Smart ships and the changing maritime ecosystem

How digitalization and advanced automation of barges, service vessels and sea ships create new opportunities and challenges for the maritime industry

Introduction

Change is a constant in the maritime industry. Sixty years ago, the introduction of the shipping container revolutionized trade and changed the way transportation, shipping, loading and unloading of goods is done even to this day (Levinson, 2008). Some even believe that its introduction is what gave globalization its biggest push. Today, the maritime industry is once again at the cusp of a new era—one driven by increased digitalization and innovation, in particular, automated ships. This evolution has the potential to impact all aspects of operations and business in the industry. In this whitepaper, we explore the introduction of autonomous ships, outline their business impact on different activities and discuss the new opportunities that arise for all parties in the maritime ecosystem.

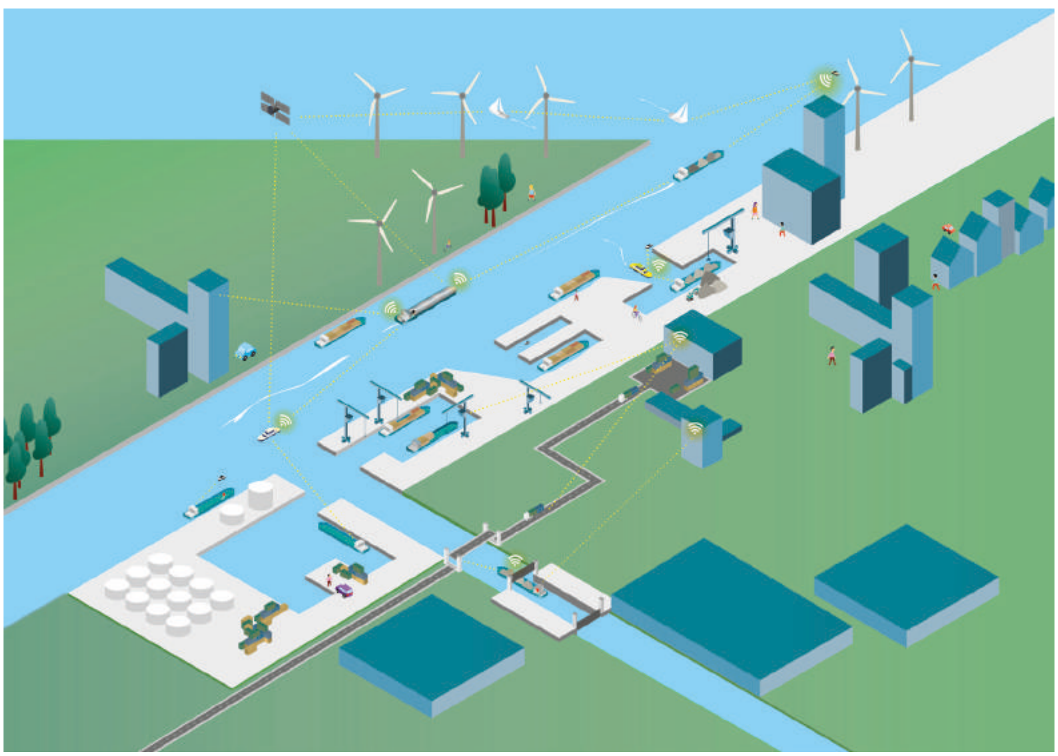


Figure 1: Representation of the connected maritime ecosystem.

Context

The maritime industry is one of the key pillars of global trade. It is part of an international transport system that can be roughly divided into three categories (Martimo, 2017):

1. Inter-regional deep-sea shipping and air freight between continents
2. Short-sea shipping in coastal seas
3. Land transport via road, rail and rivers

All the different players in the ecosystem are inextricably linked, making interconnectivity and cooperation between them crucial for effective and efficient operations of the transport system. Cargo can, for example, arrive in Europe by a deep-sea container vessel from Asia, be transshipped to a smaller port by a short-sea ship, where it is then loaded aboard a barge sailing to an inland destination.

Traditionally, the shipping industry has been highly dependent on its various mini-ecosystems, consisting of ports, authorities, ships, ship operators, ship-owners, cargo owners and many more. However, over a decade ago, researchers noted that the traditionally conservative shipping industry "is undergoing a change, where it is believed that the demands for increase in efficiency, safety and protection of the environment can be only achieved by more innovation"(Perunovic & Vidic, 2011). More recently, the Boston Consulting Group identified a number of emerging technologies like advanced analytics, autonomous shipping, robotics and artificial intelligence that are set to change how planning, operations, commercial and support functions within shipping are performed (Egloff, Sanders, Riedl, Mohottala, & Georgaki, 2018).

Autonomous shipping is one of the major developments that could radically transform maritime operations. In 2017, the trio of the Delft University of Technology (TU Delft), TNO (Netherlands Organisation for Applied Scientific Research) and Erasmus University in the Netherlands, conducted a scientific state-of-the-art analysis that discussed the various aspects of autonomous shipping and how these developments might impact all the parties involved in the maritime supply chain. This whitepaper is a practical interpretation of the analysis as performed by Negenborn et al. (2018). The framework presented in this paper has been validated by two expert panels, one focusing on deep-sea shipping and the other on barge shipping, comprising a total of 20 specialists from varied professional and academic backgrounds. The paper concludes with a series of recommendations.

Understanding smart ships

So what is a smart ship? Smart ships are best seen as a further evolution of already existing subsystems of a ship, which together constitute an (autonomous) vessel. (Schiaretti, Chen & Negenborn, 2017; van Cappelle, Chen & Negenborn, 2018).

"Smart ships will be a consequence of developing traditional ships with a number of sustaining innovations, but the new way of connecting ships to different processes makes a strong proposition of smart-shipping being a disruptive (business model) innovation" (Martimo, 2017).

In general, smart ships consist of four main elements (see Figure 2):

- **Navigation:** The navigation subsystem of a smart ship receives inputs from various sensors on the ship (see "Possible extra sensor components on a physical ship"). The data from these sensors is combined by a software-based sensor fusion block to create an image of the real world. Situation Awareness (SA), a software-based system assesses this image to translate the data into actionable information.
- **Guidance:** The picture created and assessed by the navigation subsystem is used by the guidance subsystem to chart the ship's path. Several elements need to be considered including nearby obstacles (collision avoidance), route from origin to destination and other navigational aspects (global path planner), and the status of other ships (communication block). These different information blocks are combined to generate the ship's path.
- **Physical ship:** To support the software-based decision making system, additional hardware is needed on the physical ship to collect data (see "Possible extra sensor components on a physical ship"). Where traditionally the master steered the ship and altered speed based on what was seen from the ship's bridge, now new hardware provides the same view and ability to act on information.
- **Control:** The control subsystem of an autonomous ship, also called the motion controller, is what actually steers the ship in the right direction. The software-based control system processes the data provided by the path generation software, converting it into commands for the various hardware positioning systems on the ship.

Together, these four elements form the backbone of intelligent applications on a ship. A topic that will be discussed in more detail later in this whitepaper.

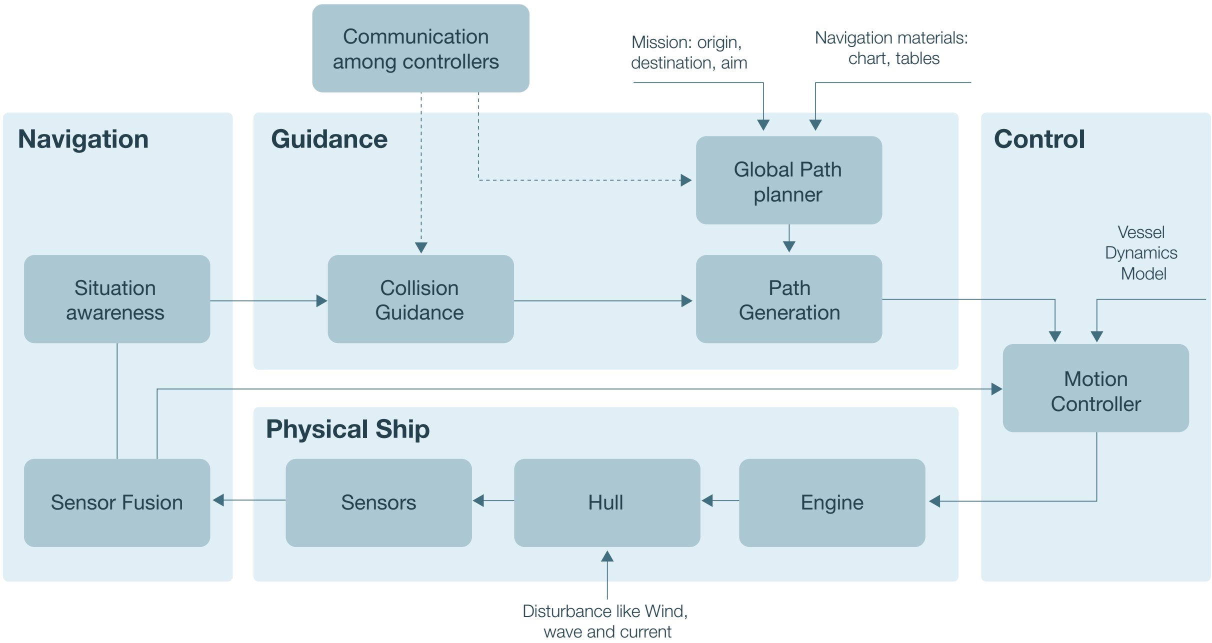


Figure 2 - Parts of an autonomous ship. Figure derived from Schiaretti, Chen & Negenborn (2017) and van Cappelle, Chen & Negenborn (2018)

Possible extra sensor components on a physical ship

- GPS/DGPS is the (differential) Global Position System ((D)GPS) that provides the position and speed of the ship.
- Vision systems create an image of the surroundings using stereovision, radars, cameras, lidars etc.
- Environmental sensors measure aspects like wind, waves, draught, and weather.
- Inertial navigation is an advanced system that determines the status of the ship using components such as gyroscope, acceleration meter, magnetic compass, and altimeter.
- Automatic Identification System (AIS) is a mandatory system that shares information about the location and speed of the vessel with other ships or port authorities.
- Automatic Radar Plotting Aid (ARPA) uses a radar to obtain the information of an object such as its course, speed and closest point of approach (CPA).
- Route Sharing System (RSS) interacts with nearby ships and shares (ship-to-ship) its intentions, helping to avoid collision.

Steps in increasing autonomy

One of the defining characteristics of a smart ship is its ability to function autonomously. Several roadmaps have been published that examine the possible evolution from today's ships to fully autonomous ships. In this whitepaper, we discuss the models as defined by Blanke, Henriques & Bang (2017), Negenborn et al. (2018) and Devaraju (2017). The roadmaps of both models share a growth trajectory for autonomous ships similar to the models in use for autonomous cars that have been developed by the intelligent transport systems (ITS) community.

Autonomy is described in six levels (see Figure 3), starting from level 0, the traditional human-based steering mode to level 6, full autonomy. The models of Blanke, Henriques & Bang (2017), Negenborn et al. (2018) and Devaraju (2017) can be simplified into four phases:

- Traditional way of working
- Increased sensors and decision support
- Human-assisted autonomy
- Full autonomy

Current technology readiness levels

'Technology readiness levels' help to analyze the current maturity level of technology. Technology readiness level 1 indicates the stage of basic technology research, while level 9 signifies a fully operational, tested system. Research by Negenborn et al. (2018) reveals that sensor technology is currently at a high technology readiness level and is already being implemented in operational environments. Technology that assists ships (see Fig. 2) is at an average maturity level and is currently being tested in select environments, such as the Port of Rotterdam. Presently, fully autonomous ships are at a low technology readiness level. However, technology is developing rapidly, and there are already some large vessels fitted with very advanced technological systems.

Business drivers for autonomy

Developments in ship infrastructure and technology are driven by business challenges and the need to make shipping safer, cheaper and more sustainable. Around 70% of all accidents occur due to human error (van Capelle, 2017). Furthermore, with a declining interest in maritime operator careers, a shortage of 150.000 maritime officers is expected in 2025 (van Capelle, 2017). Finally, the significant costs of employing on-board crew, which is approximately between 31% and 36% of the total operational costs (van Capelle, 2017) is driving the move toward increased autonomy of ships.

Autonomy Level 0

Manual Steering: Steering controls or setting points for the course, etc. are performed manually.

Autonomy Level 1

Decision-support on board: Automatic steering of course and speed in accordance with the references and route plan given. The course and speed are measured by sensors on board.

Autonomy Level 2

On-board or shore-based decision support: Steering of the route through a sequence of desired positions. The route is calculated to follow a defined plan and an external system can upload a new route plan.

Autonomy Level 3

Overall decisions on navigation and operation are calculated by the system. Navigation decisions are proposed by the system based on sensor information from the vessel and its surroundings. The consequences and risks are countered as far as possible.
The operator is contacted in case of uncertainty about the interpretation of the situation.

Autonomy Level 4

Execution with a supervisor who monitors and can intervene: Decisions on navigation and operational actions are calculated by the system which executes the calculations after the operator's approval.

Autonomy Level 5

Monitored Autonomy: Overall decisions on navigation and operation are calculated by the system. Consequences and risks are countered as far as possible. Sensors detect relevant elements in the surroundings and the system interprets the situation. A human operator is contacted in case of uncertainty about the interpretation of the situation.

Autonomy Level 6

Full Autonomy: Navigation and operation decisions as well as consequences and risks are calculated by the system. The system acts based on its analyses and calculations of its own capability and the surroundings' reaction. Knowledge of the surroundings and previous and typical events are included in the machine intelligence.

Figure 3: Levels of autonomy (Blanke, Henriques, & Bang, 2017)

Activities impacted by innovations

The introduction of the shipping container roughly six decades ago spurred a stream of innovations in the maritime ecosystem that radically changed global shipping over the course of half-century (Watson, Lind, & Haraldson, 2017). Ship capacity, for example, has grown 400-fold. Today, some of the largest vessels can hold over 20,000 TEUs. To accommodate these large vessels, terminals and port operators had to invest in new cranes, dredging equipment, reinforced quay walls, and extended berths (Saxon & Stone, 2017).

The standardization that followed the introduction of the shipping container laid the foundation for efficiency gains in multi-model transport and automation of container handling processes (Watson, Lind, & Haraldson, 2017). Although containerization has changed operations over the years, transportation activities, remained largely the same. In essence, even today, the main functions of the maritime industry include the following:

- **Sailing over sea/river/port.** The ship sails from point A to point B, either over sea, rivers and/or through the port. Interaction with the environment takes place to prevent collision.
- **Passing locks and bridges.** The ship interacts with locks and bridges en route, passing through them when opened.
- **Docking or departing.** The ship arrives at or leaves its berth. If needed, with physical support or coordination.
- **Loading and unloading.** Goods are unloaded or loaded from or on to the vessel, to be transported to the hinterland or to the ship's destination.
- **Preparing for next sail.** The ship is readied for its next voyage with all old waste discarded and new supplies loaded. Checks are made to ensure the ship is seaworthy.

The next section will outline the impact of increased automation of ships on the maritime ecosystem.

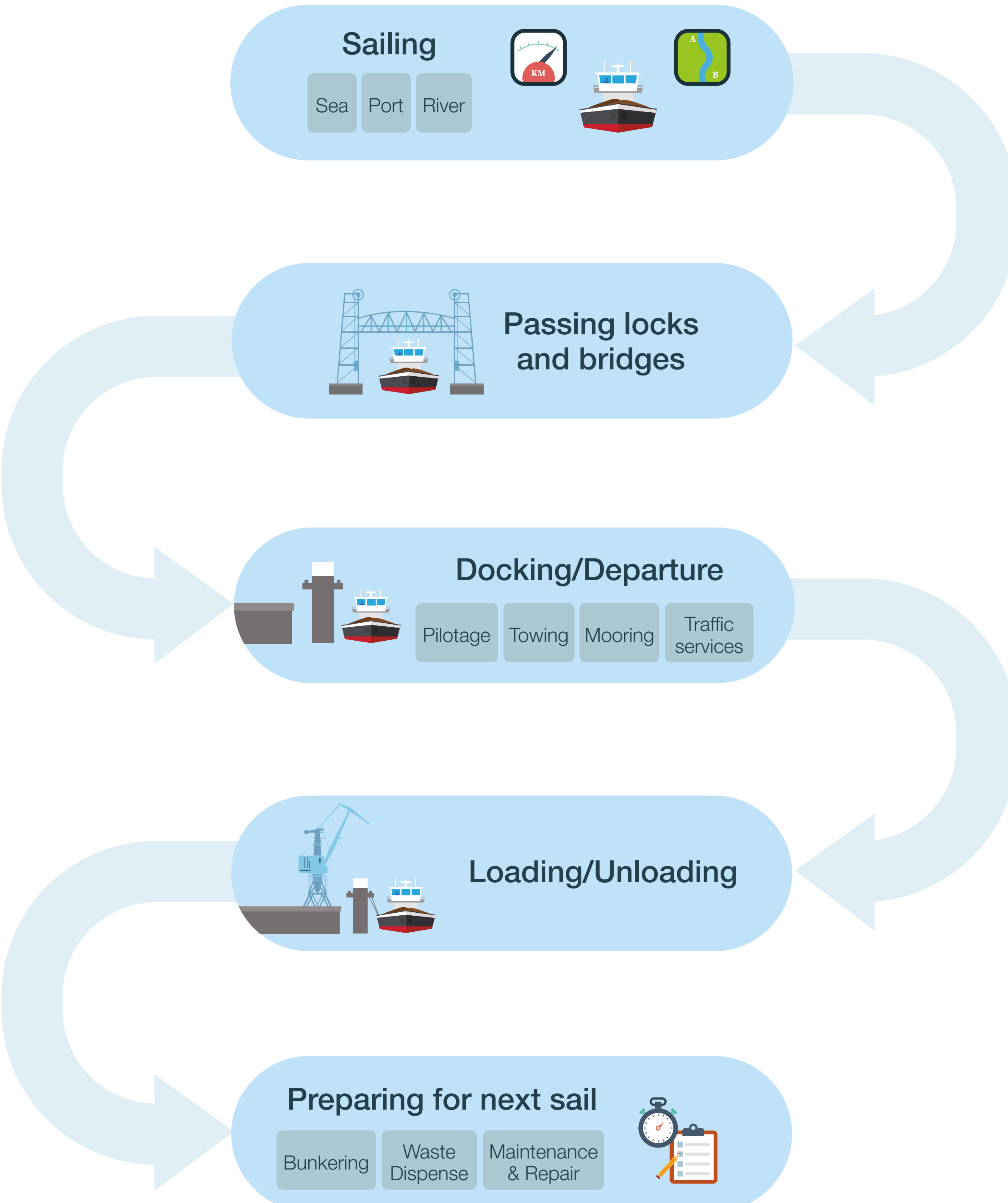
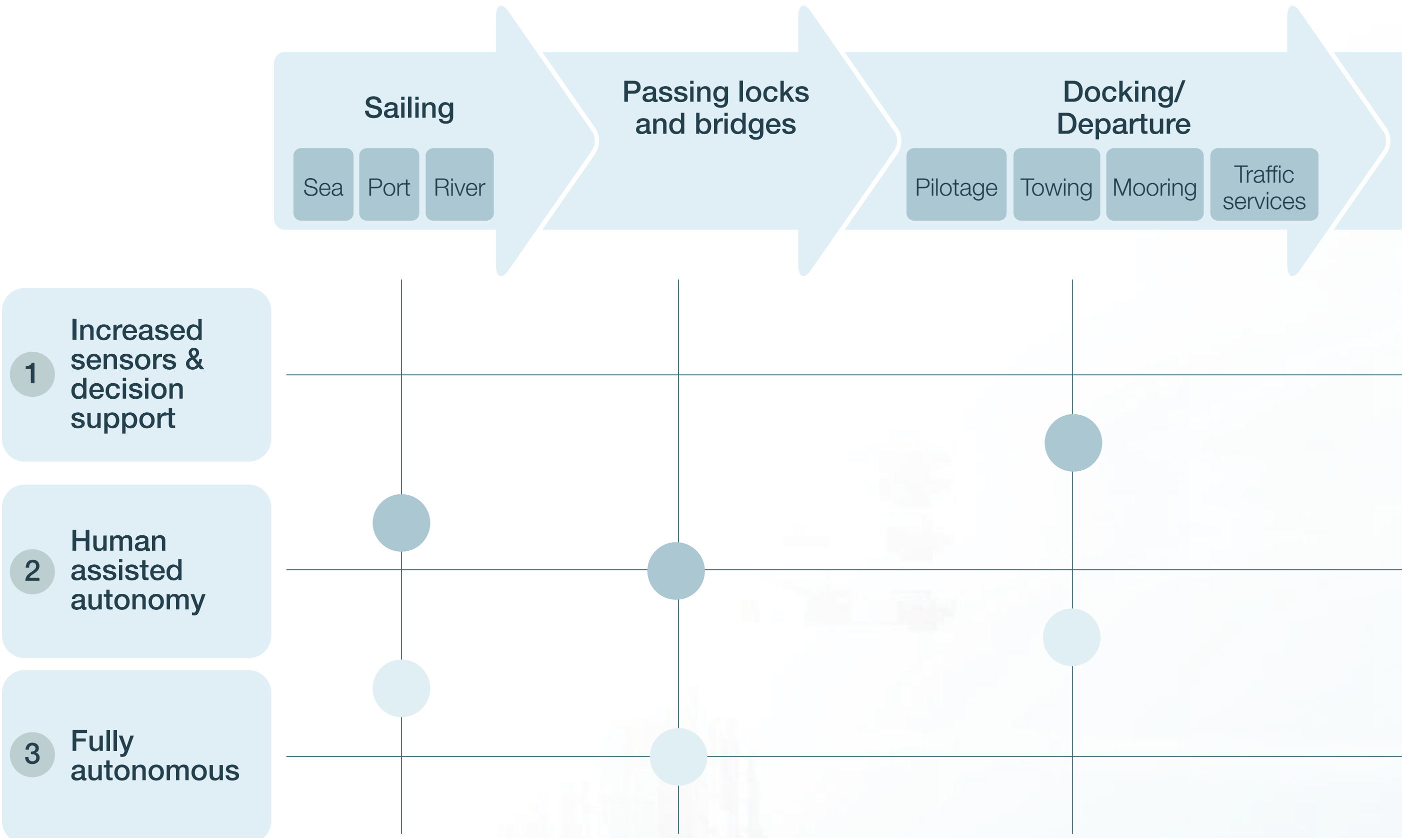


Figure 4: Activities in the maritime industry as partly derived from (Van der Horst & De Langen, 2008)

How smart ships impact activities in the maritime ecosystem

In this diagram, the X-axis plots the different physical activities performed within the maritime ecosystem. The Y-axis displays the three rising stages of autonomy: (1) increased sensors and decision support; (2) human-assisted autonomy; and (3) fully autonomous ships. The colored circles demonstrate the expert panel's consolidated opinion on how the ecosystem will evolve in the next 5 and 15 years' time. Each activity in the model is further explained in the next few sections.



New opportunities on the horizon in:

= 5 Years

= 15 Years

Sailing

- Most Ideal, safe, sailing speed and engine power is calculated and proposed
- Fully automated optimall sailing without human awareness of ship-to-ship and ship-to-infra interaction

Passing locks and bridges

- Optimal planning of opening times and lock/bridge capacity
- Fully automated opening of locks/ bridges without human ship-to-infra interaction

Docking/Departure

- Optimal planning of harbour capacity and coordinating/nautical services
- Fully automated guidance of ships
- New digital services for ship guidance without (much) human assistance

Loading/ Unloading

Preparing for next sail

Bunkering | Waste Dispense | Maintenance & Repair

Loading/Unloading

- Optimal planning of loading/unloading capacity
- Fully automated (un)loading terminal without human ship-to-terminal interaction
- New methods of (un)loading cargo

Preparing for next sail

- Predictive maintenance and bunkering/waste disposal planning
- Fully automated bunkering, waste disposal and repair without human ship-to-infra interaction
- New methods of bunkering and repair adjusting for new ship demands/designs

Sailing

Sailing or coordinating a ship's functions from the time of its departure to arrival at its destination consists of a group of tasks that are still performed primarily by humans. Increased ship automation creates new opportunities for better, safer and cheaper operations with reduced human involvement.

Future scenarios

- **Increased sensors** – Sensors help to ensure a safe and efficient sailing speed, where engine power is calculated and proposed to the skipper based on the desired ETA and data from:
  - The ship, including its status, position, direction and speed
  - Other ships (ship-to-ship interactions)
  - Sailing environment (ship-to-infra interactions)
- **Human-assisted autonomy** – In this scenario, the ship automatically adjusts for the most optimal sailing route and speed, based on sensor data and its mission. Humans can still support the ship in case of exceptional and more complex sailing scenarios.
- **Fully autonomous** – Sailing involves automatically setting the most optimal sailing route and speed without any human assistance. The sailing plan dynamically changes based on changing circumstances.

Business impact

- **Business case** – Over time, automated sailing, without human intervention, could lead to lower fuel consumption, lesser idle hours, possibly fewer personnel and lower costs of operating the ship (Negenborn, et al., 2018).
- **Planning** – Real-time insight of the ship and its environment allows for optimal real-time automated scheduling and operations. It will be possible to anticipate and plan ship operations based on the best current situation, for example, changing ETA, availability of the port and situation of the ship.
- **Employment** – With better information and smart algorithms that determine a ship's mission, commercial and planning roles may diminish. With autonomous ships in place, fewer personnel will be required, mostly for supporting roles, while more jobs will move from ship to shore.
- **Environment and safety** – As ships dynamically adjust their sailing speed, become more efficient, reduce idle time and make better use of capacity, a large reduction in fuel consumption per ship is expected. Safety is another important potential benefit that can arise from the adoption of automated systems. Improved sensor technology and ship-to-ship communication could benefit the reliability and availability of the vessel and prevent incidents (Negenborn, et al., 2018).

Business drivers of autonomy – Differences between sea and river transport

In general, shipping can be categorized into three segments. First is deep-sea shipping, which is the only economically viable option to transport high-volume cargo between continents. Second is short-sea shipping that focuses on port-to-port routes within regions. And third is inland (barge) shipping where the commute is between terminals and docks in the port with inland destinations upstream on local rivers. The business case for sailing with a reduced crew as a result of automation, and the shift to more onshore personnel, is substantially different between the various shipping segments.

The share of personnel costs in the total cost of ownership heavily influences the business case (Negenborn, et al., 2018). For deep-sea shipping, the cost of personnel is, in general, a relatively lower part of the total cost to operate a ship, compared to inland shipping, where navigation assistance or remote sailing could replace one of the two/three captains aboard the vessel. On the other hand, remote control as well as fully automated sailing is considered especially useful for sailing long stretches in low-traffic conditions, which is more common in deep-sea shipping.

For newbuild vessels, fully autonomous shipping is expected to lead to significant cost savings. For instance, vessel design changes like getting rid of the deckhouse and hotel systems could lead to more streamlined smaller vessels and thus to significantly reduced fuel costs or to additional capacity for cargo (Negenborn, et al., 2018).

Passing locks and bridges

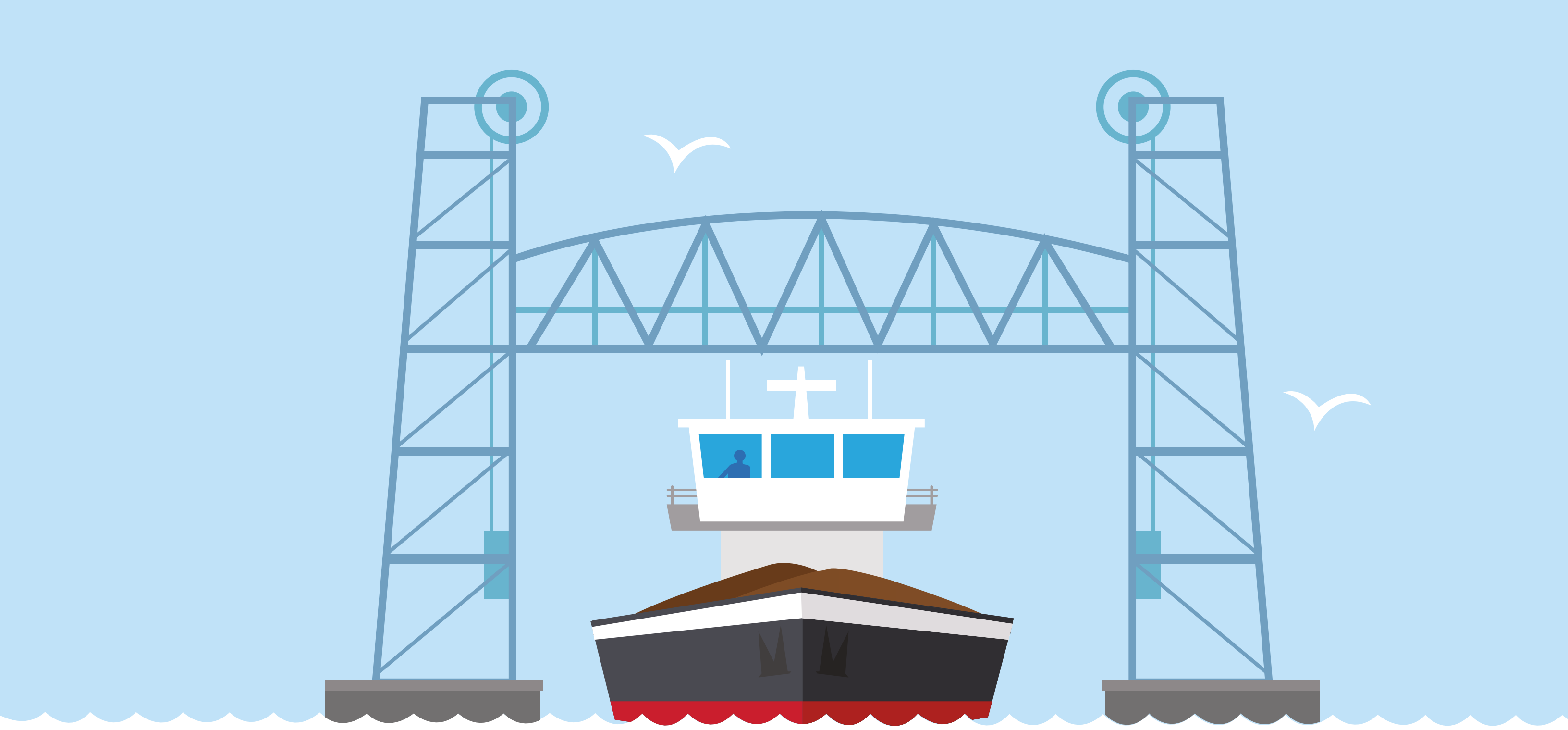
Currently, the coordination required between the ship and locks and bridges is achieved through human interaction and communication. Increased ship automation creates new opportunities for optimal interaction, safety and streamlined operations for all parties involved.

Future scenarios

- **Increased sensors** – Ships will communicate their exact status to the lock/bridge, such as expected arrival time and sailing schedule to request a slot. The lock/bridge receives this information as a live feed and based on this input, communicates back to the ship with the intended plan. This works the other way around as well. Improved real-time ship-to-shore information can provide the ship's operators with better insight into the availability of a quay in the port.
- **Human-assisted autonomy** – This enables automatic (slot) planning of passage and if needed, automatic reservation of waiting quays based on expected arrivals and availability. The expected time and location is communicated to the ship and the sailing speed is adjusted automatically.
- **Fully autonomous** – At this level of autonomy, lock/bridge decisions are made automatically, taking into account the impact of the individual plans of other ships in the vicinity and bound for the same lock/bridge. Communication between the ship and infrastructure will be an integral part of the journey optimization process.

Business impact

- **Business case** – Better planning and smoother operations require fewer personnel and less rework. Also, increased digitalization allows for the automation of lock and bridge operations, enabling seamless communication between infrastructure and autonomous ships.
- **Planning** – Insight into the status of the vessel provides improved predictability and enables self-planning. The bridge/lock regulations can be combined with the vessel's plans to identify the most optimal opening times and slots.
- **Employment** – The number of onsite personnel will reduce and there will be a shift toward remote lock and bridge control. However, onsite support and expertise will still be required in the case of exceptional situations.
- **Environment and safety** – Improved planning and coordination allows ships to optimally slow steam and avoid fuel wastage. This also improves safety, since there are no waiting ships queued up and less/no humans present onsite. There needs, however, to be a contingency plan in place on how to proceed if an incident occurs around the ship or while it passes through the lock/bridge and no human is present.



Pre-conditions for autonomous operations

Before systems can operate in a fully autonomous way, the following components need to be in place:

- Maturity and reliability of the situational awareness of the object: As long as there will be humans in the loop, interfaces must be developed that compliment an operator's ability to obtain and maintain situational awareness (Man, Lundha, Poratheb, & Mackinnon, 2015).
- Availability of adequate communication network infrastructures
- Common data architecture, interfaces and governance for effective data exchange between companies, implementable on a large scale: Reliability of the data network between the shore support center and the vessel needs to be guaranteed (Negenborn, et al., 2018).
- Security: Proper cybersecurity practices must be in place and followed by operators. IT systems on-shore and onboard must be kept updated to mitigate new threats and vulnerabilities as they arise (Negenborn, et al., 2018).
- Design and creation of a shore control center (SCC)
- Regulations: There will be more demands for flexible crew regulations (Negenborn, et al., 2018). As technology systems and standards on the ship mature, shipping companies will be able to minimize the crew required on board.
- Smart ships must be at least as safe as conventional ships (Negenborn, et al., 2018): Safe manning procedures must be implemented.
- Clear legal responsibility in case of hindrances and occurrences: There should be a clear understanding of who is ultimately responsible in case of failures and incidents.

Docking/Departure

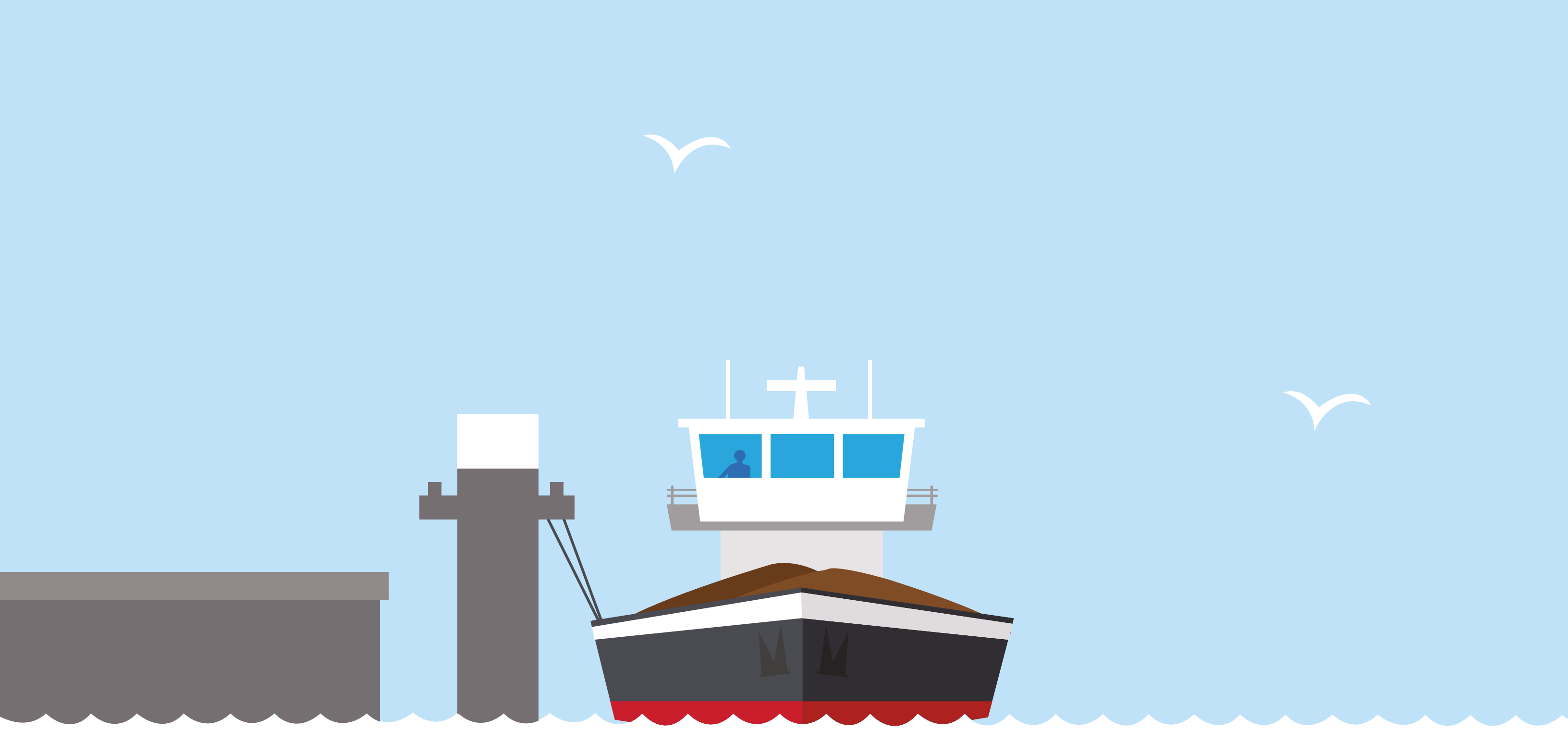
Docking and departure, or moving the ship safely in and out of the harbor, is a process that is mainly coordinated on the ship via interactions with port authorities. In this context, it is important to differentiate between deep-sea and short-sea/barge shipping, as the size of the ship plays an important role during docking/departure. The larger the ship, the more nautical services support, such as pilotage, mooring, towing and coordination are required for safe docking/departure. Technological advancements have the potential to impact both ship operations as well as the nautical services.

Future scenarios

- **Increased sensors** – With more sensors, the ship can constantly communicate its exact status to port authorities, including expected arrival time, sailing schedule and specifics about the ship and cargo on board the vessel. Based on this input, optimal timeslots in the port and nautical services can be reserved, which are conveyed back to the ship.
- **Human-assisted autonomy** – At this stage, increasingly autonomous mooring operations are possible with remote support in case of exceptional situations. In this scenario, good situational awareness inputs are essential for optimal nautical navigation. Towing may still be required in specific situations, however, with more digital support (such as towing drones) the need for traditional physical pilotage could change.
- **Fully autonomous** – Ships will utilize new technologies like digital coordination systems and magnetic mooring to make mooring a highly autonomous process. In this scenario, passive monitoring will still exist, while automated pilotage assistance may be required to manage the physical forces of nature, such as strong winds, that can still impact large ships.

Business impact

- **Business case** – As technology evolves rapidly, opportunities arise to create new digital products and digitize certain nautical services like pilotage, mooring and coordination.
- Planning – Real-time insight of the vessel's status enables improved predictability and creates opportunities for optimal self-planning of slots and coordination of assisting services in the port.
- **Employment** – Fewer planning and onsite personnel will be required with a shift toward offshore roles, remote support and digital products. Onsite support may still be required in exceptional situations.
- **Environment and safety** – Optimal ship control during mooring can significantly reduce fuel consumption both by the ship as well as by nautical services. For example, full control of towing traction can save redundant towing energy. In addition, automated mooring could lead to improved safety in the mooring operation (Negenborn, et al., 2018).



Port pre-conditions for autonomous operations

It is imperative for autonomous shipping to be as safe as traditional shipping, if not more so. The more complex an environment becomes, the more demands there will be on autonomous ships and infrastructure to keep shipping safe and efficient. A port is one such complex environment. Some of the key considerations for successful and safe autonomous operations in a port include the following:

- **A shore control center (SCC)** to monitor, navigate and control autonomous ships will need to be set up. The design of the SCC can have a potentially large impact on its investment and operating costs and could pose a major challenge for stakeholders.
- The **roles of the port authority and the harbor master** must be clearly defined. For instance, do they actively coordinate all activities in the port from the control center, including navigation within the port, or does the port only provide the infrastructure, leaving all other responsibilities, liabilities and risks to the ships?
- **Investments in infrastructure** for unmanned vessels will be needed. This is dependent on the pace of at which emerging technologies are adopted. However, as the benefits of unmanned vessels are highest for newbuild vessels, and also dependent on port investments, uptake of new technologies could be slow.
- The port needs to have **control over the risks** associated with autonomous shipping. This will necessitate a continuous process of risk assessment and ensuring required mitigating measures are in place. Some aspects to consider include, what information and certifications are required to allow an unmanned ship to enter the port and what will be done if (on-board) systems of autonomous ships in the port (or its vicinity) fail?

Loading/Unloading

Loading and unloading operations, which involves getting goods on and off the ship is currently performed by human-controlled or -supported terminals that are monitored by the ship's crew. Increased ship automation creates new opportunities for optimized planning and operations without human interaction and new loading and unloading methods.

Future scenarios

- **Increased sensors** – Sensors can provide real-time insight into a ship's location and its expected arrival time. These inputs, combined with intensive communication between the ship and the terminal before its arrival will streamline operations. Based on information such as sailing schedules and stowage, optimal terminal planning can be calculated, crane operations prepared and plans communicated well in advance to the ship.
- **Human-assisted autonomy** – At this level of autonomy, loading/unloading is completed automated, guided by stowage plans and terminal planning systems. Here, communication between the terminal and the ship takes place via the control center or by automated systems. Mooring and other tasks on board the vessel such as connecting hoses and stacking containers may still be done manually.
- **Fully autonomous** – In this scenario, there are no personnel onsite and all systems are fully automated. All communication from the ship, including information related to loading and unloading operations is computer driven. The terminal takes care of the dynamic stability of an autonomous ship, based on insight into the stowage and the cargo that is being loaded/unloaded.

Business impact

- **Business case** – Increased automation allows for optimized (integrated) operations, creation of new business models, increased efficiency and reduction of onshore personnel. In addition, shorter transit times are important competitive factors in (liner) shipping (Negenborn, et al., 2018). Excess shipping capacity can be filled last-minute by smart algorithms, driven by tight integration with clients to speed up or slow down cargo operations.
- **Planning** – Insight into the real-time status of the vessel will lead to increased predictability of the ship, enabling optimized self-planning. Available cargo and the ship's free capacity can be dynamically matched resulting in efficient coordination. In addition, alignment of a ship's sailing plan with the port schedule will be largely automated to reduce waiting time and increase reliability.
- **Employment** – While less onshore personnel will be needed, new jobs to monitor and develop IT systems will be created. However, it is expected that the net amount of jobs will be less than today (Negenborn, et al., 2018).
- **Environment and safety** – Dynamically adjusted sailing speeds and optimized loading will help to ensure sizeable fuel savings, helping to lower the environmental impact of operations. In addition, lesser human involvement and increased predictability will improve overall safety.

Development of technologies

Autonomous shipping integrates seamlessly with increasingly smart infrastructure and other digital developments, such as:

- **Fully automated bridge and locks** – Numerous countries are currently working on locks and bridges that can not only be remotely operated, but can be fully automated. Technologies like lasers, radar detection, video content analysis and electronic sensors will create full environmental awareness and enable safe autonomous operations.
- **Self-mooring systems** – A new development that is currently being tested, automated mooring robots employ vacuum pads to hold the vessel in position during the lockage process. Data from the Traffic Management System will automatically be sent to the mooring system as the vessel approaches the lock. This data will indicate how many vacuum pads are required to achieve the minimum system capacity to safely process the specific vessel (Dejonckheere, 2017).
- **Fully automated terminals** – Robots, with ‘eyes’ to see an object, a ‘brain’ capable of coordinating a task, ‘feet’ to move the object to another place and ‘hands’ to pick-up items will be utilized more and more in the not-so-distant future to fully support logistics operations. In fact, two terminals in Rotterdam (RWG and APM) already have highly automated terminal operations.
- **Internet-of-Things (IoT) networks** – The connectivity and exchange of data among maritime systems, based primarily on sensor information, is seeing increased adoption. Currently, IoT applications in shipping range from route optimization to maintenance and smart cargo storage.
- **Augmented reality innovations** – Solutions based on augmented reality could enable emergency repairs to be performed by (non-specialist) crew members on board, who are assisted remotely by onshore personnel.

Preparing for the next journey

Activities to prepare the ship for its next voyage such as bunkering, waste disposal, and maintenance and repair are currently performed by the onboard crew. Bunkering (refueling), in particular, is a critical operation that requires highly specialized skill and safety precautions. Operators consider maintenance and control as one of the first tasks that could be outsourced, since many systems in the engine room can already be monitored remotely (Negenborn, et al., 2018).

Future scenarios

- **Increased sensors** – Machines and sensors aboard the ship generate a tremendous amount of data that provide ship and port authorities with real-time insight into the status of the ship. This includes information on the maintenance levels of machines, fuel status and waste levels. This data can be used increasingly by both operators and nautical services providers to improve planning.
- **Human-assisted autonomy** – An intelligent ship is a proactive (supported) system that can signal and suggest the need for maintenance so that port services can be arranged. At this level of autonomy, emergency repairs are performed by crew members on-board, assisted by shore personnel.
- **Fully autonomous** – Unmanned shipping comes with the technical challenge to keep engines running for weeks without access to maintenance or repair (Burmeistera, Bruhn, Rødseth, & Porathec, 2014). Ships will evolve to be self-maintaining, where human support is needed only for non-routine maintenance. Over time, software will evolve to become one of the most significant maintenance support functions.

Business impact

- **Business case** – Predictive operations for maintenance, refueling and waste disposal ensure reliable operations, eliminate unnecessary downtime (at unexpected moments), and improve cost savings as a result of better planning.
- **Planning** – Smart processes make it possible to better coordinate and integrate all activities at the port to reduce wait time and optimize utilization, while predictive maintenance prevents system failure at unexpected moments.
- **Employment** – As more operations and coordination become automated, maintenance will be driven by system predictions, reducing the number of personnel required for these tasks. It is expected that the volume of physical maintenance will reduce, while software maintenance will rise.
- **Environment and safety** – Optimized coordinated activities and predictive maintenance will help to reduce waste, resulting in lower environmental impact; while better coordinated activities with lesser human involvement will result in improved safety.

Development of electric “green ships”

A large number of engine problems on a ship are related to fuel and combustion systems. The hybridization and electrification of (inland) vessels is one of the developments that will address this challenge to some extent (Negenborn, et al., 2018). According to Ni, Hu, & Li (Ni, Hu, & Li, 2017) the electrification of shipboard power systems and the concepts of all-electric ships is an unstoppable trend. “Vessels with dynamic positioning systems already have taken advantage of the power plant model where electricity can be produced at any time” (Dale, Hebner, & Sulligoi, 2015). The key drivers for the commercial ship business to convert to all-electric ship propulsion include (Dale, Hebner, & Sulligoi, 2015):

- Environmental requirements and cost of operation leading to the need for reduced fuel consumption and lower environmental emissions
- Increased efficiency of the prime engines, as they can be run at optimum speed
- Better efficiency of the electric propulsion motors at lower loading speed
- Improved dynamic response and fuel savings resulting from the use of stored energy
- Reduced weight, size, and footprint of electrical equipment
- More flexible equipment placement, resulting in increased space for payloads
- Reduced manpower through more automation and better safety management systems
- Reduced lifecycle costs through reduced maintenance
- The evolution of computing and telecommunications provides the opportunity to control the ship’s power system with levels of control that were unachievable before (Dale, Hebner, & Sulligoi, 2015), making electrification and smart ships a winning combination.

A new paradigm for digital solutions

The activities described in the previous chapters demonstrate how the maritime industry is in the process of transitioning from traditional assets and infrastructure to digital products and solutions. This evolution will bring to the fore new opportunities like optimal planning (integration), seamless and safe operations, and better utilization of the capacity that is available for all activities. These developments aren't just changing operations; they are set to fundamentally transform how the shipping industry functions as a whole.

Smart connected products

Three years ago, Porter & Heppelmann (2015) introduced the concept of "smart connected products" to the world. They began by broadly identifying how information technology is revolutionizing today's products. "Once composed solely of mechanical and electrical parts, products have become complex systems that combine hardware, sensors, data storage, microprocessors, software, and connectivity in myriad ways". Keeping the earlier sections of the whitepaper in mind, it is not hard to envision future ships as smart connected products (see "Smart connected ships").

Smart products and smart support of products have significant implications for the maritime industry. Their development follows a path similar to the concept of the Physical Internet that looks to apply the principles of the digital Internet to the physical world. In the maritime industry, the idea is to organize real-world shipping processes much like how data is transferred over the internet–as separate data packets sent via the most efficient network. Similarly, a shipment comprising different components can have some or each of its components sent to the final destination individually via the best routes. The Internet might eventually transform the way physical objects are handled, moved, stored, realized, supplied and used, aiming towards global logistics efficiency and sustainability (Montreuil, 2012; Andel, 2012). These "smart, connected products" have unleashed a new era of competition and are changing the way companies are organized internally as well.

New solutions and services

In the future, ship builders and other hardware providers will extend their products to include digital variants and will begin to collaborate to build new value added services for the maritime industry. Consider for example, ship maintenance. Knowing the history of the vessel, the actual usage, its current sailing schedules, spare parts inventory levels, etc., will make it possible to easily design an improved, predictive maintenance strategy or resell data, insights and knowledge to third-party services firms.

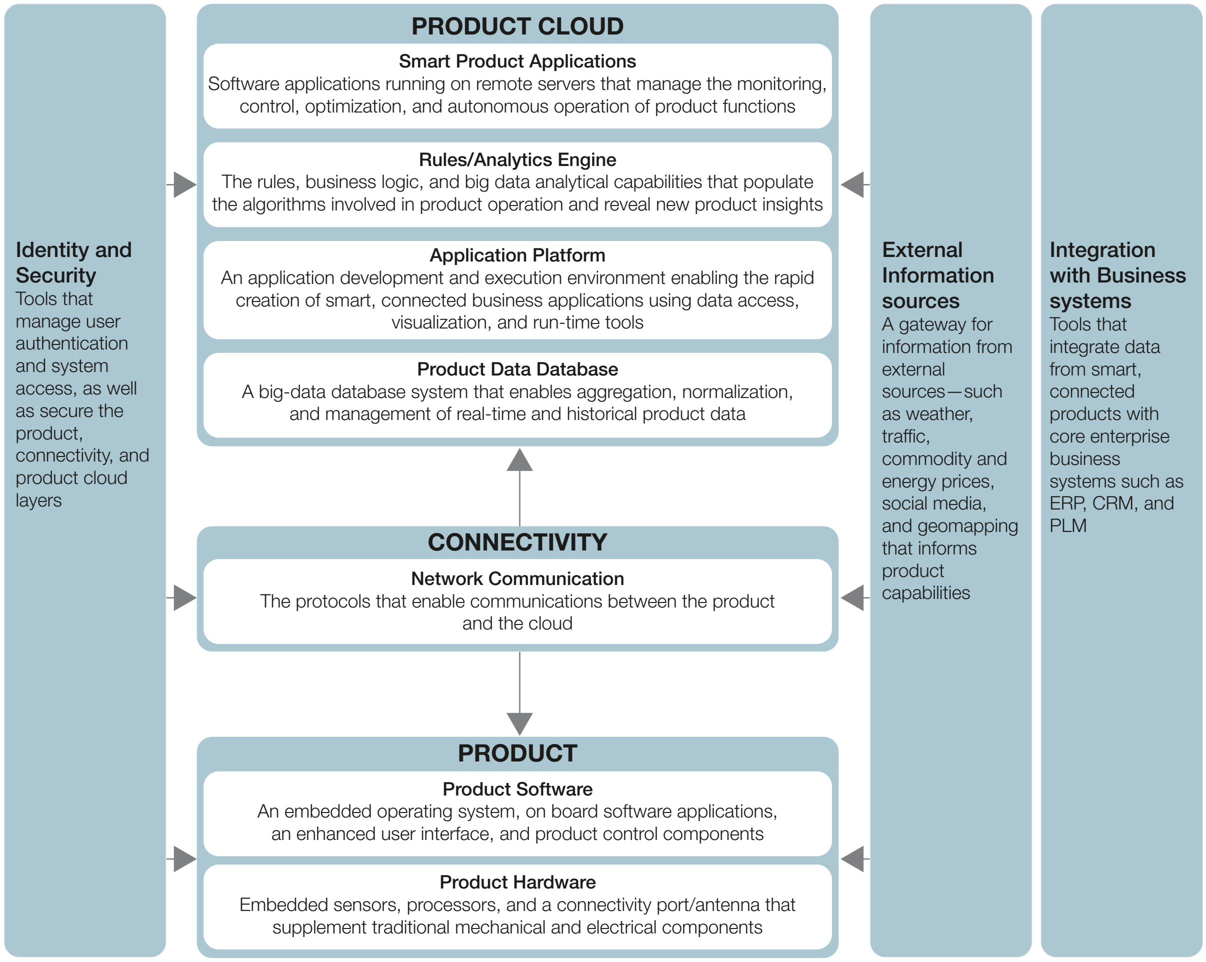


Figure 5: Technology stack of smart connected products (Porter & Heppelmann, 2014)

Smart Connected Ships

Smart connected products come with a so called generic “technology stack”, made up of multiple layers, including the product hardware itself, the embedded software, connectivity, a product cloud with software services, security tools, a gateway for external information sources, and integration with existing enterprise systems. These are the same elements used on smart ships to provide constant digital insight in to the physical status of a ship. The “smart connected product” concept is pretty comparable to the idea behind digital shadows, or digital twins, as increasingly mentioned in literature (Dalmolen et al,, 2012; Uhlemann et al., 2017).

Experts roundtable: The transition to autonomous ships

How will autonomy develop and what are the early successes to expect? To validate our research and gain deeper insight into the present status, business rationale and expected timeliness of the introduction of smart ships, CGI organized two roundtables with 20 experts from the maritime industry. The roundtables were divided into two groups—one focused on deep sea shipping and the other on inland shipping. Our research results and the outcomes of the roundtable discussion lead us to a number of conclusions about the digital journey toward autonomous ships.

Maturity and timing

The technological building blocks to create autonomous ships are already maturing, alongside all four major components of smart ships as described earlier in the paper (see Figure 2). In fact, we can expect to see the first fully autonomous ships in less than 5 years. Initially though, they will be developed in standalone environments like a windmill park at sea or deep-sea survey activities that don't require too much interaction with other infrastructure, ships or assets and where autonomy meets a clear business requirement. From an applications perspective, the first to be automated will center around dangerous, potentially hazardous and repetitive work. For example, automating tug boats in Australian mining areas or maintenance ships for windfarms at sea and offshore services.

The journey to fully autonomous (deep-sea) shipping lines, and fully autonomous port operations will take longer, with predictions ranging from between 10 to 30 years. A particularly challenging phase will be during the long transition period where autonomous ships will need to operate in mixed environments alongside analog ships, boats and traditional infrastructure.

Potential and business case

The opportunities and potential of autonomous shipping to support timely, safe, environment-friendly and cost efficient sailing are well recognized in the shipping industry. Ports, such as the Port of Singapore and the Port of Rotterdam for example, are already investing to prepare for increased autonomy.

Also the potential for new smart applications in shipping is clear. Concepts like automatic mooring, or new business models with smaller autonomous ships, sailing in the deep sea as a convoy or even physically docked together in a large ship could be on the cards. If these smaller ships become a reality, it might impact the current hub and spoke model in the maritime industry, where large ports like the Port of Rotterdam (one of the main shipping hubs and distribution centers in the world) play a central role in maritime logistics. Nevertheless, it is still uncertain if smart ships can truly turn around the ongoing quest for economies of scale in deep-sea shipping.

Perhaps the biggest challenge that faces some of the world's largest shipping companies is to create an indisputable business case for increased autonomy. Despite the push from international players like Rolls Royce, most shipping companies are not yet seriously investing in autonomous technology. Therefore the question is: are we waiting for a new entrant like Tesla, or even an outsider like Amazon, to shake up and disrupt this market?

Challenges to the development of autonomous ships

Currently there are numerous large and small companies investing in various developments to support fully operating autonomous ships. In addition to the challenges around developing a strong business case and navigating the in-between phase of interactions with analog ships and traditional infrastructure, some of the other significant challenges in the journey to autonomy are:

- **Change of contracts.** Many of today's contracts hinder the adoption of smart shipping, as financial incentives motivate "full steam ahead" rather than dynamic speeds.
- **Information exchange.** A key element of autonomous shipping is the ship's interaction with the environment. This includes its direct surroundings and various infrastructure as well as access to important information like stowage details when rotating in the harbor. Currently there is too little data available/exchanged. Added to this, the current definitions and data standards are inadequate to make widespread data exchange possible.
- **Regulations.** For inland-shipping in particular, current regulations can be a limiting factor. For example, there are stringent rules about the number of people that need to be on board all the time. There is a need for less specific regulations and more general guidelines. As technology advances, regulators will need to adjust the laws to keep pace with the changes in the industry.
- **Ship design.** Ships will need to be less traditional in design and more suited to autonomy. For example, autonomous ships will require specific engines and screws, the addition of electronics and intelligence components (as described in figure 2) and interchangeable parts whose components can be upgraded.
- **The human factor.** Despite complete autonomy, humans will continue to play an important role in the ship's functions, especially in case of emergencies. While in general, the operator's role may be one that is centered around monitoring activities and is software-focused, ensuring that humans are still a key part of the equation will be key.

Getting started

Change has been a constant within the maritime industry, and digitalization and automation might be—much like the introduction of the container—a development that will permanently alter the way transportation, sailing, loading, and unloading of goods is done.

It is clear that smart ships are going to be a part of this new future. However, to become a reality, major investments from ship owners, port authorities, port service providers, infrastructure providers and terminals will be needed. However, progress can also be made in small(er) steps. Despite the many technological, legal and business case challenges, the potential of autonomous shipping is clear and recognized.

This whitepaper combines the theoretical and practical elements of smart ships. Based on the gathered insights, five steps (see Figure 6) have been defined for the maritime industry's digital transformation. Most important is to recognize the potential of upcoming developments and begin to think about how autonomy will change roles and operations. Create a vision, start experimenting, but most of all, extend the vision to collaborate with other parties in the ecosystem to generate value. This will enable organizations to reap the full benefit of autonomous ships, and assure their positions in the rapidly-evolving and challenging future of the industry.

1. Define your role in the future ecosystem. Don't close your eyes to the developments coming your way.
2. Start experimenting. Thing big, start small and begin building the required new competences.
3. Create shared (data) standards and start sharing. Smart shipping is all about being connected.
4. Design for autonomy, both physical and digital products. Don't forget the human factor.
5. Evolve regulations to facilitate innovation.

Figure 6: Five steps to for parties in the maritime ecosystem

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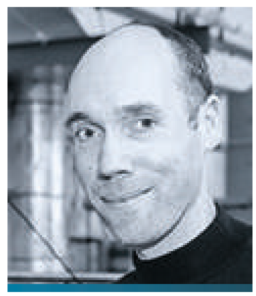

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Thomas van Meerkerk	Vertom
Gerald Menkveld	Ministry of Infrastructure and Water Management
Heidi Dekker	CMS

Experts roundtable (barge)	
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SmartPort is a joint venture between the Port of Rotterdam Authority, Deltalinqs, the Municipality of Rotterdam, TNO, Deltares, Erasmus University and Delft University of Technology. By inspiring, initiating and forming alliances SmartPort stimulates and finances scientific research for and by the companies in the port of Rotterdam in collaboration with knowledge institutes.

It is about developing knowledge, share and use it from one collective ambition. The transition onto the best and smartest port can only become successful when all parties involved jointly provide solutions to changes the future will bring.We are convinced that the most impact in developing knowledge is based on specific questions from the market and that the best results arise when the optimal benefit is gained from joined forces of trade and industry, authorities, and science.