detecting and sketching contemporary drivers and pressures for change in the shipping industry, eventually leading to the concept of autonomous shipping. For the latter was then given a more thorough understanding by introducing and elaborating on forerunners, autonomy levels, contemporary examples and relevant definitions. In order to arrive at a serviceable foundation for exploring the barriers and opportunities of autonomous shipping, the *second step* then focussed on carving out and analysing aspects considered most relevant by the scientific community for realizing autonomous shipping. This resulted in four guiding cornerstones that were used for gathering data and elaborating on the barriers and opportunities of autonomous shipping purposefully (more extensive information in section 2.5, providing the foundation for the results displayed in chapter 5). These cornerstones comprise:

- Technology and infrastructure
- Safety, security and insurance
- Societal, legal and regulatory acceptance
- Economical attractiveness and feasibility

Subsequently, the *third step* dealt with identifying applicable principles and mechanisms of transition theory (further explained in chapter 3) to be used for casting a different light on the results on the barriers and opportunities of autonomous shipping in the discussion of this study (chapter 6).

2 Setting the stage

In order to provide a comprehensive understanding of the setting within which the concept of autonomous shipping finds itself in, this chapter begins with introducing centric characteristics of both the shipping sector (2.1) as well as port environments (2.2) as areas of investigation. Afterwards, drivers and pressures for change within the shipping sector are briefly sketched (2.3). As an outcome of these, this is then followed by a thorough introduction to the concept of autonomous shipping (2.4), leading to the above mentioned cornerstones (2.5).

2.1 The shipping sector

In our globalized world, moving vast amounts of goods from place A to place B over thousands of kilometres would not be possible without seaborne transport. Holding a share of around 90 percent on international goods carriage (ICS, 2019a; United Nations, 2019b) and thus functioning as "the backbone of world trade and globalization" (IMO, 2019a), the maritime industry's centric role in international transport is evident. Or in the words of the International Chamber of Shipping: "Shipping is the life blood of the global economy" (ICS, 2019a). Over the past decades, the shipping sector has grown remarkably in size and is furthermore expected to continue doing so (ICS, 2019b). Nowadays, in the year 2017, international seaborne trade amounts to 10.702 million tons loaded. This continuous growth in shipping trade is illustrated in figure 1.

Year	Crude oil, Petroleum products & Gas	Main bulks[a]	Dry cargo other than main bulks[a]	Total (all cargoes)
1970	1 440	448	717	2 605
1980	1 871	608	1 225	3 704
1990	1 755	988	1 265	4 008
2000	2 163	1 295	2 526	5 984
2005	2 422	1 711	2 976	7 109
2006	2 698	1 713	3 289	7 701
2007	2 747	1 840	3 447	8 034
2008	2 742	1 946	3 541	8 229
2009	2 642	2 022	3 194	7 858
2010	2 772	2 259	3 378	8 409
2011	2 794	2 392	3 599	8 785
2012	2 841	2 594	3 762	9 197
2013	2 829	2 761	3 924	9 514
2014	2 825	2 988	4 030	9 843
2015	2 932	2 961	4 131	10 024
2016	3 055	3 041	4 193	10 289
2017	3 146	3 196	4 360	10 702

Figure 1: International seaborne trade development in selected years (Millions of tons loaded) (UNCTAD, 2018b)

In monetary terms altogether, for the year 2017, the shipping sector's economic value of global merchandise exports amounts to the enormous number of US$17.7 trillion (UNCTAD, 2018a).

As the shipping industry is a strongly international sector, "perhaps [even] the most international of all the world's great industries" (IMO, 2019e), this implies that a multiplicity of different stakeholders is involved that relies on a well-functioning global system. This also mirrors in the sector's variegated vessel fleet. According to the International Chamber of Shipping, nowadays around 50.000 merchant vessels are involved in worldwide maritime transport with these ships being registered across more than 150 different states (ICS, 2019b; cf. BPB, 2017). Those vessels come with different purposes and thus different characteristics which are "determined by the nature of trade (or traffic), and more specifically the type of transported cargo or commodity" (UNCTAD, 2004, p. 10). In total, the world maritime fleet equals to an overall cargo carrying capacity of 1.9 billion dead-weight tons (dwt), a seaborne trade volume of 10.7 billion tons, a global container port throughput of 753 million TEU[1]s for the year 2017 (UNCTAD, 2018a) and is said to altogether produce an annual revenue of more than half a trillion US$ (ICS, 2019b).

Respectively, the most prominent types of vessels are container ships, bulk carriers or dry-bulk ships, tankers, ferries or cruise ships and eventually specialist ships. As their name indicates, the operation of *container ships* is concerned with carrying various (consumer) goods as well as (semi-final and final) products in containers around the globe. In most cases, this is known as liner shipping which implies that regular, scheduled transportation services are provided at designated routes, between specific ports and predefined tariffs (ICS, 2019c; Woodward et al., 2018; World Shipping Council, 2019c). Respective services account for approximately 60% of the monetary value of worldwide trade on seaway (World Shipping Council, 2019a).

As opposed to container ships, *bulk carriers* or *dry-bulk ships* carry raw materials (e.g. ore, coal, grains and iron) across the oceans and can hence be perceived as the "work horses of the [merchant] fleet" (ICS, 2019c) (ibid.; Woodward et al., 2018).

While bulk ships carry raw materials, *tankers* are ships that carry liquid cargo such as petroleum, crude oil and chemicals. More recently, these vessels are also increasingly transporting other products such as natural gas (ICS, 2019c; Woodward et al., 2018).

Ferries or *cruise ships* are not transporting goods or materials. While ferries are concerned with carrying passengers as well as civil and commercial vehicles across rather short distances quickly from one port to another, cruise ships are predominantly dealing with bringing passengers from location A to B across long distances (ICS, 2019c; Woodward et al., 2018).

In most cases, *specialist ships* are considerably smaller since they are not required to transport large amounts of cargo or passengers. Ships falling under this category are for example tugboats operating mainly in harbours to support and guide larger vessels, research vessels, icebreakers and ships that supply offshore undertakings (ICS, 2019c; Woodward et al., 2018).

[1] volume unit, an equivalent to a 20-foot ISO container (EC, 2019; World Shipping Council, 2019b)

Considering the global extent and high importance of shipping, it consequentially also requires effective coordination – this is ensured by the International Maritime Organization (IMO). The IMO is a United Nation's specialized agency and assigned the task of assuring safety, security, cleanness and efficiency of international maritime transport and shipping (IMO, 2019a). These objectives are incorporated and addressed in numerous regulations, conventions and treaties in order to pave the way for a "framework for the shipping industry that is fair and effective, universally adopted and universally implemented" (IMO, 2019a).

Out of the plethora of international treaties, the *International Convention for the Safety of Life at Sea (SOLAS)* is considered the most relevant. The centric task of SOLAS is "to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety" (IMO, 2019b). Hence, various ships have to live up to these requirements set out in the convention. This implies that all states which have vessels sailing under their flag are required to ensure that their ships observe the SOLAS standards (ibid.).

The *International Convention for the Prevention of Pollution from Ships (MARPOL)* functions as "the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes" (IMO, 2019c). In order to achieve this, MARPOL includes several regulations targeting for example pollution by oil, noxious liquid substances in bulk, harmful substances carried by sea in packaged form or sewage from ships (IMO, 2019c).

The *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)* puts the quality and competence of all navigators to test by stipulating "minimum standards relating to training, certification and watchkeeping for seafarers which countries are obliged to meet or exceed" (IMO, 2019d) (ibid.).

Further conventions comprise, for example, the *Convention on the International Regulations for Preventing Collisions at Sea (COLREG)* (IMO, 2019e) and the *International Convention on Maritime Search and Rescue (SAR)* (IMO, 2019f). A list of all existing conventions can be found in the appendix**.**

2.2 Port environments

Both goods and passengers are not simply 'to be found on sea', they are brought from one place to another, namely to ports. Not least because the latter procure and increase the number of jobs, labour and business income as well as taxes, they function as an important 'motor' for economic development (Talley, 2017).

While there are different kinds of ports, this study is predominantly concerned with seaports as these mostly account for the entities dealing with shipping on the largest scale (Roa et al., 2013). Seaports can be defined as "as a terminal and an area within which ships are loaded with and/or discharged of cargo and includes the usual places where ships wait for their turn or are ordered or obliged to wait for their turn no matter the distance from that area. Usually it has an interface with other forms of transport and in so doing provides connecting services" (Branch, 1986 in Audigier et al., 2000). Seaports come with a number of common characteristics, with terminals being a pivotal feature as the transition point of ship loadings. These terminals mostly consist of cranes, anchoring berths, warehouses and/or transit sheds, roadways, railways as well as administrative facilities (Audigier et al., 2000). The outstanding relevance of seaports is summed up by the European Commission as follows:

> *"The [European] Union is highly dependent on seaports for trade with the rest of the world and within its Internal Market. 74% of goods imported and exported and 37% of exchanges within the Union transit through seaports. Ports guarantee territorial continuity of the Union by servicing regional and local maritime traffic to link peripheral and island areas. They are the nodes from where the multimodal logistic flows of the trans-European network can be organised, using short sea shipping, rail and inland waterways links to minimise road congestion and energy consumption."* (EC, 2014, p. 4)

In conjunction with the ever-growing shipping sector, port environments have likewise frequently grown, reaching 753 million TEUs in 2017. This mirrors in the three biggest European cargo ports: Rotterdam (NL), Antwerp (BE) and Hamburg (DE) all illustrate a continuously positive growth rate between 2011 and 2016 (UNCTAD, 2018a).

2.3 Drivers and pressures for change in shipping industry

In the *era of digitalisation* and *industry 4.0* (see introduction) with their vast technological possibilities at the doorstep, the shipping sector inevitably seems to encounter an ever more salient pressure for innovative improvements. However, the drivers for change and advancement are not solely technological. The launch of the 2030 Agenda for Sustainable Development with its 17 Sustainable Development Goals by the United Nations in 2015 has applied another source of pressure on shipping (United Nations, 2019a). Bearing in mind that shipping provides by far for the biggest share in international goods carriage and thus functions as core stimulus for world trade and globalisation (IMO, 2019a), it comes as a vital pillar in achieving the mission of sustainable development. The IMO thus has composed a number of documents in which it lays out a long-term and sustainable pathway for the maritime industry (e.g. *A Concept Of A Sustainable Maritime Transportation System*) (IMO, n.y. a/b). Kitack Lim – Secretary-General of IMO - puts the sector's future trajectory in the following nutshell:

> *"We must ensure that the opportunities presented by the digital revolution to improve efficiency in shipping are incorporated effectively into the regulatory framework. (…) Thanks to the opportunities afforded by new technology, shipping is on the brink of a new era. The*

technologies emerging around fuel and energy use, automation and vessel management, materials and construction and so many other areas, will lead to new generations of ships that bring substantial improvements in all the areas that IMO regulates. Technology and the use of data hold the key to a safer and more sustainable future for shipping."

(Kitack Lim, 2018 in UNCTAD, 2018b, p. 38)

2.4 The dawn of autonomous shipping

In section 2.3, Kitack Lim already indicated that the enormous potential of both contemporary and future technology, paired with the necessity to pursue and achieve more sustainability, will have profound impacts on the shipping sector. In particular, 'new generations of ships' are expected to lie ahead. Indeed, when having a closer look, one observes the gaining momentum of considerably more autonomy in ships. Among the benefits attributed to more ship autonomy and thus incentives for their pursuit are "reduced operational costs, reduced manning, increased operational times, reduced fuel consumption, improved lifestyles for the seafarers, and increased maritime shipping capacity" (Kobyliński, 2018; cf. DMA, 2017; Benson et al., 2018; TU Delft, n.y.). The potential to increase maritime safety comes as another strong stimulus (Kretschmann et al., 2017; Benson et al., 2018; TU Delft, n.y.).

By introducing and elaborating on forerunners, autonomy levels, contemporary examples and relevant definitions, this chapter gives an understanding of the concept of autonomous shipping.

2.4.1 Smaller-scale forerunners of autonomous ships

Waterborne vessels with these characteristics are commonly referred to as unmanned surface vehicles (USV), defined as "any vehicle that operates on the surface of the water without a crew" (Yan et al., 2010, p. 451), furthermore known as autonomous surface vehicles (ASVs) or autonomous surface crafts (ASCs). Once these vehicles are operating underwater, they are called unmanned underwater vehicles (UUVs) (Manley, 2008; Liu et al., 2016). Reasons behind the pursuit of such vessels is their linkage to a number of benefits. For example, USVs are linked to "lower development and operation costs, improved personnel safety and security, extended operational range (reliability) and precision, greater autonomy, as well as increased flexibility in sophisticated environments, including so-called dirty, dull, harsh, and dangerous missions[2]" (Liu et al., 2016, p. 71; cf. Bertram, 2008; Breivik et al., 2008; Breivik, 2010; Roberts & Sutton, 2006). By operating on the surface of the water, USVs may moreover function as an interface between

[2] 'Dirty': e.g. disaster monitoring and action under significant pollution; 'Dull': e.g. surveillance for maritime purposes and geophysical surveys; 'Dangerous': e.g. military observations, operations against piracy and mine countermeasures (MCM) (Breivik, 2010)

other unmanned vehicles which act above or beneath the water surface area (Breivik, 2010). An illustration of USVs is provided in figure 2.

Figure 2: Compilation of current unmanned surface vehicles (USVs) (Breivik, 2010)

2.4.2 Introducing the idea of autonomous ships and autonomy levels

According to the European Waterborne Technologies Platform Implementation Plan of 2011, an autonomous vessel describes a ship which comprises "next generation modular control systems and communications technology [that] will enable wireless monitoring and control functions both on and off board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control" (Waterborne TP, 2011, p. 8). In order to provide shipping players with a more detailed basis for classification and thus investment decisions concerning design and operations, Lloyd's Register differentiates between seven levels of ship autonomy (AL 0 – 6) (figure 3) (Lloyd's Register, 2016a).

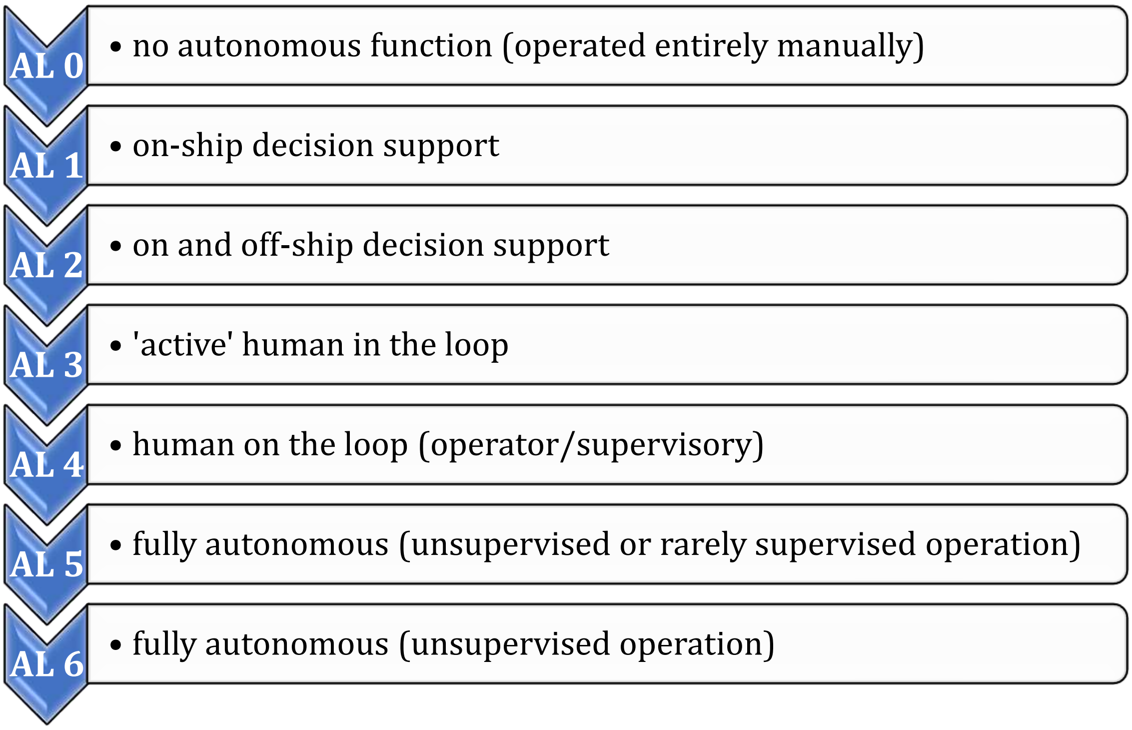

Figure 3: Levels of ship autonomy (Author, 2019; based on Lloyd's Register, 2016a)

Autonomy level 0 implies that all activities as well as decision making on the entire ship level are thoroughly conducted manually under the control of a human being (if applicable, partial autonomy of on-board systems included). On a ship with autonomy level 1, a human operator still executes all actions but is afforded additional decision support systems or tools that may contribute further information to help take appropriate action. While in case of autonomy level 1 tools or systems for decision support are exclusively provided for on-board, autonomy level 2 now comprises and allows for both on and off-ship decision support. In addition to extensive decision support, level 3 then implies a considerable shift towards more autonomy of the ship. The human operator no longer executes all actions and decision making himself but transfers these responsibilities to the vessel and thus functions merely as a supervisor. Nevertheless, the operator is still afforded capacity to intervene in highly important decisions. Here, the operator is considered an *'active' human in the loop*. Autonomy level 4 is then only different to the former in the sense that decision support tools (both on- and off-ship) are no longer foreseen. The operator is now *on the loop*. From autonomy level 5 onwards, the ship has full autonomy. While level 5 implies that the autonomous ship is either unsupervised or rarely supervised, level 6 then explicitly stands for the ship operating entirely without human supervision. However, only level 6 is entirely considered a fully autonomous vessel (Lloyd's Register, 2016a/b).

2.4.3 Recent examples of and efforts concerning autonomous ships

The trend towards and pursuit of unmanned and autonomous vessels on a larger scale has accelerated remarkably in the last couple of years (Komianos, 2018; Kretschmann et al., 2017; Sriwijaya, 2016). For example, under the name of 'One Sea', the Finnish Collaboration DIMECC brings together numerous marine players (e.g. shipbuilders, -owners, suppliers and researchers) to facilitate a "high-profile ecosystem with a primary aim to lead the way towards an operating autonomous maritime ecosystem by 2025" (DIMECC Oy, 2017). Especially in Scandinavia, the idea of autonomous shipping receives strong endorsement. Test sites have been designated (e.g. Trondheimsfjord in Norway; NorthSEE, 2019) and research into further development of maritime systems essential for this endeavour is state-subsidized (Bruhn, 2017a). Due to these fertile circumstances, also a number of private companies investigate and stimulate the realization of bigger autonomous ships. Respective examples comprise Norwegian Kongsberg and Yara that collaboratively aim to deliver the "world's first autonomous and fully electric container vessel" (Kongsberg, 2017) until 2020 (ibid.; NorthSEE, 2019). Moreover, Finnish company Wärtsilä has proven that technology has highly matured and is already working successfully in practice. For instance, in October 2017 the company managed to remotely operate an 8.000km distant platform support vessel with a length of 80m and weight of 4.000t from San Diego, California (Wärtsilä, 2017). Apart from that, using Wärtsilä technology, 85m long ferry 'Folgefonn' of Norwegian ferry operator Norled successfully executed the "believed to be (..) first ever attempt at fully automated dock-to-dock operation, in complete hands-off mode, for a vessel of this size" (Wärtsilä, 2018) (ibid.). Furthermore, the European Commission launched and co-funded the *Maritime Unmanned Navigation through Intelligence in Networks* (MUNIN) project (running from 2012 – 2015) under its Seventh Framework Programme in which a concept for an unmanned merchant vessel got developed. In this, technical, economic and legal feasibility had been investigated (Bruhn, 2017b; MUNIN, 2016). German government has recently likewise announced plans to disclose certain test fields for autonomous ships and their systems (Deutscher Bundestag, 2018).

As of May 2018, the International Maritime Organization (IMO) has also joined the growing community that follows the mission to facilitate and expedite autonomous shipping. In order to do its part, the IMO thus puts autonomous shipping to test as aspects pertaining to safety, security as well as environmental compatibility are investigated. This so-called 'regulatory scoping exercise' is conducted by the Maritime Safety Committee (MSC) as IMO's senior technical body (IMO, 2018a). To provide a solid basis for examination, a novel definition was launched: the *Maritime Autonomous Surface Ship* (MASS) as a "ship which, to a varying degree, can operate independently of human interaction" (IMO, 2018a) (ibid.). In the regulatory scoping exercise, particular emphasis is placed on investigating and determining the applicability of IMO instruments and provisions (e.g. *SOLAS* or *COLREG*) to vessels falling under the characteristics of

MASS and whether these may even frustrate respective operations. It furthermore gets explored how the operation of *MASS* can most suitably and serviceably be approached - not least also in terms of technological, operational as well as human-related aspects. Eventually, the scoping exercise is scheduled to be finished in 2020 (IMO, 2018a/b).

2.5 Cornerstones for realizing the idea of autonomous shipping

The previous sections have introduced the narrative behind the concept of autonomously operating vessels and indicated that the vision of unmanned ships sailing across the world's oceans keeps maturing. However, since the shipping sector has been built upon and tailored to manned shipping it hence entails a pivotal role of human personnel on board a ship. As a result, the idea of autonomous shipping and its feasibility can be expected to considerably depend on the possibilities for harmonization with the existing system and its long-grown modus operandi (Carey, 2017; Karlis, 2018; Van Hooydonk, 2014). It thus can be assumed that there need to be strong incentives for the industry and its stakeholders to stimulate and encourage a shift from manned to unmanned or eventually autonomous shipping.
Different aspects are here commonly brought forward by players in the shipping industry that are considered particularly relevant for the feasibility and success of autonomous shipping. For the purpose of classification, these aspects are henceforward termed 'cornerstones'. In order to enable a viable research scope respectively, the Advanced Autonomous Waterborne Applications (AAWA) initiative and the Danish Maritime Authority (DMA) are here consulted as serviceable representatives of the shipping community. These sources provide the basis for carving out said cornerstones which will later on be used in chapter 5 to purposefully guide the exploration of the barriers and opportunities of the trend towards autonomous shipping.

With a budget of 6.6 million € provided by the Finnish Funding Agency for Technology and Innovation (Tekes), AAWA is a collaboration of a variety of different maritime players and stakeholders[3] concerned with investigating and fostering the concept of remote controlled and autonomous vessels. More specifically, AAWA "explore[s] the economic, social, legal, regulatory and technological factors, which need to be addressed to make autonomous ships a reality" (Rolls-Royce plc[4], 2016, p. 5). In this respect, AAWA highlights four distinct pillars that demand further inquiry (figure 4):

[3] Including e.g. Tampere University of Technology, VTT Technical Research Centre of Finland Ltd, Aalto University, University of Turku, Rolls-Royce, DNV GL, Deltamarin, Finferries, ESL Shipping (Rolls-Royce plc, 2016)
[4] The company Rolls-Royce plc is not consulted here to deliberately foreground an industrial perspective but only incorporated as a source that serviceably exhibits relevant objects of research.

Figure 4: Research Areas (Rolls-Royce plc, 2016)

Moreover, in December 2017, the DMA compiled a final report that dealt with the 'Analysis of Regulatory Barriers to the Use of Autonomous Ships'. Alongside regulatory aspects being centric to the report, it also recognized other important facets: "regulatory barriers are merely a part of the overall formula for society's response to autonomous ships" (DMA, 2017, p. 3) (figure 5).

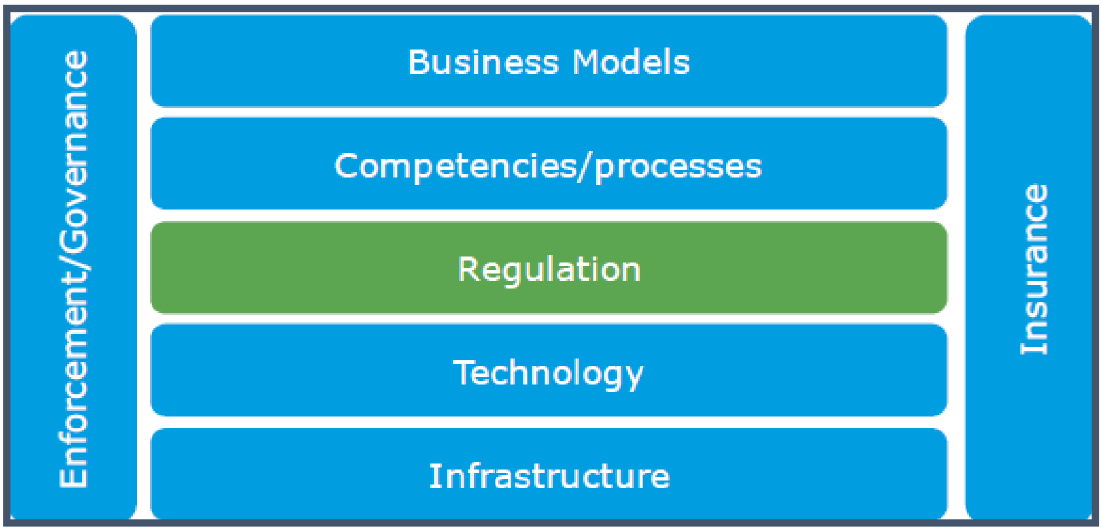

Figure 5: Circumstances of importance to the development of autonomous ships (DMA, 2017)

The DMA complements AAWA's outline in the sense that it also points at issues pertaining to e.g. infrastructure and insurance. Many perceptions of AAWA and the DMA also resonate in publications from other scholars: *technological* (Kobyliński, 2018; Bruhn, 2017a), *safety* (Acanfora et al., 2018; Burmeister et al., 2014; Hoem et al., 2018; Kobyliński, 2018; Rødseth & Burmeister, 2015; Vistiaho, 2018), *legal* (Karlis, 2018; Kobyliński, 2018), *regulatory* (Komianos, 2018; Kuhn, 2017) and *economical* (Kobyliński, 2018; Kretschmann et al., 2017; Kuhn, 2017).

Taken as a whole, above observations indicate that there is a recognizable consensus regarding a set of aspects that are considered crucial for making the idea of autonomous shipping a reality.

Drawing on this consensus, four different cornerstones are composed to provide guidance for purposefully exploring the barriers and opportunities of the trend towards autonomous shipping as the core of this thesis (figure 6):

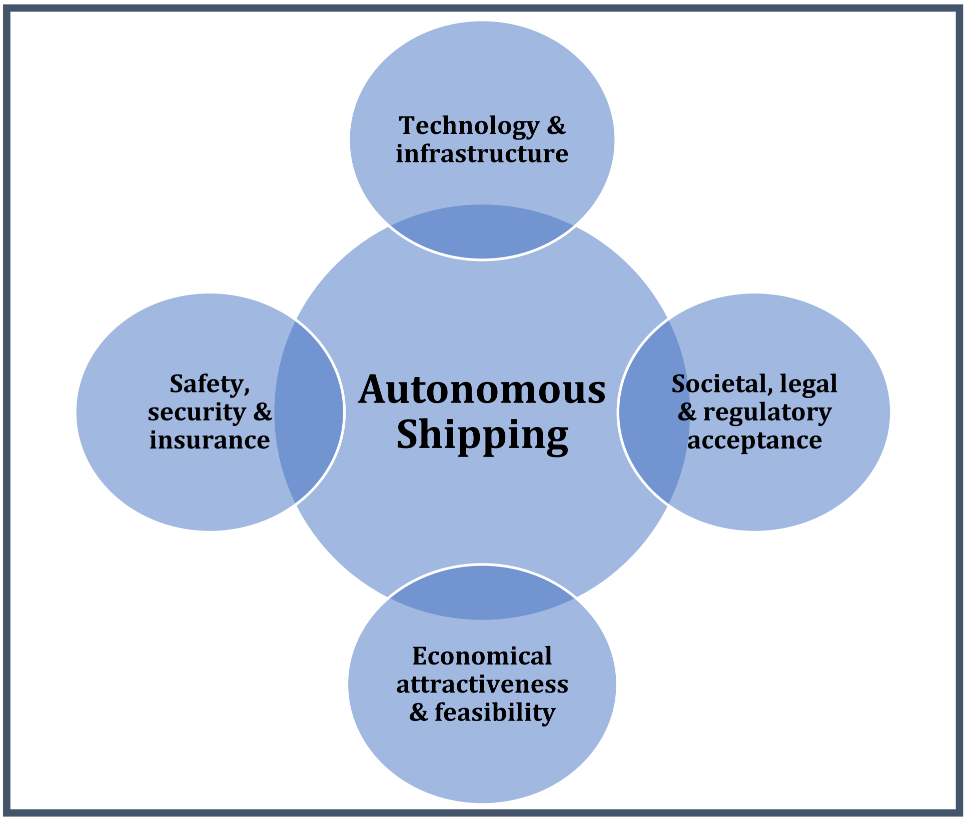

Figure 6: Guiding cornerstones for exploring the barriers and opportunities of the trend towards autonomous shipping (Author, 2019)

3 Conceptual framework

As indicated in section 1.2 and 1.3, this study draws on notions of transition theory (socio-technical transitions as well as the multi-level perspective and the multi-stage concept) to shed light on the trend towards autonomous shipping from another angle. The respective considerations provided below are revisited in the discussion of this thesis (chapter 6) and build on the results carved out for the trend's barriers and opportunities (chapter 5) according to the previously composed four guiding cornerstones. Together with these cornerstones and areas of investigation (chapter 2), this brings forward the conceptual model of this study which is used to guide the research of this thesis (figure 9).

3.1 Transition theory and autonomous shipping

Considering that both the shipping industry and port environments have been built upon and tailored to manned shipping over centuries, a smooth and quick implementation of the concept of autonomous shipping on a large scale may be far too optimistic. Simply revamping the existing shipping system in a way that autonomous vessels can both be accommodated and present the new status quo by replacing manned vessels may not be realistic. In other words, this procures the notion that a lot more than modest changes may eventually be required if the idea of autonomous shipping is to be realized: a system-change or *transition* towards a new system may be necessary.

Transition theory provides a fundament to better grasp and understand substantial and profound changes in societal systems. According to Rotmans et al. (2000; in van der Brugge et al., 2005), a "transition is a structural change in the way a societal system operates (…) [and] a long-term process (25 – 50 years) (…) on various scale levels" (p. 165-166). Such processes are often strongly coupled with technical aspects, implying that "societal functions are fulfilled by sociotechnical systems" (Geels, 2005a, p. 681). These systems comprise a number of different interconnected elements such as culture, knowledge, supply and maintenance networks, infrastructure, markets and regulation. Hence, profound changes in respective systems are of a systemic nature (Geels, 2005a/b, 2011; Hodson & Marvin, 2010) and can be considered socio-technical transitions (Geels & Schot, 2007; Hodson & Marvin, 2010; Pettit et al., 2018; Smith et al. 2005; cf. Grin et al., 2010). Notions of socio-technical transitions have also been linked to changes in the shipping sector, for example in respect to carbon emissions reduction (Pettit et al., 2018) and the move from sailing to steam ships (Geels, 2002).

3.1.1 Multi-level perspective (MLP)

According to van der Brugge et al. (2005), transition theory is grounded on a number of different concepts. One of these is the ‘multi-level perspective’ (MLP) which helps to analyse and describe socio-technical transitions (Geels, 2011; van der Brugge et al., 2005). The MLP is characterised by three distinct, functional scale levels (figure 7):

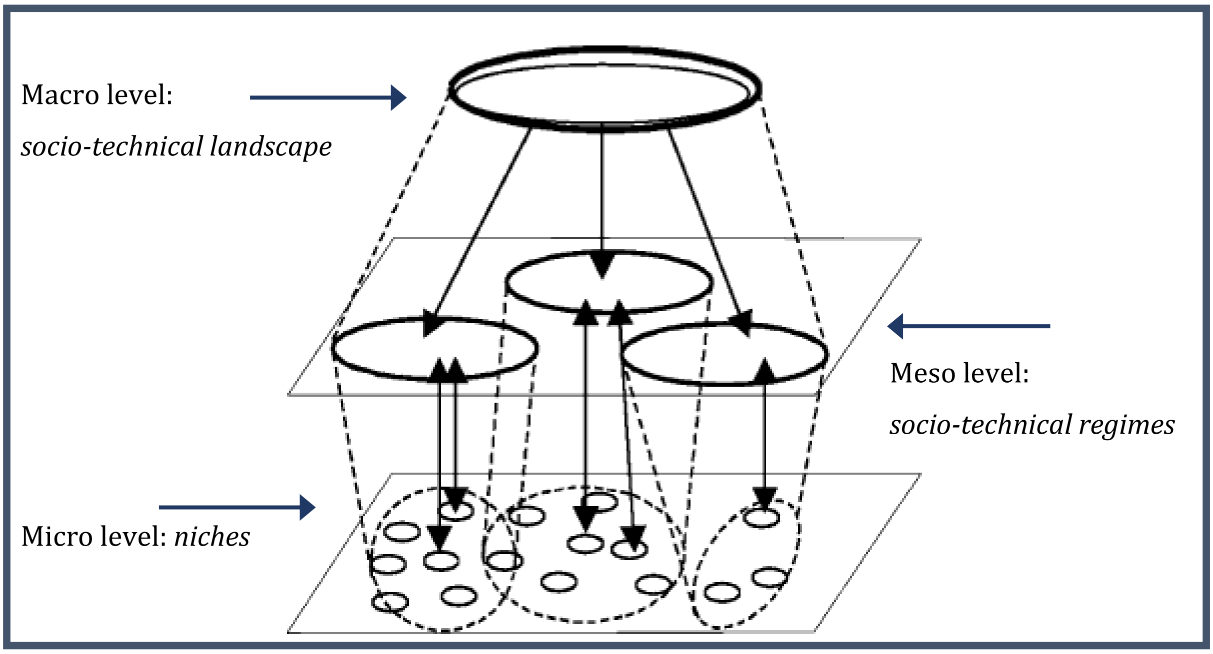

Figure 7: Multi-level perspective (adapted; based on Geels and Kemp, 2000 in van der Brugge et al., 2005)

Macro level: *socio-technical landscape*

- broader exogenous environment with slowly altering external factors and thus a considerable degree of durability (Geels, 2002, 2005a/b, 2011)
- comprises e.g. demographic trends, emigration, societal values, macro-economic aspects, cultural changes, environmental issues (Geels, 2002, 2005a/b, 2011)
- landscapes are rather inert to efforts of different actors to alter it and hence cannot be manipulated consciously within the near future (Geels, 2005a/b, 2011)
- depending on the landscape’s response to external trends and changes, transitions are either stimulated or impeded (Berkhout et al., 2003 in van der Brugge et al., 2005)

Meso level: *socio-technical regimes*

- fundament which provides for the continuity of the current socio-technical system (Geels, 2002, 2004)
- is grounded on a package of rules which guide actors in their behaviour within the socio-technical system and thereby stimulate the reproduction of a system’s existing elements (Geels, 2002, 2011)

- rules comprise e.g. shared beliefs, lifestyles and user practices, beneficial institutional arrangements as well as regulations (Geels, 2011)
- while rules are both launched and applied by actors, following the 'duality of structure', they are either empowered or hindered in a certain behaviour (Geels, 2002, 2011)
- reproduction of current regime rules leads to a lock-in of the overall regime (Geels, 2011)

Micro level: *niches*

- 'incubation rooms' or 'protected spaces' in which novel and/or radical innovations occur in isolation from common market choice processes (Geels, 2002, 2005a/b, 2011)
- comprise individual actors (e.g. entrepreneurs, start-ups and spinoffs), alternative technologies and locally specific practices (Geels, 2011; Kemp et al., 1998 in van der Brugge et al., 2005)
- innovative techniques and new social practices instigate divergence from the current modus operandi/status quo (Kemp et al., 1998 in van der Brugge et al., 2005)
- offer room for different learning processes (Geels, 2002, 2005a/b)

3.1.2 Multi-stage concept

Following van der Brugge et al. (2005), the 'multi-stage concept' is another tool for conceptualizing transitions. Here, a transition is considered a shift from one dynamic equilibrium to another. In this, based on a composition of system indicators[5], the transition is analysed via the pace of changes in the current system (Rotmans et al., 2000).

First of all, in order to allow for a transition to take place, there need to be developments within a variety of sectors (ecological, economical, socio-cultural, technological and institutional) that move into the same direction. Or in other words, they are required to positively reinforce each other. Revisiting the aspect of structural change, a transition then implies that above mentioned sectors co-evolve and hence jointly go through distinct consecutive phases (figure 8) (Rotmans, 1994; Rotmans et al., 2000; van der Brugge et al., 2005):

[5] System indicators not further specified in van der Brugge et al. (2005)

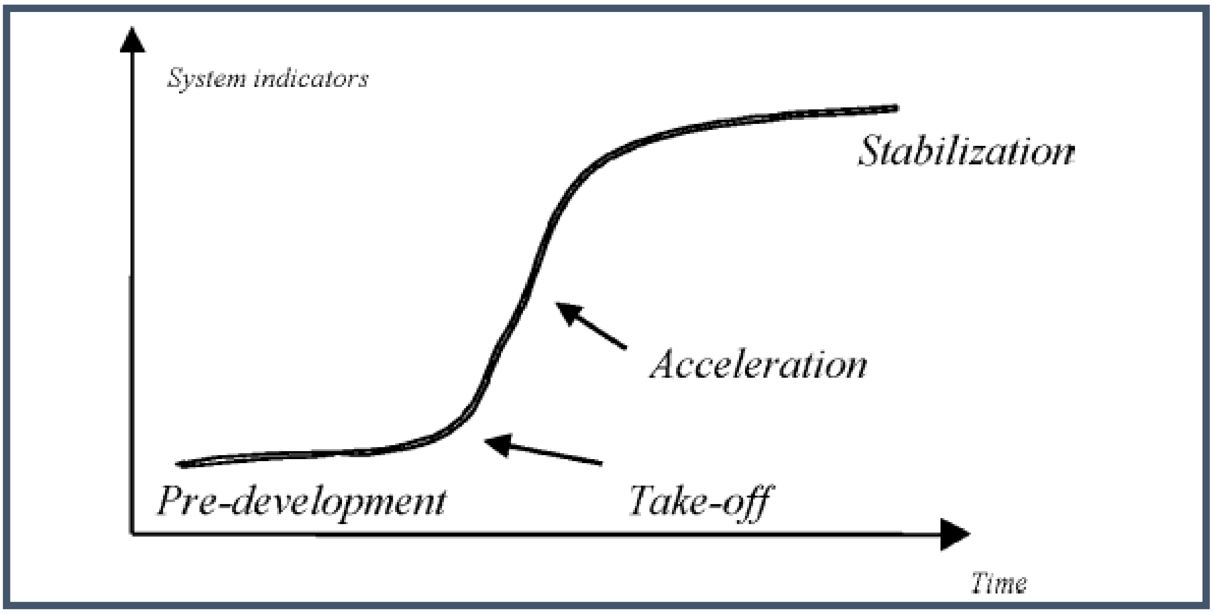

Figure 8: Multi-stage concept (based on Rotmans et al., 2000 in van der Brugge et al., 2005)

Based on the underlying multi-stage concept, the above phases or stages can be characterized as follows (Rotmans et al., 2000; van der Brugge et al., 2005):

1. Pre-development phase ('present' or 'old' dynamic system equilibrium)
    - changes happen but are not yet observably affecting the system
2. Take-off phase
    - changes further accumulate and touch a tipping point
    - a system change gets initiated
3. Acceleration phase
    - co-evolving ecological, economical, socio-cultural and institutional alterations further converge and positively reinforce themselves
    - torrential, structural transformations in the system are observable
4. Stabilization phase ('new' dynamic system equilibrium)
    - fast-paced system transformation simmers down and changes stabilize
    - transition is completed, a novel equilibrium state is active

3.1.3 Merging the concepts with trend towards autonomous shipping

While the above introduced concepts certainly stand for themselves, they allow for more comprehensiveness in analysing and understanding a transition when brought together. As displayed in 3.1.1, the regime at the meso level of the MLP is providing for stability of a socio-technical system. The reproduction and recurrent application of the existing rules by actors foster the persistence of the present regime. Or in other words, the maintenance of consolidated rules keeps the activated 'carousel' spinning and thus works against a change in the carousel's current motion. This situation aligns with the predevelopment phase of the multi-stage concept in which, although changes may happen, the system is not yet significantly affected and thus retains its status quo. However, once occurring changes at the micro level (e.g. concerning behaviour or technology) converge with alterations at the macro level (e.g. concerning worldviews or macro policies), developments gain increasing momentum and approach tipping points that cause the current system to totter. Here, as opposed to the rather isolated changes in the predevelopment phase, this now take-off phase implies that changes not only further accumulate but positively reinforce each other to exert greater pressure on the regime. This phase is decisive for the success of a transition as "results are needed in order to push and pull the regime over the 'edge'" (van der Brugge et al., 2005, p. 167). When this has occurred, the transition reaches the acceleration phase in which the previously dominant system paradigm undergoes major transformations as a result of co-evolving, strongly reinforcing developments at micro, meso and macro level. While the regime functions as an 'inhibitor' of change in the predevelopment phase, the regime now acknowledges the urge for its transformation and thus fosters change through investing capital, technology and knowledge. Eventually, when changes fall off and the transformation of the regime is completed, the stabilization phase is reached. Then, a new dynamic equilibrium with a once more change-resistant regime is reached (van der Brugge et al., 2005).

It has become apparent that realizing autonomous shipping will not be an easy endeavour and will likely necessitate greater changes in the shipping industry and society. This issue has also been recognized by the previously introduced Advanced Autonomous Waterborne Applications (AAWA) initiative through their slogan 'redefining shipping – a transition to autonomous shipping'. In this regard, AAWA links autonomous shipping to socio-technical transitions: "autonomous shipping is not merely about technology but also about the respective social change" (Rolls-Royce plc, 2016, p. 75) (ibid.). Therefore, it seems a solid basis for applying transition theory to the trend towards autonomous shipping is given. The discussion in chapter 6 will thus revisit this particular interface in relation to the results on the barriers and opportunities carved out in chapter 5. This will be done based on both the multi-level perspective (MLP) and multi-phase model (see section 3.1.1 and 3.1.2). For this, the following understanding of a transition will be consulted:

- *For a transition to occur, a disturbance of the socio-technical regime (meso level) is needed. This is because the regime and its characteristic arrangements have been reproduced by various actors involved over a longer period and is thus rooted in the past. The regime has therefore become the default system for which extensive experience exists. As long as it keeps functioning satisfactorily, it hence resists the occurrence of a transition.*
- *Disturbance of or pressure on the regime derives from the socio-technical landscape (macro level). An initiator can be, for example, cultural changes or environmental issues. In case its*

disturbance is strong enough, the regime then looks for solutions. These are drawn from the niches (micro level) and can be, for example, innovative techniques or new social practices.

- *Once these factors come together, a transition is initiated. The speed and success of the transition then depend on how much the solutions in the niches and sectoral developments reinforce each other. This produces the characteristic S-curve of the multi-stage model.*

3.2 Pulling the strings together: conceptual model

Resting on the information given in the previous sections, the conceptual model below (figure 9) is providing theoretical guidance for the research of this thesis. It distinguishes between two steps. In step 1, for each of the four cornerstones displayed in figure 6, barriers and opportunities of the trend towards autonomous shipping will be explored from two perspectives: the shipping sector in general as well as port environments (case study port of Hamburg, see chapter 4) in particular. In step 2, the results on the barriers and opportunities of autonomous shipping will be once more analysed from the view of transition theory. This will be done based on the understanding of transition characteristics given in section 3.1.3.

Step 1: Exploring barriers and opportunities of autonomous shipping

- Guide for exploration: four cornerstones (figure 6)
- Two perspectives
  - a) Shipping sector (section 5.1)
  - b) Port environment: port of Hamburg (section 5.2)

Step 2: Analysing barriers and opportunities from view of transition theory

- Guide for analysis: understanding of transition characteristics (section 3.1.3)
  - a) Consulting multi-level perspective
  - b) Consulting multi-phase model

Figure 9: Conceptual Model (Author, 2019)

4 Methodology

This chapter introduces the methodological approach used for this study to explore the barriers and opportunities of the trend towards autonomous shipping. In order to gather relevant data for this endeavour comprehensively, this thesis both draws on desk research as well as qualitative research in the form of case study research (port of Hamburg) and semi-structured interviews. Altogether, these are the methods used in order to answer the central research question "*What are the barriers and opportunities of the trend towards autonomous shipping, concerning the general shipping sector on the one hand and port environments on the other?*".

4.1 Desk research

As opposed to field research, desk research (also: secondary research) makes use of existing data to derive relevant information for a specific topic. In this, data may originate from studies with purposes different from the one at hand which is then further processed and exploited for the object of research. Respectively, among reasons for desk research are the valuable complementarity with data from field research as well as the limited possibilities to self-gathering of the data required (SKOPOS, 2019).

Because collecting all the relevant data about the barriers and opportunities of the trend towards autonomous shipping is not possible within the scope of this study, desk research inevitably comes as a necessary fundament. For the desk research, the search engine *Google (Scholar)* was used. In order to gather relevant data for researching the topic, keywords (including synonyms) and short phrases such as 'autonomous shipping', 'unmanned ships', 'barriers and opportunities of autonomous shipping' were employed in the engine. Next to English, this was similarly done in German. The output of the search engine was then appraised by the researcher and, if the data was considered serviceable for answering the research question, further processed in the thesis. While the data used in this thesis mainly derive from a scientific literature review (published articles, conference papers etcetera), websites from different official (national and international) organisations were also consulted for complementation. The desk research took place between November 2018 and July 2019.

4.2 Qualitative research

Data can be collected in different ways. In this, there are two often juxtaposed approaches that follow a different rationale: quantitative and qualitative research (Hammarberg et al., 2016; Pathak et al., 2013). Based on the assumption that the world is about facts which can be observed and measured, quantitative research tends to follow a positivist world view (Glesne & Peshkin, 1992; Henn et al., 2006). Respectively, it thus is concerned with larger sample sizes (Martin &

Bridgmon, 2012; Queirós et al., 2017) to provide for generalization and reliability (Henn et al., 2006).

In contrast to that, qualitative research "is an exploratory approach emphasizing words rather than quantification in gathering and analyzing the data. It is a matter of the inductive, constructivist and interpretative exploratory approach" (Devetak et al., 2010, p. 78). Hence, qualitative research refrains from quantitative or statistical methods (Strauss & Corbin, 1990) and instead embraces the distillation of data from real-world settings (Patton, 2002). Here, particular emphasis is placed on the perspectives, experiences and notions of people interviewed (Hammarberg et al., 2016; Pathak et al., 2013; Taylor et al., 2015) which foregrounds the usual investigation of a smaller number of cases or even one single individual case (Devetak et al., 2010). Common techniques for data acquisition are different types of interviews such as semi-structured interviews (Adams, 2010; Devetak et al., 2010; Hammarberg et al., 2016). Altogether, "qualitative researchers seek (..) illumination, understanding, and extrapolation to similar situations" (Hoepfl, 1997 in Golafshani, 2003, p. 600).

Notwithstanding the value of detailed and in-depth information for a particular setting (Queirós et al., 2017), it nevertheless has to be acknowledged that the insights generated from qualitative research derive from a specific setting and hence come along with significant limits to generalization (O'Leary, 2004). Moreover, since qualitative research builds on perceptions and experiences of individual people that operate in a specific setting, corresponding findings are consequentially not presenting an objective, absolute truth (Borland Jr., 2001). With the researcher being "both the subject and the object of his research" (Queirós et al., 2017, p. 370) as well as "the instrument" (Patton, 2002, p. 14), he is required to steer his research in a way that promotes both certainty and objectivity (Borland Jr., 2001).

Since exploring the barriers and opportunities of the trend towards autonomous shipping is about procuring in-depth knowledge from experts about a particular issue (and thus does not aim to address questions of quantity), qualitative research is a centric pillar of this study. This type of research is deliberately chosen to arrive at an understanding and not a quantification of the phenomenon of autonomous shipping – implying that words and not numbers are brought into focus. The choice of qualitative research as another form for data acquisition is furthermore motivated by the still scarce body of literature on the topic of autonomous shipping. Because therefore the capacity of desk research alone to answer the study's research question is limited, an additional source for information is necessary.

4.3 Case study research

Building on the above described value of qualitative research, this thesis incorporates a case study as a type of qualitative research (Starman, 2013). Following Yin (2003, pp. 13-14), the case study "is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". In this, it is "the study of the particularity and complexity of a single case, coming to understand its activity within important circumstances." (Stake, 1995, p. xi).

Resulting from the circumstance that port environments are said to so far hardly recognize and embrace their role concerning the idea of autonomous shipping (Ship Technology, 2018), corresponding knowledge on the interface *port environments – autonomous shipping* is scarce. Since it can be expected that ports will continue to function as both starting and end points for voyages of autonomous vessels, research into this appears necessary. Hence, for the purpose of gaining in-depth data on this particular interface and thus to help closing this present knowledge gap, a case study of the port of Hamburg (Germany) as an exemplary port environment is conducted. The specific investigation of a case here enables the researcher to arrive at a deeper understanding of how the concept of autonomous shipping unfolds in a clearly defined environment. Combined with investigating the barriers and opportunities for the shipping sector in general, the insights gained from the case study enable a more comprehensive perspective on the trend towards autonomous shipping. Since there is no literature available linking the port of Hamburg to autonomous shipping, semi-structured interviews will be used as the source for gathering data on this apparent knowledge gap (see section 4.5).

However, the choice of conducting case studies needs to be defended, as case studies are often considered strongly limited in their capacity for generalization (Hammersley et al., 2000; Tsang, 2014) and adequate representation (Gerring, 2004), mainly because of the use of small sample sizes (Gerring, 2007; Wikfeldt, 2016). This hence is seen even more critical when conducting only a single case study, which is sometimes considered unscientific (Mariotto et al., 2014). Nevertheless, when approached with a certain lens, it is still possible to even generalize from single cases, as explained by Wikfeldt (2016, p. 4): "The claims made when generalising from cases cannot be considered as "proof" in a statistical sense. Rather, they build theoretical premises which function as tool to make assertions about situations akin to the one studied". There furthermore are different advantages of singles case studies, such as their character of "empirically-rich, context-specific, holistic accounts (..) and their contribution to theory-building" (Willis, 2014). Not only can they "create high-quality theory" but also "richly (..) describe the existence of phenomenon" (Gustafsson, 2017, p. 11), something especially beneficial in the context of the yet still emerging concept of autonomous shipping. Altogether, it certainly needs to be taken into consideration that any research method has its drawbacks and thus requires a researcher to attend to inevitable trade-offs - this also applies to single case study research (Willis, 2014).

4.4 Case selection and introduction: port of Hamburg

There are different reasons for choosing the port of Hamburg as a case. First of all, "We study a case when it itself is of very special interest" (Stake, 1995, p. xi). Since the characteristics of the port of Hamburg align with two out of three conditions that are considered adequate for autonomous shipping by the German government (see introduction), this particular port presents a fitting example for investigation. Moreover, it is Germany's biggest seaport (Hafen Hamburg Marketing, 2019a) and thus certainly presents an important object of research for the German shipping sector. Also, when it comes to case selection, Stake (1995, p. 4) denotes that "Our time and access for fieldwork are almost always limited. If we can, we need to pick cases which are easy to get to and hospitable to our inquiry, perhaps for which a prospective informant can be identified". This supports the choice of the port of Hamburg. On the one hand, this is because the author of this study originates from Hannover (Germany) which enables better accessibility for one-to-one interviews compared to, for example, the port of Rotterdam (the Netherlands). On the other hand, connections to the port of Hamburg and thus knowledge about serviceable interview partners already existed prior to this study. Furthermore, being able to offer conducting interviews in German as their native language increased both the willingness and comfortableness of potential interviewees to contribute to the study.

Ranked 3rd in Europe and 18th in the world in terms of container processing capacity (Hafen Hamburg Marketing e.V., 2019a), the port of Hamburg is Germany's largest universal port and thus comes with "vital importance for supplies to European domestic markets with a consumer population of up to 450 million" (Hafen Hamburg Marketing e.V., 2019b). An illustration of the port's container handling area is provided below (figure 10).

Figure 10: Container terminal port of Hamburg (Handelsblatt, 2018)

Its outstanding economic relevance mirrors in the port's nationwide annual gross value of around 20 billion euros (Hafen Hamburg Marketing e.V., 2019b). For example, the direct and indirect chain of economic value added in the year 2014 amounted to 21.8 billion euros across Germany with 12.6 billion euros allotted to Hamburg alone (~7.1 billion euros generated via port economy, ~4 billion euros via indirect value-added chain and ~1.5 billion euros via port industry). Instancing the same year, all of this rested upon nearly 270.000 directly and indirectly port-related jobs (Hafen Hamburg Marketing e.V., 2016). Port facilities are able to handle all types of vessels and nearly all kinds of goods (Hafen Hamburg Marketing e.V., 2019b). Further parameters are provided below (figure 11).

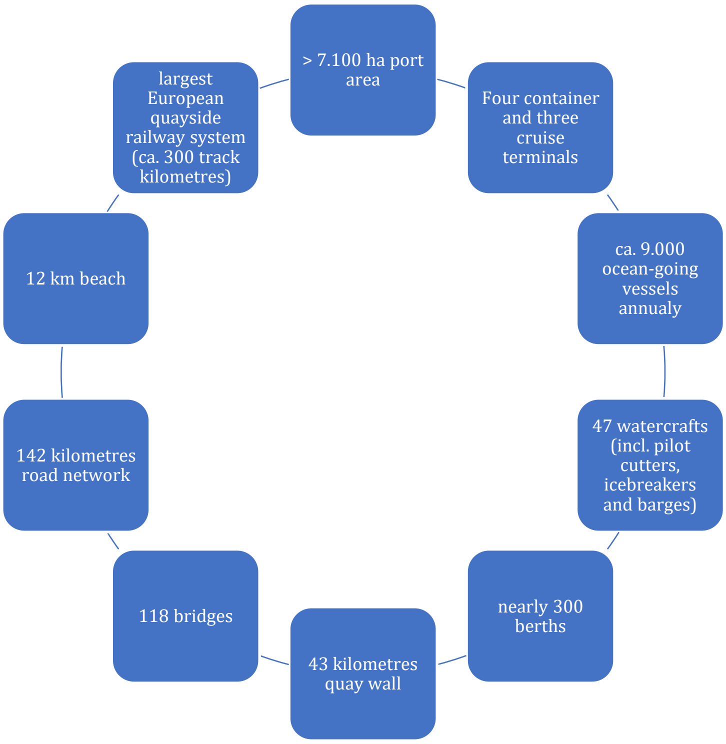

Figure 11: Further parameters port of Hamburg (Author, 2019; based on Hafen Hamburg Marketing e.V., 2016/19a; Hamburg Port Authority AöR, 2017)

When it comes to the port of Hamburg, one institution is of crucial importance: the Hamburg Port Authority AöR (HPA). Since 2005 and one-stop, the public service institution HPA is entrusted with the city-state of Hamburg's port management. More specifically, the HPA is assigned the task of warranting for the "efficient, resource-gentle and sustainable planning and execution of infrastructure measures in the port" (Hamburg Port Authority AöR, 2017, p. 9). Alongside issues about infrastructure, it answers to questions pertaining to the safety and facilitation of shipping traffic, quayside railway facilities, real estate management as well as the port's business environment. Building on its 1.900 employees, the HPA is committed to enable an integrated and future-oriented port of Hamburg (Hafen Hamburg Marketing e.V., 2019c; Hamburg Port Authority AöR, 2017).

4.5 Semi-structured interviews

In qualitative research, as indicated in section 4.2, a common technique for gathering data are semi-structured interviews. This method finds itself between interviews with mainly similar, closed-ended questions with larger sample sizes on the one hand and a detailed inquiry of focus groups with open-ended questions and smaller sample sizes on the other hand (Adams, 2015). Following a middle course, semi-structured interviews hence come along with a number of central steering questions which still give leeway for novel questions and ad hoc answers (ibid.; Whiting, 2008). In other words, "The dialogue can meander around the topics on the agenda" (Adams, 2015, p. 493). Eventually, when conducting a semi-structured interview, a number of aspects should be warranted for by the researcher: attentive listening, dealing with moments of silence, remaining neutral, afford interviewee to navigate, staying focussed, professionalism and exercising emotional control (Adams, 2010). Nonetheless, the researcher "must [still] keep the direction of interview in his own hand, discouraging irrelevant conversation and must make all possible effort to keep the respondent on the track." (Kothari, 2004, p. 99).

Since investigating the barriers and opportunities of the trend towards autonomous shipping in this thesis is an explorative study, semi-structured interviews are considered the most serviceable type of interview for gathering data on the topic. On the one hand, this is because this study is not concerned with a statistical inquiry or quantification of an issue for which larger sample sizes of interviewees would be required (interviews with closed-ended questions). On the other hand, the desk research conducted enables the researcher to already limit the scope of the interview. This is in the sense that the interviewees can be provided with guiding questions around which the interview shall revolve around. In doing so, the interviewees may still deviate from a question and give insights into other aspects considered relevant (which would otherwise be lost when using closed-ended questions). Thereby, the researcher can retain the pre-set direction of the interview and ensure that various interviewees essentially address the same aspects (as opposed to interviews with open-ended questions).
Table 1 below gives information about the organisations consulted for this study to acquire interviewees serviceable for the research topic. Table 2 informs about the expertise of the respective 8 interviewees. For the purpose of full anonymity, the interviewees are not linked to an organisation. The interview guide used for the semi-structured interviews can be found in the appendix.

Table 1: Organisations consulted and their relevance for shipping (Author, 2019)

Organisations consulted and their relevance for shipping
The Hamburg Port Authority (HPA) is the public service institution entrusted with the city-state of Hamburg's port management (see section 4.4)
Germany's biggest shipping company (Handelsblatt, 2017) and the world's fifth largest container carrier in terms of vessel capacity (Statista, 2019)
The Directorate General Shipping of Belgium provides all services for Belgium flagged vessels around the world and accommodates foreign flagged vessels through Belgium ports
The Institute of Maritime Logistics of the Hamburg University of Technology (TUHH) is concerned with contributing to "the planning and implementation of innovative system solutions taking advantage of modern technologies, organisational forms and IT-tools" (MLS, 2018). As one part, the Fraunhofer Center for Maritime Logistics and Services (CML) is concerned with researching sea traffic and nautical solutions, including the concept of autonomous ships (CML, 2019)
The Federal Maritime and Hydrographic Agency of Germany (BSH) is Germany's public institution for maritime tasks, including "the surveying of ships, flag law, the testing and approval of navigation and radio equipment and the issue of certificates for seafarers" (BSH, 2019)

Table 2: Interviewees consulted and their expertise in shipping (Author, 2019)

Interviewees consulted and their expertise in shipping
Navigation and communication systems
Involved in 'BMVI Expertennetzwerk' for assessing chances and risks of new innovative technologies, advises around autonomation in maritime navigation
Maritime jurist; team member of German delegation at IMO for regulatory scoping exercise of *MASS*
Maritime jurist, specifically dealing with maritime security, team member of Belgian delegation at IMO for regulatory scoping exercise of *MASS*
Responsible for safety and facilitation of shipping traffic in port of Hamburg
Researcher for unmanned and autonomous shipping, former mate at German navy, nautical patent for cargo vessels
Responsible for managing all operations of the city of Hamburg's vessels; former captain at sea
High-ranked representative of shipping company

5 Results

This chapter introduces and elaborates on the barriers and opportunities linked to the trend towards autonomous shipping. As indicated in the conceptual model (figure 9), this is done according to the four cornerstones in a bipartide manner: for the shipping sector on the one hand and the port of Hamburg (case study) on the other.

5.1 Barriers and opportunities of autonomous shipping – Shipping sector

This section is concerned with delineating both corresponding barriers and opportunities of autonomous shipping for the general shipping sector. After sketching current notions drawn from literature, the picture is complemented with the insights gained from the semi-structured interviews with shipping experts and researchers.

5.1.1 Technology and infrastructure: Opportunities

In contrast to previous years, it is now widely acknowledged that the technology for autonomous ships is already - or to a large degree - available (Jokioinen, 2016; Kobyliński, 2018). According to Kobyliński (2018), "there are no technical factors that would prevent the introduction of smart ships" (p. 30). Consequentially, this comes as a window of opportunity. This mirrors with the perception of interviewee 5:

„There is actually no true main barrier given with technology because one can achieve the technology and adapt the infrastructure"

The improvement as well as decreasing prices of technical sensors now allow a ship to be equipped with a vast amount of them at comparably low costs. With sensors foreseen to range between 15.000 and 20.000 different types on a vessel, such smart ships would then be empowered to incessantly oversee their crucial functions and assets. These would for example comprise both navigation and safety systems, machinery and automation, freight loaded as well as its surroundings. In the context of unmanned and autonomous vessels (or smart ships) where correct and reliable operation of technology is crucial, these monitoring devices are "essential (…) to discover any irregularity before a failure occurs" (Kobyliński, 2018, p. 29). Finally, today's highly sophisticated data processing and transfer capabilities then provide the necessary link between information from smart vessels and mainland operators to render the remote supervision and control from a shore operation centre possible (Kobyliński, 2018). Respectively, Carey (2017) notes that these ships will act in a rather dynamic manner, implying that vessels are expected to operate fully autonomous on deep-sea travel and with constrained autonomy (more intense supervision and remote control) on the remaining sections of the journey. In the latter case, the shore-based operator would then be the primary operator of the ship and take over the role of both a ship's master and chief engineer. While human involvement will certainly still be required for some time, Carey (2017) points out that "In the longer term it is possible that the ship will become self-learning and operated by artificial intelligence, removing the human element altogether" (p. 3).

5.1.2 Technology and infrastructure: Barriers

While on the one hand it is now widely acknowledged that the technology for autonomous ships exists or is at least to a large degree already available, there are nevertheless different technological challenges and constraints on the other hand. For example, as stated in Sriwijaya (2016), especially infrastructural modifications, changes and hence investments have to be made in order to accommodate these new types of vessels in shipping environments. Respectively, remote control and mooring facilities as well as special ports may currently come as a barrier. Other modifications deemed required pertain to automatic berthing and autonomous cargo handling systems. In this respect, particular emphasis needs to be placed on harmonizing and bringing both the ship's autonomous systems as well as onshore facilities effectively together (Sriwijaya, 2016). Such technological challenges are likewise highlighted by interviewee 6:

"What is extremely difficult and often disregarded, we also have to become active at the ITU, International Telecommunication Union, because if we want to send ships autonomously on the voyage, (..) then enormous amounts of data have to get from land to ship and be exchanged between ships. And these communication channels not only have to be ready, they also have to be safe. (..) it cannot be that any disturbance frequencies or something cross shoots there. All of that, there are still many things that technologically have to be clarified before it can even keep moving. The ideas that are all there, they are good. There are first prototypes but the way there will yet be very very stony"

Although the technology for autonomous vessels is already deemed considerably mature, Rødseth and Burmeister (2012) still point at some constraining areas. For example, once crews are no longer present on board an unmanned vessel, both the previously human-executed reparation or exchange of broken or inoperable system parts become an issue. In other words, there are still important limits to technology, as indicated by interviewee 6:

"Clearly there are camera systems and there are also sound signal reception installations. But, and this is the interesting, based on our experience with the testing of those devices (..) we know the limits of those devices and the human being is in part better than the technology"

The value of crew intervention also comes to the fore when a situation necessitates operational redundancy that was previously enabled through personnel onboard. Therefore, "a major challenge for unmanned ships is to improve the system robustness to a degree where the operator can have a very high confidence that critical subsystems will not fail during the trip." (Rødseth and Burmeister, 2012, p. 12). Apart from that, although the introduction of unmanned and autonomous vessels seems to move forward at a fast pace, shipping will nevertheless not simply discard the traditional manned operation of vessels. Hence, there certainly has to be found a way in which an autonomous navigation system of the new types of ships can safely and effectively function side by side with ships under human control. In this, obstacles for autonomous navigation comprise, for example, current rules of road, practices for good seamanship as well as the issue of SAR operations (Rødseth and Burmeister, 2012).

5.1.3 Safety, security and insurance: Opportunities

Among the most important drivers for the pursuit of autonomous ships is the possibility to enhance maritime and navigational safety (Burmeister et al., 2014a/b; Kari et al., 2018; Kretschmann et al., 2017; Wróbel et al., 2017). Especially the potential to eliminate the issue of human error – the biggest share of maritime accidents is caused by human fault (Apostol-Mates & Barbu, 2016; Burmeister et al., 2014b; Rolls-Royce plc, 2016; U.S. Coast guard Research & Development Center, 2002) – comes as a strong stimulus respectively.

In this context, Hoem et al. (2018) specifically highlight human-related sources of danger that could be averted by automation. For example, one aspect mentioned is the issue of fatigue of maritime personnel. Since "Humans are day animals" (Hoem et al., 2018, p. 422), even with technological support as well as conformity with shift working at night, their capabilities for effective navigation in the dark are severely limited. This notion mirrors in the circumstance that "A larger degree of accidents happen during night." (ibid.; cf. Wagstaff & Sigstad Lie, 2011). Next to fatigue of mariners, alcohol as well as drug abuse are also brought forward as crucial issues linked to negative effects on shipping safety (Komianos, 2018). Apart from fatigue, Hoem et al. also point at the issue of the human attention span. Respectively, there is consensus that humans are hardly capable of concentrating effectively on a task for more than 10 to 20 minutes (although subject to a variety of influencing factors). Once more, this consequentially leads to the assumption that technology could eliminate this problem by simply not being susceptible to limited attention capabilities. Furthermore, their research also refers to aspects of information loading in regard to the human brain. Here, both too much information (issue of limits to human working memory) and too little information (issue of boredom-caused calamities) may lead to dangerous outcomes. Eventually, referring to the so-called 'normality bias', Hoem et al. (2018) also denote that humans tend to embrace denial when encountering catastrophic or disastrous situations. Thereby, both the chance and results of such potentially severe situations would be underestimated (cf. Omer & Alon, 1994). Interviewee 8 spins these thoughts further as he points out that not only humans as sources of danger could be averted but humans also prevented from dangerous situations:

„There simply are operational procedures or decision procedures that after all a machine can do more securely than a human being or can even keep a human being out of a dangerous situation"

Alongside eliminating negative aspects linked to human shortcomings, there are also other benefits of operating a ship without human personnel on board. For example, Wróbel et al. (2017) hint at the fact that previous shipping hazards caused by fire, flooding as well as loss of stability would no longer be empowered to severely endanger human beings "for nobody was on board in a first place" (p. 25). Furthermore, a different design of an unmanned or autonomous vessel would also provide the opportunity to better guard a ship against pirates trying to enter it (Carey, 2017). This could be done, for example, through constructing it in a way that there are no longer "any easily accessible openings" (Kobyliński, 2018, p. 33). These less attractive circumstances for piracy are also explained by interviewee 4:

"[It] will be less interesting for pirates, for example, to attack an autonomous ship because it will be sealed more and pirates are still going after the crew and to the belongings of the crew and things like that, if that's not on board it will be less interesting for them to attack an autonomous ship. (…) Another thing is that they will be built in a way that it is much more difficult to get on board a ship, for example, nowadays you have a flat deck, because people have to walk there, if you don't have people on board then you can make your ship as hydrodynamical as possible without a flat deck so it would be difficult to get on board"

Then, in case pirates would still somehow manage to enter the ship, an automatically shut down and thus non-manoeuvrable unmanned vessel finally makes taking it to a desired destination nearly impossible. Besides, holding shipping crews to ransom is an important incentive for pirates. Without a crew, this incentive is gone (Bertram, 2013). Altogether, physical attacks may hence become both even less viable and thus unattractive for pirates (Kobyliński, 2018).

5.1.4 Safety, security and insurance: Barriers

Although a pivotal driver for the pursuit of autonomous ships is the chance to improve maritime and navigational safety, there are nonetheless a number of obstacles and impeding factors. As interviewee 8 indicates, one should not simply expect technology to come as a remedy for failure:

"Although one always says all faults are somehow to be traced back to human error, someday we will say all faults are to be traced back to technical failure. So I think that (..) over all the autonomation does not compulsorily have to make this better"

In this regard, Hoem et al. (2018) also point to drawbacks and limits of automation. More specifically, they highlight that a programmed technology is only capable of dealing with simple or complicated situations. Crucial is here that shipping can be considered complex as it involves a plethora of different, unforeseeable factors and hence comes with an infinite solution space. Hence, because the dissolving powers of automation require a finite solution space, above circumstances make it impossible to program autonomous systems in a way that they can handle various arising situations. In other words, "The dynamic maritime environment with sea and current, weather, topography, manned and autonomous ships is such a complex environment and will for a very long time need a human to step in and resolve problems out of the range of automation" (Hoem et al., 2018, p. 423). This perspective conforms to aspects brought forward by Kobyliński (2018). He likewise points to maritime situations that are hardly foreseeable. To illustrate his standpoint, he draws on the dangerous phenomenon of freak waves which may peak at 40 metres or above. Although these waves are very seldom appearing, their unpredictable occurrence would severely impede the design of a serviceable automatic avoidance system being able to forecast and thus deal with them. Van Hooydonk (2014) likewise identifies drawbacks of technology. In particular, he considers controllers working remotely from a shore-based operation centre and thus not on board a ship significantly constrained in their intuition for adequately assessing and deciding about situations at sea. According to Wrobel (2017), this already is a highly challenging task for both masters and crews with long-standing experience in the field. Thus, a shore-based operator would certainly assume an extremely important responsibility. In addition to that, remote control presupposes that all technical components enabling its operation without personnel on board are reliably functioning. This would consequentially entail new kinds of risks, once more illustrating the pressure on technology (Van Hooydonk, 2014). In accordance with above considerations, Wrobel (2017) denotes that that "the introduction of unmanned vessels will be very challenging from the safety point of view" (p. 25). It inevitably also needs to be ensured that both manned and unmanned or autonomous vessels can safely operate side by side, as pointed out by interviewee 5:

"It needs to be safeguarded that both can function in parallel. I think that will be similar to driving cars, that the autonomous units are the rare and will at some point become more and more and then this will eventually switch. But firstly, this will exist jointly for many years"

Another centric issue of unmanned and autonomous ships are cyber threats which can be expected to increase when a vessel is eventually solely or at least to a large degree operated by a technical instead of a human brain (Kobyliński, 2018; Komianos, 2018). For example, Kobyliński (2018) here detects the risks that pirates may hack a ship and thereby be electronically afforded full control of a vessel. As a result, a situation could arise in which pirates remotely sail a ship to a certain destination where they would be able to gather potentially highly valuable freight from the vessel. Next to Kobyliński's example, it may also be that pirates will use their navigating power to blackmail and threaten society with directing a vessel deliberately into ports or other vital locations. Concerning these potential scenario's, as Carey (2017) highlights, sealing off an autonomous ship against physical attack would then appear a lot less helpful: "If the system can be over-ridden and the ship accommodate people then this benefit is obviated" (p. 25).

Furthermore, there are also issues concerning the insurance of unmanned and autonomous vessels. Due to the significant alterations in terms of how such ships are operated and controlled, marine insurance likewise is required to be modified accordingly to accommodate related novel characteristics. Most relevant in this is that a great share of marine insurance policies understand that both a master and crew are on board a vessel. Besides, additional risks linked to cyber security, technical events of fault as well as communication likewise require modified ways of insurance handling (Vogtwiig, 2017). An executive officer of P&I Clubs which provide around 90% of marine insurances to worldwide fleets, foregrounds the issue even more drastic: "Unmanned ships are illegal under international conventions, which set minimum crew sizes. If drones don't comply with such rules, they'd be considered unseaworthy and ineligible for insurance" (in Komianos, 2018, p. 345). Notwithstanding possibly required modifications, Komianos (2018) still hints at the fact that insurance policies for e.g. cyber threats already exist irrespective of the advent of autonomous ships. Hence, he does not perceive distinct hurdles for their integration in current marine cyber security insurance.

5.1.5 Societal, legal and regulatory acceptance: Opportunities

There are also a number of societal benefits in the context of autonomous shipping. For example, Rødseth and Burmeister (2012) point out that increased automation and thus the move towards unmanned and autonomous ships "would free officers from routine tasks and let them focus on more cognitively demanding and challenging tasks in a shore side operations center" (p. 11). Respectively, this picks up on the safety pillar through the opportunity of counteracting the potentially disastrous consequences following a seafarer's fatigue as likewise described in section 5.1.3. Furthermore, the shore side operation centre renders additional benefits possible. On the one hand, the prospect of becoming a remote vessel controller may come as a novel facet reviving the rather traditional shipping sector and thus stimulating the attractiveness for (especially younger) professionals to pursue a career respectively. On the other hand, a shore side operation centre on land would allow jobs related to both marine navigation and engineering to become considerably more friendly with regard to family and social life as corresponding personnel would no longer be required to sail on a vessel for several weeks or even months (Rødseth and Burmeister (2012). In essence, breathing new life into the shipping sector and becoming more appealing for prospective employees is certainly important to help combat the issue of the contemporary shortage of seafarers (cf. Karlis, 2018). Comparable social plus factors are likewise pointed out by interviewee 5:

"Socially it would though, from my point of view, simplify the field of work a bit, because then one is not anywhere in the world in the Pacific, but actually (..) in the sea zone monitoring centre and has shift-work there and is at home every evening. (…) More job relocation ashore would (..) make the profession more attractive, to (..) occupy oneself with ships"

When it comes to legal and regulatory acceptance, there are also a number of enabling aspects of autonomously operating vessels. For example, as Bruhn (2017) elucidates, adjacent test areas for autonomous ships of different countries could be connected in a way that transnational voyages would become possible. In principal, ambient test fields would only have to be upscaled and predicated on a shared regulatory framework for navigation of said ships. Respectively, particularly Scandinavia here presents fruitful soil for harnessing this opportunity. Eventually, with both more vessel maturity as well as endorsement and support of flag and coastal states, Bruhn (2017) considers such a joint operation potentially empowered to provide initiation for normal operation.

Moreover, since autonomous ships are sailing with significantly reduced or no personnel (depending on the autonomy levels), both the resulting human and general waste arisings would likewise be significantly lower or even absent. In a similar vein, "the intentional pollution by oil, chemicals, and other harmful substances, which may occur with the complicity of some or all the members of a crew, is not possible" (Komianos, 2018, p. 342). These circumstances would harmonize well with *MARPOL*, the International Convention for the Prevention of Pollution from Ships from 1973 (see section 2.1). Nevertheless, although crews would no longer be an adversely contributing factor, Komianos (2018) denotes that inadvertently caused pollution via accidents or unforeseen events such as severe weather conditions or explosions would still remain an issue to be solved on autonomously operating vessels.

In this respect, the DMA (2017) hints at other possibilities of applying existing regulations to autonomous vessels: "On the condition that autonomous ships are designed so that it would be physically possible to inspect them, neither *SOLAS*, *MARPOL*, *STCW* or the Paris MoU[6] nor directive 16/2009[7] contains regulatory barriers to autonomous ships." (p. 43). This stands in accordance with the point of view from interviewee 7:

"Ad hoc, I actually do not see anything that would (..) explicitly prohibit the autonomous shipping, because there is no rule, in no treaty, that says an (..) autonomous ship must not sail – then I could definitely say 'Ok, that now will not work'. Where one has to look is when the human being is addressed in the treaties, he is assigned tasks that he has to assume. Then I would have to find ways how I can change that, or rather, what is also his role, can he also possibly do that from ashore"

Furthermore, concerning remotely controlled ships, the DMA sees the possibility to circumvent certain amendments to *COLREG* in case that a human operator controlling a ship from a distance without being physically onboard, for example from a shore side operation centre, would be considered sufficient in the eyes of the international shipping community. Respectively, the fundament potentially allowing for this is that the remote operation of the ship by a human would still be conducted in real time with him or her in equal measure taking navigation decisions. Eventually, this may live up to COLREG's requirement of human control as well as simultaneous decision competence (DMA, 2017).
Concerning the future implementation of autonomous ships, Karlis (2018) moreover foregrounds certain options which would not stand against current regulation. Next to explicating that an unmanned ship would enable "overcoming the impediments from the regulatory regime" (p. 9), he also points out that thereby the lack of mariners could be attended to. Apart from that, Karlis (2018) furthermore highlights that the characteristics of liner shipping would present a good starting point for autonomous ships. This is in the sense that its mostly preassigned operation schedules would provide for improved oversight of the individual regulatory regimes at ports of call. On this note, it would also help to attenuate risks linked to vessel operation with both long duration and great distance from mainland.
Altogether, Van Hooydonk (2014) fittingly sums up above notions: "Although some legal doctrine stresses the essential importance of the typically maritime on-board labour community (in addition to the technically essential characteristics of a ship), unmanned ships would be covered by the great majority of the existing regulatory definitions and it would appear that the existing conventions and national laws would in principle continue to be functional in respect of these craft." (p. 409).

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[6] Paris Memorandum of Understanding; administrative agreement of 27 maritime authorities "to eliminate the operation of sub-standard ships through a harmonized system of port State control" (Paris MoU, 2019a/b)

[7] DIRECTIVE 2009/16/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on port State control (Official Journal of the European Union, 2009)

5.1.6 Societal, legal and regulatory acceptance: Barriers

When it comes to the idea of autonomous shipping, a prominent barrier to its realization is considered to lie in the current legal and regulatory framework of the shipping sector. So far, with the sector's traditional focus on manned shipping, the concept of an unmanned and autonomously operating vessel has not yet been recognized in legal and regulatory provisions (Bruhn, 2017; Komianos, 2018; Rødseth and Burmeister, 2012; Rolls-Royce plc, 2016; Sriwijaya, 2016). Hence, in order to pave the way for these ships, questions concerning both the applicability of existing provisions (e.g. IMO conventions) as well as the need of modifications and amendments enter the agenda. However, the scope of potential changes should be reduced to a modicum, as explained by interviewee 4:

"We want to change as little as possible, so if we can fit in autonomous ships within the existing legislation, then its fine, that's the best and those things that are not suitable within existing legislation, we will create new legislation"

According to different scholars, the prevailing obstacle to the legal and regulatory viability of unmanned and autonomous vessels is the eventual absence of human personnel and thus a master and crew onboard these ships. This is due to the fact that a great share of the plethora of corresponding maritime provisions presume and hence are predicated on human presence on vessels. As a result, the introduction of unmanned and autonomous ships is confronted with the problem that the existing legal and regulatory framework deals with essentially different types of ships. Therefore, there is considerable consensus that significant amendments to the current framework are required (Bruhn, 2017; Carey, 2017; DMA, 2017; Kobyliński, 2018; Komianos, 2018; Rødseth and Burmeister, 2012; Sriwijaya, 2016).

One distinct problem related to the potential absence of a master is that "full responsibility for the ship at sea lies with the master who is onboard and is "the first after God"" (Kobyliński, 2018, p. 32). As noted by the DMA (2017), this is particularly problematic as the master functions as the primary representative for both shipowners and the vessel itself. Hence, he likewise comes as the ship's centric contact person for maritime authorities. Respectively, the master may be provided with information concerning, for example, course changes, stopping, detention, access to the vessel and may need to produce different maritime certificates and documents when asked to do so. This affords him a crucial communicative responsibility. In this, however, the DMA sees the option to delegate the tasks and functions previously performed by the master to the shore-based controller or remote operator of the vessel. Hence, the latter would then be the person approached by the maritime authorities. As Kobyliński (2018) points out, this would "put full responsibility for the ship at sea in the hands of this station" (p. 32), with the station being the location where remote operators would work from. However, the idea of remote controllers yet would have to prove both its adequacy and acceptability in the face of the conservative shipping community.

Besides the issues outlined above, the absence of a master and crew poses a number of challenges with respect to different aspects of the shipping conventions. For example, the International Convention for the Safety of Life at Sea (*SOLAS*) requires that a vessel "shall be sufficiently and efficiently manned" and "shall be provided with an appropriate minimum safe manning document or equivalent" (in Komianos, 2018, p. 341). In principle, these demands would clash with an unmanned or autonomous vessel. However, as already indicated beforehand, a shore-based operation centre has the potential to satisfy different requirements such as the one of 'sufficient' manning. Likewise, more sophisticated (automation) technology may also live up to 'efficiency' requirements which would previously have been considered impossible to warrant for without human personnel onboard ships (Komianos, 2018).

Furthermore, since the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (*STCW*) specifically presumes and thus deals with standards pertaining to manned operation of vessels, its application to unmanned and autonomous ships so far appears constrained. Therefore, significant modifications concerning STCW or even a new convention may be required to accommodate the new situation that comes with different demands on competences and remote operation (Komianos, 2018).

Next to this, the International Convention on Maritime Search and Rescue (*SAR*) is also grounded on manned ships and hence dictates how human personnel onboard a vessel has to proceed respectively. As Komianos (2018) explains, in a situation where fast and effective assistance to people and ships in danger is required, "For the Autonomous ship, such actions range from being very difficult to being impossible to perform" (p. 343). With aspects about safety and rescue at stake, dealing with this can certainly be expected to come as a considerable challenge that needs to be acceptably met (cf. Kobyliński, 2018).

Apart from that, the Convention on the International Regulations for Preventing Collisions at Sea (*COLREG*s) make high demands on technology as various tasks normally executed by humans would now have to be warranted for without involvement of personnel onboard. For instance, this would pertain to the requirement of "proper look-out by sight and hearing" which foregrounds the relevance of human senses. Likewise, potentially losing the value of deliberative judgement and thus appropriate action based on personal experience would have to be legitimized and properly substituted by technology. However, the list of challenges with regard to COLREGs goes beyond these examples and will require in-depth investigation to align it with the concept of unmanned and autonomous ships (Komianos, 2018).

To name a few, there nevertheless remain a number of other conventions, rules and provisions such as The International Ship and Port Facility (ISPS) Code, *MARPOL*, the Paris MoU and The Hague-Visby Rules that will also need reconsideration with the advent of unmanned and autonomous ships (DMA, 2017; Kobyliński, 2018). Further issues demanding inquiry comprise physical vessel maintenance through experienced personnel, quality assurance, updated and modified standards for technology and operation (Komianos, 2018), flagging of ships and their conception as flag state territory, aspects concerning liability and insurance (Rødseth and Burmeister, 2012; Van Hooydonk, 2014), compulsory pilotage areas in ports and environmentally sensible regions as well as seaworthiness (Carey, 2017).

However, alongside the prevailing legal and regulatory obstacles to the introduction of autonomous ships, there are also (potentially adverse) effects on the maritime working environment that need to be taken into account. Respectively, a protruding question is whether the increasing digitalization as well as automation of ships and thus the idea of autonomous shipping will cause seafarers and other personnel working the industry to lose their jobs (HSBA, 2018). Interviewee 4 here envisions a future path:

"There will still be manned ships where you can do training, where you can have your expertise at sea, to have a better understanding of how a ship moves and what can be the conditions at sea, so this will be part of the training as well. It will be a completely different training for seafarers but we will still need seafarers, it's not that we don't need it, especially high-trained seafarers"

Commissioned by the International Chamber of Shipping (ICS), the Hamburg School Of Business Administration (HSBA) has put these aspects on the touchstone in its 2018 paper '*Seafarers and digital disruption - The effect of autonomous ships on the work at sea, the role of seafarers and the shipping industry*'. When it comes to the endeavour of making autonomous shipping a reality, seafarers are posing a considerable challenge. Recognizing the attractive benefits of more technology for industrial players, seafarers are consequentially worried about their future. For example, in a joint study of the International Transport Federation (ITF) and the International Federation of Shipmasters' Associations (IFSMA), "more than 80% of seafarers voiced their anxiety about possible job losses with the advent of automation" (HSBA, 2018; cf. Komianos, 2018; Sriwijaya, 2016; Van Hooydonk, 2014; etc.). In this, without a fair involvement and adequate communication about what will change with the introduction of autonomous ships, seafarers especially see negative effects for their livelihood and safety (HSBA, 2018). Moreover, seafarers also perceive issues of mental health when crew sizes are significantly reduced on board a ship. With technology increasingly undertaking tasks previously executed by mariners, the diminished personnel will have less opportunities of interaction with fellow colleagues. Eventually, this may lead to the feeling of loneliness as well as depression (Adamson et al., 2018; HSBA, 2018). In this connection, the relevance of gaining support from the maritime community - with the seafarers being a centric stakeholder – can be expected to come as a decisive factor (HSBA, 2018; Sriwijaya, 2016). Having seafarers and their corresponding unions opposing and thus stalling a possible introduction of autonomous vessels will hardly be in the interest of the various stakeholders involved. Sriwijaya (2016) also points at the issue of acceptance. For example, autonomously operating vessels may procure new possibilities for and types of shipping accidents which may face considerable resistance from the societal and public domain. In addition to the fear of seafarers losing their jobs, Sriwijaya additionally points out that both port labour as well as working conditions of other maritime personnel will likewise encounter changes. Moreover, in accordance with previous aspects, Kobyliński (2018) foregrounds that the issue of "emotional barriers against the introduction of autonomous ships should not be dismissed lightly" (p. 32). On the one hand, the shipping sector's tendency to conservatism as well as the pride of seafarers may pose one challenge. On the other hand, both substituting ship masters with an external controller operating from a distance in a shore control centre as well as allowing strongly reduced shipping crews to only assume unattractive shifts may additionally devalue the seafaring profession (ibid.). All of these aspects may eventually work against an emotionally positive standpoint regarding an introduction of autonomous ships. Komianos (2018) also picks up the stick of the importance of warranting for 'social acceptability'. Alongside potential job losses, "social discomfort to sea nations" (p. 340) may also come as a crucial issue. This can certainly be expected to hamper the prosperity and well-being of a state when it largely builds its economy around revenue derived from the shipping sector. In this regard, Bertram (2013) additionally highlights the notion of 'solidarity with seafarers'. Also recognizing issues about devaluation of the seafaring profession as well as potential job losses and possibly poorer working conditions, he particularly foregrounds the process: "It depends on how we do it. Poorly designed automation is detrimental to our goals and values." (2013, p. 42). Particular emphasis on the process is likewise placed on by interviewee 8:

"Not only develop technology further but also enable the community to evaluate that technology and to be able to accept [it]"

Facets of the social dimension are likewise shed light on in Van Hooydonk (2014). Revisiting the issue of job uncertainty, Van Hooydonk furthermore questions how the future of the shipping sector's working environment would then unfold. This pertains to both the future of present as well as novel occupations for maritime personnel. Respectively, Van Hooydonk points at the difficulties of finding suitable forms of employment, training and qualifications that would be able to handle autonomous shipping. In this regard, interviewee 5 primarily indicates a shift in occupational tasks:

"Ships have more technology, that needs to be handled by the those who are still onboard. The second aspect is that less people go to sea but for the supervision of ships in the land control stations there of course are people needed who are able to monitor these ships that are sailing and to appraise the situation on the spot (..) for example when an autonomous ship requests that human decision is required because a situation cannot be resolved or a damage has occurred"

Apart from that, valid questions about the actual operation of unmanned or autonomous vessels also arise in the context of passenger transport (cf. Komianos, 2018). Referring to 'psychological thresholds' in connection to the character of such ships, Van Hooydonk brings forward the issue whether passengers will even be comfortable in and enjoy being carried by ships operated without human personnel on board. Moreover, alluding to safety aspects, he also questions whether different societal groups (e.g. politicians and environmentalists) will eventually oppose the operation of unmanned vessels carrying oil or chemicals around coasts and to ports. While answers to these questions and potential barriers may still have to be found, Van Hooydonk nonetheless states that "What, however, is certain is that a huge portion of romance, tradition and culture will be sacrificed for the sake of the anticipated gain in efficiency" (2014, p. 406).

5.1.7 Economical attractiveness and feasibility: Opportunities

When it comes to the pursuit of autonomous shipping, there are several economic benefits. Most prominently appears to be the opportunity to significantly reduce operational costs by either extensively lowering or even entirely removing manning fees from the cost equation (Carey, 2017; Kobyliński, 2018; Komianos, 2018; Rødseth and Burmeister, 2012). Following Rødseth and Burmeister (2012), from the total operational costs of bulkers allotted 31 – 36% alone to the payment of corresponding onboard crews in the year 2011. Since "Labour costs onboard are one of the main operational cost categories" (ibid., p. 8), being able to save or invest these enormous financial means otherwise would certainly come as a strong incentive for ship owners. Moreover, in case that vessels are then remotely or autonomously operated, previously necessary infrastructure on ships for accommodating and serving personnel becomes redundant and hence can likewise be removed. This entails a number of attractive benefits. On the one hand, construction expenditures of modified ship designs could be significantly lowered. On the other hand, the attained space-savings would both allow for increased cargo-carrying capacities (Carey, 2017; Komianos, 2018) and potential fuel savings because the now absent superstructure leads to reduced air resistance of vessels. Concerning the latter aspect, Levander (2016) highlights that thereby a prospective 12 to 15% reduction in fuel costs could potentially be obtained for a 40.000 dwt bulk carrier (Kobyliński, 2018). Such advantages are also highlighted by interviewee 5:

"There are also advantages in the area of shipbuilding. If one had an unmanned ship, one certainly could build it lighter when the hotel system, all the accommodations facilities, hot water generation, heating and so forth, everything that man needs, is no longer necessary (..) that one would have this on an equally sized ship for cargo or building the ship smaller. That would also be an economic benefit and it would of course, in case that it would sail as artificial intelligence, potentially move more ecologically worthwhile"

This would also align with the overall urge for more sustainability and thus reduction of greenhouse gas emissions (Kretschmann et al., 2017). Altogether, Rødseth and Burmeister (2012) consequentially note that "autonomous and unmanned vessels would provide a possibility to foster ecological sustainability and overcome the shortage of labor that might otherwise arise. Thereby, an unmanned vessel could diminish this effect as it focuses on the reduction of the demand side of the maritime labor market." (p. 10).
Furthermore, Kobyliński (2018) points out that the significantly greater demand for sensors in unmanned and autonomous ships should not pose an unsurmountable challenge as their price is nowadays much lower compared to a decade ago. Thus, "the possibility to increase the number of sensors onboard is almost unlimited" (p. 29).
On a different note, Bruhn (2017) moreover detects specific areas of application. In particular, picking up on the issue of dirty, dull and dangerous missions (see section 2.4.1), unmanned and autonomous vessels could still execute tasks under conditions that would be unreasonable for crews. He likewise sees the possibility for employing such ships for short-distance ferry transport both at sea and within cities which are currently hardly profitable. Additionally, interviewee 5 considers coastal areas particularly suitable for even a high degree of autonomous shipping operations:

"I think that for coastal cases of operation, for small vehicles, there actually can be fully autonomous vessels"

In a similar vein, Bruhn (2017) especially hints at economic potentials linked to inland waterway transportation. Here, a number of services that would in the conventional way presently be economically unattractive could become viable. Respective exemplars would here comprise smaller-scale normal operation of ships as well as unmanned barges in bigger ports carrying cargo between terminals. Finally, Bruhn considers the character of inland waterway transportation especially eligible for unmanned and autonomous shipping. As opposed to deep-sea navigation, it deals with national legislation and thus comes with significantly less legal and regulatory obstacles as well as economic risks.

5.1.8 Economical attractiveness and feasibility: Barriers

Although the idea of autonomous shipping comes along with different potential economic benefits and incentives for maritime-engaged businesses, pursuing the introduction of corresponding vessels nonetheless also has certain constraints. With regard to autonomous shipping, Sriwijaya (2016) highlights the decisive importance of endorsement by industrial players: "As soon as some major shipping companies or consortium of maritime companies make a commitment to the development of autonomous ships, all other barriers will be overcome, and autonomous ships may become reality. So, missing commitments from the shipping industry itself are the key barrier to the implementation of autonomous ships" (p. 26f.). In the same vein, certain maritime-engaged countries and authorities may furthermore simply oppose the idea of ships sailing unmanned or autonomously on the world's oceans. A core issue could here be that autonomous shipping can certainly be expected to significantly alter and thus affect the maritime industry - with its effects being hardly foreseeable. Hence, because facilitating the introduction of such vessels may also potentially entail unwanted results for businesses and organisations, maritime players may rather tend to stall or impede this trend – or even substantive change at all (Sriwijaya, 2016).

Moreover, as already indicated in 5.1.2, autonomous vessels will likewise necessitate the adaptation and construction of relevant infrastructure to accommodate these ships. As Sriwijaya (2016) points out, next to general infrastructure, this could for example also comprise shore control centres and novel technical systems. Similarly, since technology will be afforded significantly more control of a ship, technical redundancy as well as sensor systems have to be improved in way that safety can be warranted for. All of these novel requirements would consequentially impose additional costs on the design and operation of autonomous ships. Although these new vessels may come with better fuel efficiency as well as reduced or no manning that would both allow for cost reduction in the end, these benefits may eventually not be sufficient incentives for shipping companies to foster autonomous shipping. With this in mind, the advent of autonomous ships needs to be substantially more efficient and profitable as opposed to contemporary manned operation of ships: "This is essentially the main factor; if autonomous ships cannot make money, nobody will build them. Thus, a good business model is absolutely essential in encouraging entrepreneurs to take a risk and invest in such an untapped industry" (p. 28). Karlis (2018) recognizes similar issues. Taking the circumstance into account that the shipping regime is tailored to and built on manned shipping, a serviceable and enabling framework for unmanned and autonomous vessels is still lacking. Hence, for the time being, "the risk from an investment in the new concept design is considerably higher than an investment in a manned ship. The risk element is enough to deter shipowners from investing in the new technology" (Karlis, 2018, p. 8). A potential lack of attractiveness for investments into autonomous vessels and thus current limits to economic feasibility are also highlighted by interviewee 4:

"I think it will be, at the moment it's not. The costs to have an autonomous ship sailing around, possibly for the level 6[8] one, are enormous, it's six times the cost in comparison with a manned ship, so at the moment it's not economically feasible for big companies to go full for autonomous ships"

A rather sceptical position to economic viability is also taken up by interviewee 3:

"Well, the economic advantages, if one would refer to possibly saving personnel expenditures, then this is not a significant factor for our business model. Personnel costs in a container shipping line, or at least for us, lie at approximately 5.5%. That is an evanescent part in light of all the other costs that we have, such as fuel, harbour and canal dues, empty container refeed or such, that is a minor part"

Connecting to the marginal attractiveness of reduced manning costs, interviewee 3 furthermore points out that crews onboard a vessel are vital due to numerous different reasons. Especially upkeep and corrective maintenance of the ship operation are crucial along its voyage. As he says, related works would comprise regular inspections, lubricating, cleansing the machine as well as rust removal of the vessel – all of which is presently done by a team of engineers onboard. If the latter were no longer onboard the ship, servicing and maintenance works would have to be done in highly expensive shipyards. This would also imply a costly business interruption since the ship cannot sail and thus generate money for this time. Eventually, interviewee 3 also pinpoints the crucial economic role as maritime instructor. In order to ensure the continuity of Germany as a trading and shipping nation as well as German-flagged vessels it hence assumes a considerable responsibility in not allowing maritime professions in Germany to become extinct. Altogether, interviewee 3 highlights that *"It is not entirely unimaginable, but (..) [we] will not be the first shipping line doing that"*.

Apart from this, another issue mirrors in the cross-trading of different European countries with third countries which presupposes that regulations and conventions are internationally applicable in unison as well as that trade is not hindered by restricted markets. In case that there is no such framework for unmanned and autonomous ships, these vessels are severely limited in there use for trade and can thus be expected to be unattractive for shipowners. Altogether, the facilitation and endorsement of those ships once more hinges on the issue of economic efficiency (Karlis, 2018). In accordance with the issue of uncertainty, Kobyliński (2018) also points to the question of economic viability. Due to the fact that there so far are no unmanned or autonomous ships in operation and thus no real exemplars, shipping companies are still lacking the fundament to build a substantiated investment decision on. Thus, knowledge concerning impacts on, for

[8] Referring to levels of autonomy based on Lloyd's Register

example, construction and insurance costs as well as salaries still has to be procured. However, as Bruhn (2017) elucidates, once there are no more impediments in terms of regulation and classification with regard to autonomously operating vessels, fertile soil for both investors and insurers will finally be given.

5.2 Barriers and opportunities of autonomous shipping – Port of Hamburg

This section is concerned with exploring the barriers and opportunities of autonomous shipping in the context of the port of Hamburg (Germany). The following considerations are drawn from the semi-structured interviews conducted with experts working with or in the port of Hamburg. Due to either a lack of data for barriers or opportunities within different cornerstones or because a clear demarcation of the latter two is difficult, each cornerstone is here addressed in a combined manner.

5.2.1 Technology and infrastructure: Opportunities and barriers

Providing that the infrastructure required as well as a functioning technology and clear markings for autonomous vessels are given, interviewee 2 sees some opportunities for autonomously operating ships in the port of Hamburg. For instance, a loaded barge currently propelled by a haulier or tugboat, could also be moved autonomously from location A to location B, such as from the *Moldauhafen* to the *Finkenwerder* offshore terminal. In case that the barge would be capable of docking autonomously, this would also give the opportunity to save labour since presently a steerman and two mechanics are required for enabling the operation of the vessel. However, all of this certainly necessitates that respective ships are able to deal with heavy traffic and can sail under various weather conditions such as tidal range, storm surges, cross sea, fog and ice drift. Another prerequisite would be that technology is completely sophisticated and reliant, implying that there must not be any dead zones that could impair (e.g. in sluice or under a bridge) the automation system. Likewise, the system would also need to address and satisfy the demand for sufficient technical redundancy as well as the option for manual override and intervention. All of this would require extensive testing and stepwise upscaling from pilot projects. Respectively, he considers providing the infrastructural and technological framework (e.g. radio circuits, laser beams and reflection marks) as well as legal fundament as the longest part of the process. In total, while interviewee 2 potentially sees the introduction of autonomous shipping for the carriage of freight in the port of Hamburg within the next ten to fifteen years, he absolutely expects manned operation to stay in place for passenger transportation.

According to interviewee 1, the greatest obstacle in terms of technology lies within the great variety of vessel types operating in the port of Hamburg. In this he points out that, although a technology for autonomous shipping may eventually be available, it would be very difficult or even impossible to implement respective systems on all watercrafts sailing in the port of Hamburg. Such ships would comprise both seagoing and inland water vessels, pleasure boats, traditional ships and harbour vehicles. Furthermore, not only the port's heavy and multifaceted traffic comes as a difficulty, but also the requirements for various kinds of manoeuvres. For example, vessels have to berth, veer, couple and decouple tugboats as well as react to all occurring external influences. He thus rather does not see operational shipping processes improved via high autonomy and hence emphasises an enduring relevance of human control onboard ships. Nevertheless, picking up on different levels of autonomy (see section 2.4.2), interviewee 1 indicates that some autonomous operations might still be possible in the time to come. While this would not apply to the entire port environment, some sections such as shallow waters with little traffic movements could be receptive for autonomously operating vessels - provided that both human supervision and intervention are incorporated. However, other areas with heavy traffic movements such as the port's mainstream are not considered an adequate environment for ships sailing with a significant degree of autonomy. Next to this, although he is not sufficiently aware of the actual requirements that need to be fulfilled for autonomous ship operations, interviewee 1 clearly denotes that he so far does not consider the infrastructure for accommodating autonomous shipping existent in the port of Hamburg. Nonetheless, when looking ahead, the spatially clear and bounded environment of the port would provide a serviceable foundation for introducing the infrastructure required in the future. Still, he suggests that respective efforts would begin at smaller ports and then eventually scale up to bigger ports such as the one in Hamburg. Altogether, interviewee 1 certainly does not expect to see autonomous shipping being implemented in the port of Hamburg within his remaining ten years of further period of service. However, in case that technological redundancy is sufficiently provided for (e.g. buffering engine breakdown), he can see autonomous shipping finding its application within overseas traffic.

5.2.2 Safety, security and insurance: Opportunities and barriers

The interviewees primarily foreground and elaborate on perceived challenges for the port of Hamburg and hardly pointed out distinct opportunities, respectively. Opportunities mentioned allot predominantly to the general shipping sector such as avoiding human casualties through operating ships without human personnel onboard. With regard to incidents with autonomous vessels, interviewee 1 notes that insurances will still be responsible for compensating any occurring damages in the port, irrespective of a captain being or not being present onboard. If at all, the novel conditions may require strengthening of a shipowner's liability.

Interviewee 2 also refers to the benefit of avoiding human casualties through sailing autonomously. In addition, he furthermore hints at the possibility to obviate a multiplicity of sources for human failures such as the abuse of alcohol, lacking in concentration or falling asleep. Once technology is sophisticated enough to function safely and handle any weather and tidal conditions at some point in the future, the concept of an autonomous ship could then eradicate maritime accidents caused by human error – improving maritime safety also in the port of Hamburg.

However, according to interviewee 1, there are multiple obstacles when it comes to safety and security at the interface of autonomous shipping and the port of Hamburg. One of the most prominent issues would be that the capabilities for effective and timely intervention in cases of emergency are severely limited. The circumstance that radar pictures can only display the past position of a vessel poses especially a challenge in narrow waters such as in the waters of the port of Hamburg. This is because once a wrong or dangerous path of an autonomous vessel has been detected and thus the decision for intervention made, the ship has moved further along its path. In other words, at the time of intervention, it may already be too late to avoid an accident since reducing a ship's sailing speed or changing its course takes a considerable amount of time and space. On top of that, the exposure of ships to currents and winds additionally works against immediately effective countermeasures, so interviewee 1. He thus raises a number of questions: In case that intervention is deemed necessary, who would be the body or person assigned this task? In a similar vein, once there is no longer a captain onboard the ship, who will be responsible and liable for what an autonomous ship does at both the high seas and in port fairways? Would this be the manufacturer of the vessel's automation technology and software or the shipowner who potentially has never himself sailed on a ship?

Moreover, in case the idea of autonomous shipping will be realized, interviewee 1 expects this to come as a gradual process, implying that manned as well as autonomous ships would at least for a certain period of time have to operate alongside each other. He thus raises the question of how this interaction can safely be warranted for and what consequences this will entail for ship operations. In general, any kind of vessel, whether manned or autonomous, necessarily would have to know what characteristics its counterpart has to interact accordingly. While for the time being a captain can easily contact another captain to coordinate the interaction between their manned vessels, this would no longer be possible in a similar way between a manned and autonomous ship. Although technology could essentially facilitate this by sending, receiving and processing indicator signals about degrees of autonomy, interviewee 1 pinpoints that how the actual side-by-side interactions between manned and autonomous vessels would eventually look like remains unclear. These issues would also extend further to the demand on autonomous ships to be able to acknowledge and act according to, for example, the rights of way in port fairways.

Interviewee 2 hints at the above issue in a similar way. From his perspective, it is crucial to answer the question how the communication between a manned and autonomous vessel would be facilitated in the port of Hamburg. While a clear marking of an autonomous vessel for being identifiable to other traffic participants would not be a bigger technological challenge, allowing a captain to get in touch with an autonomous vessel is, however, considered one. In this, he points at a number of issues which thus pose different questions: For example, how would a captain tell an autonomous ship that he needs more space for his vessel or has to pass in front of or behind it? How would the procedure look like when a manned vessel has an engine breakdown, is no longer able to control its course and needs to communicate this to an autonomous ship in its vicinity? What happens when an autonomous ship has caused an accident with a manned ship? Would there be a 'tower' or operation centre at shore both supervising and controlling the autonomously sailing ships as well as assuming responsibility for activities of the latter?

5.2.3 Societal, legal and regulatory acceptance: Opportunities and barriers

Similar to the lack of legal and regulatory frameworks as the prominent barrier for introducing autonomous shipping on an international scale are also no such frameworks available for ports, so interviewee 1. According to him, there so far are no legal preconditions existent that allow for a ship to be operated without a person responsible onboard. This aligns with the issue of manning provisions pointed out in section 2.1. In recognition of the fact that shipping is largely international, there consequentially and first of all would international rules and regulations be required when the concept of autonomous shipping shall further take shape. While the interviewee assigns the IMO the crucial role of getting this process on track and thus providing the said legal and regulatory fundament, such prospective guidelines nevertheless will somehow have to find their way into individual national legislations. In this, interviewee 1 clearly denotes that there needs to be both the capability but also willingness of different nations to embrace and implement these provisions. This would be particularly relevant since any nation is responsible for its territorial waters and hence has to guarantee that provisions can be adequately integrated into national circumstances. Therefore, since the Hamburg Port Authority (HPA) is responsible for managing the port of Hamburg, it has to assess whether or not potentially later on given IMO provisions for autonomous shipping can properly be applied or extended to the special characteristics of the port of Hamburg. Hence, prospective autonomous shipping provisions have to give sufficient considerations to the individuality of each port in terms of its organisation and challenges, so interviewee 1.

In terms of societal impacts, interviewee 1 throws a rather sceptical glance at the prospective implementation of autonomous shipping. Since the idea of unmanned vessels can be expected to lead to a significantly reduced demand for seafaring personnel, their traditional profession may in the long run even come to an end, a certainly regrettable outcome from the perspective of the interviewee. In this potential development, at some point also the question will arise of how the future of those several thousand employees presently making a living from shipping will look like. With an introduction of autonomous shipping, one could furthermore exacerbate the already existing shortage of maritime youngsters and eventually erode the seagoing expertise highly valuable for various international and German shipping-related institutions. This could lead to the situation that people without any actual navigating experience will have to decide about the manoeuvres and operation of large-scale vessels. These alarming developments would most likely not spare a major change in conditions in ports such as the port of Hamburg. Although the concept of autonomous shipping may also offer room for innovation in the sector as well as open up possibilities for new education strands in shipping, interviewee 1 in total rather hints at dismal prospects for the seafaring profession.

Comparable issues are also brought forward by interviewee 2. When autonomous shipping becomes a reality, the numerous seafarers no longer required onboard would need to find employment onshore. Since this trend entails a large degree of uncertainty for currently working ship crews, considerable resistance can be expected to follow. The human and social element would therefore demand adequate consideration in order to not take away the means of subsistence of multiple thousand employees in shipping. Nonetheless, interviewee 2 does not expect the trend towards autonomous shipping to affect the vessels of the *Flotte Hamburg* in the near future. As he claims, this is due to the fleet's high degree of specialization and areas of application, comprising pilot cutters, sounding and diving vessels, a grader as well as firefighting boats and ships from the coast guard. Furthermore, since these ships are constantly manoeuvring, taking up personnel or debris as well as stand in close contact with other vehicles to quickly change course and receive new tasks, automation would rather complicate and impede the flexibility needed in those processes. As a result, interviewee 2 expects the ships of the *Flotte Hamburg* to be the last ones affected by the concept of autonomously sailing vessels. This would then consequentially, for the time being, spare corresponding employees from the above sketched negative impacts. In a nutshell, freight traffic as well as long-distance shipping – also at some point at the Lower Elbe - would come first but the port of Hamburg would not be affected at the moment. In the end, he finally also points to the high demands on administrative efforts, legal coverage as well as licencing generally required for sailing autonomously in the port of Hamburg.

5.2.4 Economical attractiveness and feasibility: Opportunities and barriers

Apart from general potential benefits linked to the concept of autonomous shipping such as reduced or no manning costs for shipowners as well as the option to create new jobs onshore instead of onboard, interviewee 1 does not specifically elaborate on economic opportunities or benefits for the port of Hamburg. He pinpoints that for making investments in autonomous vessels economically attractive, their absolute functionality has to be unequivocally given. If these ships would repeatedly break down because technology is not sophisticated enough, insurance rates for these ships may eventually reach unattractive dimensions.

Interviewee 2 also predominantly foregrounds the potential to save labour as well as the possibility to get rid of demanding shift-work onboard vessels with the implementation of autonomously operating ships. Furthermore, as opposed to a manned vessel, an autonomous ship would no longer have to give consideration to the rights (collective bargaining law, off-time) and needs (e.g. eating, drinking, sanitary equipment, bunks) and thus downsides of incorporating a crew onboard. In other words, an autonomous vessel would simply keep operating non-stop and hence offer the chance for increasing overall efficiency. In recognition of the fact that history indicates that automation has also been pervasive in shipping and already led to significant crew reduction, interviewee 2 expects this trend to further unfold with the concept of autonomous shipping. If automation technology is mature enough to make crews increasingly redundant, he clearly considers the implementation of autonomously sailing vessels to be the natural course. However, he emphasises that he foresees this development for longer, deep-sea navigation as well as inland waterway crafts sailing in areas such as the Lower Elbe - but not for the port of Hamburg itself within the next ten to fifteen years. As he says, this is especially due to the high degree of specialization of the *Flotte Hamburg*'s vessels as well as their diverse areas of application. Nevertheless, at some point in the future the automation trend may even also reach those ships.

6 Discussion and conclusion

This study was concerned with the centric research question "*What are the barriers and opportunities of the trend towards autonomous shipping, concerning the general shipping sector on the one hand and port environments on the other?*". First, this final chapter presents answers to the research question. Subsequently, additional light is shed on the results from the view of transition theory. This is then followed by addressing limitations of this thesis as well as making recommendations for future studies. All of this is rounded off with an outlook about the trend towards autonomous shipping.

6.1 Answering the research question

From the perspective of the general shipping sector, the results of chapter 5 indicate a diverse picture; for each cornerstone (figure 6) distinct barriers and opportunities could be detected. In conclusion, the following answers to the research question can be given:

Considering the cornerstone *technology and infrastructure*, it is evident that there is consensus about the maturity and existence of automation technology. This has already been demonstrated in different projects. However, there are still issues that need to be clarified, for example how an unmanned or autonomous vessel would be able to assure operational and technical redundancy without a crew. Moreover, while the infrastructure for the new kind of ships is not perceived existent at the moment, it is deemed possible to adapt it accordingly in the future.

For the cornerstone *safety, security and insurance*, the possibility to improve navigational safety via eventually eliminating the human factor certainly comes as a great chance. Still, new and greater risks relating to cyber security (e.g. ship hacking) are possible and an elaborate approach for safe communication as well as interaction between manned and unmanned or autonomous ships yet needs to be found. Although insurances and their rates will require reconsideration for autonomous ships, respective adaptions are not expected to be an issue.

Of all the cornerstones, *societal, legal and regulatory acceptance* clearly sticks out. While there are different societal benefits such as increased family-friendliness and the option to revive the attractiveness of the conservative industry foreseen, the present uncertainty about the future of the seafaring profession and any other jobs related to manned shipping clearly looms great. Most prominent in this cornerstone is, however, the fact that the current legal and regulatory framework is tailored to manned shipping and thus does not envisage autonomous ships. Although there is some scope for interpretation and integration, the possible realization of autonomous shipping on an international level will be stalled until the framework specifically embraces and facilitates this new concept in legal and regulatory terms.

Finally, the cornerstone *economical attractiveness and feasibility* indicates that investment incentives are still rather weak. Notwithstanding that fuel savings as well as reductions in personnel and building costs are prospective with the concept of autonomous shipping, the costs of the operation, maintenance and construction of associated vessels are presently still considered far too high. The novelty of the concept design currently entails considerable risks for investment and yet still seems to lack practical evidence that autonomous ships are both in total more profitable and efficient than traditional manned vessels.

From the perspective of the port of Hamburg, the results of chapter 5 point at a rather one-sided appraisal as predominantly barriers but hardly any opportunities were detected for the port. In conclusion, the following answers to the research question can be given:

Considering the cornerstone *technology and infrastructure*, there are only few opportunities mentioned for the port of Hamburg. Merely the possibility to operate, for example, loaded barges autonomously in the port as well as beneficial conditions for introducing relevant infrastructure someday in the future are brought forward. Conversely, the data unequivocally demonstrates that the operation of autonomous vessels would first and foremost have to satisfy multiple technological requirements. Significant obstacles respectively are the diversity of vessel types sailing in the port as well as the port environment's spatial narrowness which would make emergency intervention particularly difficult.
In terms of *safety, security and insurance*, the chances mentioned are primarily relating to the general shipping sector and not to the port of Hamburg. While this is also mostly the case concerning challenges, the issues of both emergency communication and intervention are perceived even more critical due to said spatial narrowness in the port.
The issues highlighted in the cornerstone *societal, legal and regulatory acceptance* for the general shipping sector conform to the ones of the port of Hamburg. This is merely extended in the sense that if IMO would launch provisions for autonomous shipping in the future, ports would still have to evaluate whether or not they could be applied to the specific port conditions.
The cornerstone *economical attractiveness and feasibility* lacks information that specifically addresses the port of Hamburg. The majority of the issues mentioned here once again conform with the ones for the general shipping sector.

Taken as a whole, the results of this study point to the consensus that – although different issues yet need to be resolved - the concept of autonomous shipping is expected to be realized within a time frame of 10 to 15 years for long-distance deep-sea navigation. In contrast to that, the case study of the port of Hamburg demonstrates that an introduction of autonomous shipping in the port is currently difficult to envision and thus yet remains a distant prospect.

6.2 Analysing barriers and opportunities from view of transition theory

Picking up on the understanding of transition characteristics given in the conceptual framework (section 3.1.3), different questions in connection to the results on the barriers and opportunities of the trend towards autonomous shipping can now be asked. In the context of autonomous shipping, can indicators for the occurrence of a transition be recognized?

- *Can a significant disturbance of the socio-technical regime (meso level) of traditional manned shipping be detected?*
- *If so, what does this disturbance coming from the socio-technical landscape (macro level) look like, what actually applies pressure on the regime?*
- *Is the disturbance of the shipping regime so strong that the latter looks for solutions in the niches (micro level)? Are there suitable solutions in shape of innovative techniques available?*
- *Altogether, in what phase of a transition would the trend then find itself in (multi-phase)?*

6.2.1 Multi-level perspective and trend towards autonomous shipping

Starting with the meso level, the results clearly indicate that the existing *socio-technical regime* of manned shipping is strong. The most decisive factor in this is that the legal and regulatory framework, meaning various conventions both coordinating and regulating shipping, are tailored to the traditional manned operation of vessels. While there are certain loopholes or tolerances for integrating the idea of autonomous shipping, the framework, however, does not foresee that. The regulatory scoping exercise of IMO is an indicator for this circumstance. Although there are prospective potentials, for example the improvement of maritime safety, manned shipping still functions satisfactorily and remains the default system.

When looking at the macro level, one can detect technological progress (e.g. prospects of digitalisation) and the urge for overall more sustainability as well as environmental well-being as contemporary international developments within the *socio-technical landscape*. Especially the global mega trend termed *Industry 4.0* and its associated debate on efficiency improvements and societal disadvantages seems to echo also in the context of autonomous shipping. However, these developments are apparently not able to exert external pressure on the socio-technical shipping regime in a way that it is forced to embrace change and thus look for solutions facilitating it.

Coming down to the micro level, plenty of innovative activities are observable that are taking place in the *niches*. As it has been highlighted in literature and by the interviewees, the technology for unmanned and autonomous ships is deemed existent. Although some uncertainty about profitability and risks for investment in the design exist, and safety issues yet demand further inquiry, many shipping actors are committed to boosting autonomous shipping. This is also reflected in different pilot projects such as the scheduled completion of the 'Yara Birkeland' as the "world's first autonomous and fully electric container vessel" (Kongsberg, 2017) until 2020 and employing the 85m long ferry 'Folgefonn' of Norwegian ferry operator Norled for the "believed to be (..) first ever attempt at fully automated dock-to-dock operation, in complete hands-off mode, for a vessel of this size" (Wärtsilä, 2018). Furthermore, it can certainly be said that the stimulation of innovations relating to unmanned and autonomous ships converge and reinforce each other. Examples for this are the Finnish-funded Advanced Autonomous Waterborne Applications (AAWA) initiative as well as 'One Sea' of the Finnish Collaboration DIMECC (see section 2.4.3). However, when looking at it holistically, it is striking in this study that the efforts for and pilot projects of unmanned and autonomous vessels are apparently unique to Scandinavia. While this may be a bias of research, it nevertheless is thought-provoking in the sense that above niche developments and the offerings of technology may eventually not reach international platforms. This may come as a restricting factor in the actual potential of the technology for unmanned and autonomous ships to find its way more strongly into practice. In addition to this, national legislation or a country's territorial waters are a lot more eligible for projects of unmanned and autonomous ships. While a country can issue new legislation or an exemption for such a project, this is not possible for international waters which are coordinated and regulated by the overarching IMO conventions that all countries need to obey. This hence comes as another factor that primarily facilitates the pursuit of unmanned and autonomous shipping projects on a national and impedes it on an international level.

When bringing above considerations for the multi-level perspective together, it seems that innovations at the *niches* (technology for unmanned and autonomous vessels) are available and they tend to increasingly converge (different pilot projects and collaborations). However, pressures from the *socio-technical landscape* (e.g. digitalisation and environmental concerns) appear to be insufficient to exert significant pressure on the current *socio-technical regime* of manned shipping. Hence, although innovations are offered, the regime does not encounter a sufficient disturbance that would necessitate for it to actually search for solutions and thus encourage their implementation in shipping. In sum, it thus seems a transition from a manned towards an unmanned and autonomous shipping regime has not been initiated.

6.2.2 Multi-phase model and trend towards autonomous shipping

In additional consultation of the multi-phase model, one may still characterize the occurring developments relating to autonomous shipping as constituting the pre-development phase of a transition. The phase's property "changes happen but are not yet observably affecting the system" (section 3.1.2) coincide with said developments that so far have been taking place. Extensive research into the concept of autonomous shipping, implementation of respective technologies within pilot projects as well as the launch of corresponding associations and coalitions are increasingly recognizable in different countries. However, these developments are of a rather strong technological nature and seem to lack the connection to other sectors (e.g. economical or socio-cultural) which is crucial for the trend's unidirectional reinforcement. These occurring developments hence rather appear to underachieve in terms of their capacity for greater change. Furthermore, the IMO has also begun to pay intensive regard to the concept of autonomous shipping in shape of its regulatory scoping exercise for *MASS*. With the IMO being the pivotal international institution for the regulation and coordination of shipping, as well as the source of numerous conventions respectively, this comes as a major sign of advertence. In consideration of IMO's role in shipping, it can be seen as a part of the shipping regime since its daily work provides the guidance for international shipping activities. IMO thus either comes as a significant enabler or inhibitor of change to the current shipping regime. Although IMO conducts its regulatory scoping exercise for *MASS*, this nevertheless rather seems to demonstrate only an inventory taking or appraisal of the concept of autonomous shipping. It presently yet has no effect on the existing legal and regulatory framework for international shipping. So, once more altogether, "changes happen but are not yet observably affecting the system". This would give the understanding of the trend towards autonomous shipping finding itself in the pre-development of a transition.

6.3 Limitations of research and recommendations for further studies

There certainly are limitations of this research, which implies that recommendations for further studies can be made. Since the concept of autonomous shipping is so extensive, the barriers and opportunities carved out in this study can only be seen as jigsaw pieces of a greater puzzle. The interviews conducted with shipping experts and practitioners allowed valuable insights into the topic. However, there are many more stakeholders and disciplines relevant than the 8 interviewees incorporated in this study[9] can represent. In order to both further substantiate and extent the notions presented here, subsequent studies should aim to also involve, for example, seafarers, shipowners, shipbuilders, infrastructure and terminal operators, insurance companies and the ITU. Such broader comprehensiveness was beyond the scope of this study.

Section 6.1 demonstrates several issues. Nevertheless, especially the one of societal acceptability and particularly the looming uncertainty regarding the future of seafarers and other maritime personnel seems to protrude. While insights derived from both the desk research and interviewees in part point at the potential to create new jobs, for example, on shore, conceptions

[9] This only display the number of interviewees that were able or willing to partake. Many more experts have been invited to partake but were not available for an interview.

on how these possibilities could practically be harnessed and implemented yet appear to only scratch the surface. It would indeed be advantageous for the chances of realizing autonomous shipping if its advocates came up with both elaborate and realistic ideas that would sincerely intend to keep the seafaring profession alive. This would clearly require stronger and honest communication about both the benefits and drawbacks of autonomous shipping with all parties having a stake in how the future of shipping will look like. While this would certainly imply extensive efforts, debates and eventually compromises among parties, trying to implement a technological innovation without support of its associated massive community cannot be in the interest of anyone. The question whether such a path can be found seems only answerable through studies specifically embracing the overarching employment uncertainty entailed by the idea of autonomous shipping. Envisioning and examining different possible futures for an era of autonomously operating vessels could lead to a learning process out of which finally a viable and satisfactory path may be fabricated. Detailed inquiries into actual working conceptions for shipping personnel in the face of autonomous shipping thus comes as another recommendation resulting from this thesis.

Furthermore, the investigation of the interface *port environments – autonomous shipping*, using the example of the port of Hamburg (Germany), makes a valuable contribution to the emerging but yet scarce body of knowledge on the concept of autonomous shipping. It gives a relevant starting shot for also recognizing ports in this endeavour. However, since ports exhibit individual characteristics (e.g. size) and thus individual barriers and opportunities, the capacity to make inferences from only studying the port of Hamburg is clearly limited. Nevertheless, it still provides basic insights into issues that other ports may also face when confronted with the new concept. This picks up on the circumstance that generalizations from a single case study are not to be considered as statistical validations but as a basis for making assertions about resembling situations (see section 4.3). On the one hand, this pertains, for example, to the overall spatial constraints in ports which pose a challenge for emergency intervention and effective manoeuvring of autonomous vessels. On the other hand, it is assumable that many ports are not only sailed by a uniform type of ship but rather by many different kinds of vessels (e.g. seagoing ships, pleasure boats, harbour vehicles), such as in case of the port of Hamburg. Autonomous ships would come as another type, implying that all kinds of ships would now need to be able to also acknowledge and handle unmanned ships in their vicinity. Moreover, the standpoint that certain port areas in Hamburg, for example characterized by shallow waters and light traffic, are more eligible than others can be expected to also echo in other port environments. These aspects also commonly point at a still missing answer to the question about the actual infrastructural requirements in ports for accommodating autonomous shipping operations. Finally, not only is legislation for autonomous shipping on the high seas lacking but also for port environments.

Eventually, the interviewees' prominent perception of barriers but not opportunities in the case study certainly revive the notion that ports are still hardly recognizing their role in the pursuit of autonomous shipping. All of the above considerations indicate the demand for studying these issues in multiple ports in order to arrive at a more comprehensive understanding of how the concept of autonomous shipping unfolds in port environments. In this, the assertions made from the case study of the port of Hamburg may provide the igniting spark for further studies that allow for increasing the capacity for generalization respectively.

It finally may need to be reassessed how much automation in ships is useful in the end. As it seems, different obstacles or drawbacks of the concept of autonomous shipping (e.g. job losses, technical redundancy and maintenance works) could be averted or solved by rather moderate instead of high levels of autonomy. Automation technology could be implemented more strongly for phases on a shipping voyage that are either characterized by dull work or dangerous situations, i.e. employed for tasks where human errors seem to occur most often (e.g. incidents due to lack in concentration or mental stress). This would imply that human beings and automation technology take turns in executing tasks depending on the character of the task. In order to arrive at an understanding about the respective parts on a shipping voyage where tasks are executed best by personnel or technology, further research is required. Studies are needed that juxtapose where a) human errors occur most frequently, indicating that automation technology may be more eligible for executing the task and b) human senses are crucial and cannot be satisfactorily substituted by technology, indicating that human personnel would be better suitable for executing the task. This would ideally lead to the outcome that acknowledging the weaknesses of human beings and automation technology enables harnessing their strengths. Eventually, this could mediate between the objective of pursuing more shipping autonomy and keeping the seafaring profession alive (e.g. through incorporating a skeleton crew onboard). Investigating the potential of such considerations once more points towards additional research.

6.4 Outlook

In their entirety, the results of this thesis help to make the trend towards autonomous shipping more tangible for the shipping community and its variety of stakeholders. On the one hand, the respective contribution lies within casting a specific light on the concept's barriers and opportunities from two different points of view: the general shipping sector and the port of Hamburg as an exemplary port environment. This deliberate juxtaposition provides shipping companies, institutions, investors and the like with an additional basis for decision-making (e.g. for weighing the social and economic value of pursuing full or partial autonomy in ships). On the other hand, looking at the trend towards autonomous shipping from the perspective of transition theory serves planning theory and practice with insights on interacting developments. For example, the MLP indicates that the existing innovations at the niche-level demand increased coupling to macro trends on the landscape-level to foster further progression of the trend. Looking at such influencing factors enables to arrive at an understanding about reasons behind the trend's status quo and thus groundwork for targeted stimulation, i.e. counteracting current barriers and further utilizing opportunities. This supports planners in anticipating what needs to be done in the future to help prepare the general shipping sector and port environments for autonomous shipping. In the end, it might even be most applicable to endorse a modular transition, i.e. full ship autonomy for the general shipping sector on the high seas (comparatively little obstacles for autonomy) and partial autonomy in port environments (comparatively many obstacles for autonomy).

On another note: Innovations in technology seem to perpetually allow human beings to take more and more steps back from executing tasks themselves. While autonomous driving now is at the brink of its realization, the concept of autonomous shipping points at a potential follow-up. However, in an era of digitalisation where futuristic ideas no longer appear irrational or utopic, society seems well advised to reconsider the apparent perception that high-tech should assume our tasks to the greatest extent possible. Different questions thus need to be asked. On the one hand, will a machine truly always perform a task more successfully than a human being? What about human senses and intuition, have these human assets nowadays lost their value? On the other hand, more importantly, do we in the long run even want technology to take the command? The many and diverse worries of seafarers in the face of autonomous shipping point at understandable resistance. People not only tend to identify themselves to a large degree through their occupation, they also make a living from it. Although some novel jobs would likely be created ashore, enormous job reductions with autonomous shipping may finally be salient. Putting it in a nutshell, it comes down to a wise balancing act. Technological possibilities should not inevitably imply that these have to be harnessed entirely. Rather, these should be used in a way that they relieve pressure of human beings and allow us to further advance jointly. And if societal costs outweigh societal benefits, technology necessarily needs to line up behind. So, in case that the trend towards autonomous shipping will become a reality, one may keep both an interested and worried eye on what future this will bring.

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"I herewith declare that I have composed the present thesis myself and without use of any other than the cited sources and aids. Sentences or parts of sentences quoted literally are marked as such; other references with regard to the statement and scope are indicated by full details of the publications concerned. The thesis in the same or similar form has not been submitted to any examination body and has not been published. This thesis was not yet, even in part, used in another examination or as a course performance. Furthermore, I declare that the submitted written (bound) copies of the present thesis and the electronic version submitted are fully identical."

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