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AUTONOMOUS VEHICLES' IMPACT ON PORT INFRASTRUCTURE REQUIREMENTS

Hamburg Port Authority

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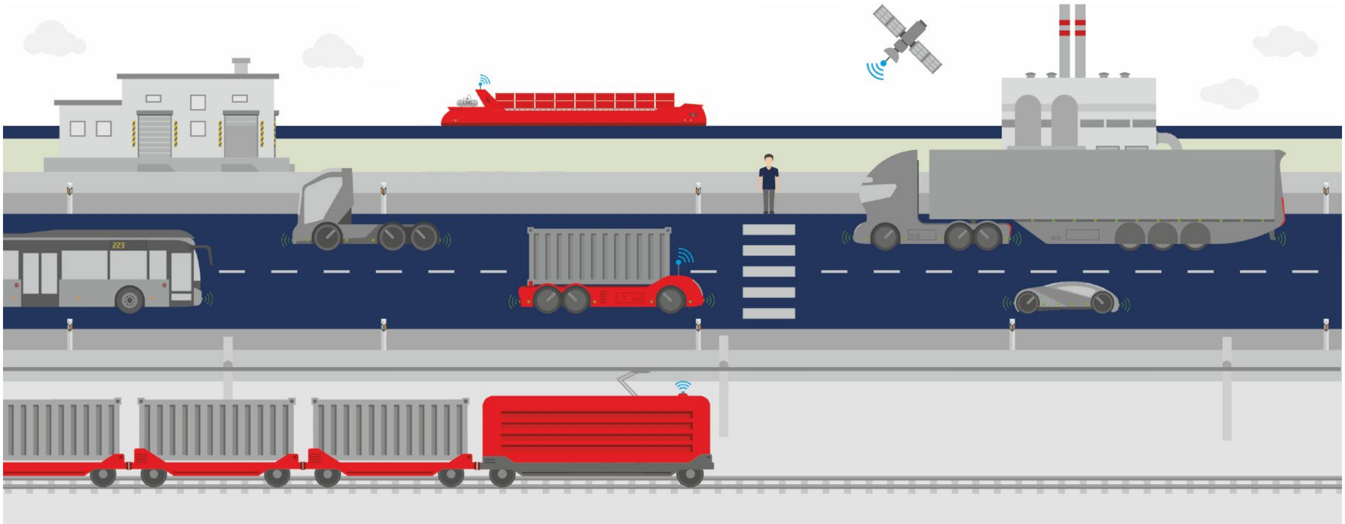
International Association of Ports and Harbors



AUTONOMOUS VEHICLES' IMPACT ON PORT INFRASTRUCTURE REQUIREMENTS

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List of Abbreviations

4G, LTE	4th Generation Mobile Networks, 100 Mbit/s
5G	5th Generation Mobile Networks, 20 Gbit/s
AI	Artificial Intelligence
AIS	Automatic Identification System
AL	Automation Level
ANS	Air Navigation Services
ATC	Air Traffic Control
ATM	Air Traffic Management
ATO	Automatic Train Operation
BVLOS	Beyond Visual Line of Sight
CAAC	Civil Aviation Administration of China
CAAI	Civil Aviation Authority of Israel
C-ITS	Cooperative Intelligent Transport Systems
DDT	Dynamic Driving Task
DSRC	Dedicated Short Range Communication
EASA	European Aviation Safety Agency
ECDIS	Electronic Chart Display and Information System
FAA	Federal Aviation Agency
FMVSS	Federal Motor Vehicle Safety Standards
FPV	First Person View
GNSS	Global Navigation Satellite System
GoA	Grade of Automation
GPS	Global Positioning System
GSM	Global System for Mobile Communications
I2V	Infrastructure to Vehicle
ICT	Information and Communication Technologies
INS	Inertial Navigation System
IoT	Internet of Things
ITS	Intelligent Transport Systems
LAN	Local Area Network
LiDAR	Light Detection and Ranging
MASS	Maritime Autonomous Surface Ship

MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
NAA	National Aviation Agency
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TEU	Twenty-foot Equivalent Unit
TOGAF	The Open Group Architecture Framework
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UN/ECE	Economic Commission for Europe of the United Nations
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VHF	Very High Frequency
VLOS	Visual Line of Sight
VTOL	Vertical Take-off and Landing
WLAN	Wireless Local Area Network

Preface

There is probably hardly any other topic that moves people more in this decade than digitalization. It offers fascinating opportunities to invent or renew established business processes for extended periods of time, to make them easier, but also to turn them upside down.

In their private lives, many people are fascinated by new apps for communicating, playing games or travelling, but in the business world, the development and use of innovative solutions are associated with great imponderability and risks.

In many cases, companies do not even have the choice whether they want to participate in the digitalization of a processes in which they are involved or not. This is particularly true for logistics companies in global supply chains. As a rule, they are regarded as service providers and are supposed to meet the requirements of their customers in the best possible way. In addition, to the complete digitalization of the information chain that accompanies the transport of goods, one of the big challenges here is the automation of transport.

Many transport companies are intensively dealing with the automation of the control of trucks, trains and ships and expect this to lead to lower personnel costs, improved efficiency and greater safety in the transport sector in the medium term.

The IAPH, as the world's leading port representation, has asked itself what impact this development will have on ports; how should ports prepare for the arrival of automated or autonomous vehicles? What are the infrastructural requirements, what knowledge do they need to have in order to successfully meet the challenges? And how can ports play a role in the development and in the setup of surroundings for autonomous vehicles?

Answers to these questions and further recommendations are provided by this study "Autonomous Vehicles' Impact on Port Infrastructure Requirements", which was prepared by the Hamburg Port Authority together with the Fraunhofer Center for Maritime Logistics and Services CML. Basing on numerous interviews with representatives of innovative projects, the extensive knowledge of the involved researchers and professionals as well as in depth desk research the study gives a comprehensive view on actual developments of autonomous vehicles that may visit the world´s ports and the prerequisites they shall meet. We hope you enjoy reading!

1 Management Summary

- Autonomous solutions are developed for road, rail and waterborne transport. Autonomous driving describes the independent locomotion of vehicles and is a further development of driver assistance systems. Autonomous means that the responsibility for the movement of the vehicle shifts from the human driver to a system.
- Ports face the challenge to prepare themselves for the arrival of such vehicles at their gates without much evidence of what these vehicles demand from the physical and digital infrastructure while being introduced.
- The required steps to prepare for autonomous vehicles depend on the existing degree of digitalization of a port and on its responsibility for the port infrastructure.
- What can be observed these days are several running autonomous applications in closed areas.
- However, the public discussion often exaggerates the level of automation; it has to be clearly distinguished in detail in which environments and for which purpose (semi-) autonomous vehicles are deployed.
- Most quoted reasons for this technology include
    - increased efficiency of transport which brings alongside better capacity utilization
    - less negative environmental impact
    - increased safety
- The transport industry only tends to deploy this technology once its operating cost is evidently low. The avoidance of driving hour regulations and a noise reduced operation are strong hints into this direction. Same is true for autonomous rail and waterborne transport. As a direct consequence, ports will increase their competitive advantage making autonomous driving possible at that early stage.
- Unmanned Aerial vehicles (UAV) play a special role in this context. There have been no predecessor transport solutions, and the range of services possibly offered by UAV extends transport solutions into completely new areas.
- Transport departments, infrastructure providers and port authorities should prepare themselves for the technology leap to come. For the time being, test applications are carried out testing the technology of autonomous driving in ports, while however the immaturity of the technology for autonomous driving persists.
- Ports should make themselves known to the technology and start, advisably together with the vehicle manufacturing industry, test sites. These should foster innovation in the ports. The test sites will have to be equipped with supporting systems such as additional sensors and wireless or mobile networks to ensure their technical capability.
- Port Authorities should steer digitalization within their domain and develop new business models sustaining their role as responsible societal partners and port business facilitators to ensure the port regions' economic wealth.
- Infrastructure planning should take into account the requirements for autonomous vehicles also in the emerging phase. Even though the overall idea of autonomous vehicles is that they should be able to cope with any infrastructure condition, in their emergence phase they will require additional aid from sound physical infrastructure – high quality pavements, intact (road) markings, and digital infrastructure as networks. The time to act is now.

2 Introduction

The opportunities and challenges of autonomous vehicles in passenger and freight traffic have become a major issue in the discussions about the future transport systems. Autonomous driving describes the independent locomotion of vehicles and is a further development of driver assistance systems. Autonomous means that the responsibility for the movement of the vehicle shifts from the human driver to a system. The degree of autonomy can be quite different for different types of vehicles. Many companies involved in the manufacturing of vehicles and their control systems work on new solutions for increasing the automation of driving.

Regarding, a wide number of ports work independently and in joint developments preparing themselves for the autonomous vehicles to come. However, this is true mostly only for the large and technology advanced ports. This is partly reasoned by the goal to sustain their own competitive position if autonomous vehicles join the markets. Moreover, infrastructure investments are made to last 30-50 years. Within this long time frame, consideration of future investments should be based on future technology developments.

But what are the reasons that drive these developments? Most people expect from automated driving a rise of efficiency, a reduced need of drivers resulting in a decrease of staff costs, a higher safety level and more efficient operations. On the other hand, as autonomous driving is still in its infancy, people are concerned about possible accidents. Furthermore, higher automation means more communication interfaces and thus more cyber security efforts to ensure reliable systems.

Among the companies and entities that own and regulate infrastructure components and facilities, there is a diffuse feeling about the future development, since the speed and scope of the realization are yet unclear (Port of Rotterdam 2018a).

Very likely, and this is one subject of this study, there will be a need of interim technologies to deploy autonomous vehicles in the very near future. Previously, the development of autonomous driving followed an approach that through the provision of intelligent infrastructure, using sensors, induction loops, road side units etc. information is submitted to the vehicles (Autonomes Fahren & Co 2018). This concept has changed. Nowadays, developers aim at making the autonomous vehicles more intelligent. Although that means a shift in equipment and investments from fixed/ static installations to moving/ dynamic entities, this development increases the flexibility of the systems.

Looking at meaningful interim technology solutions, it remains difficult to say which installations will be useful for the years to come. Many ports and cities experiment with test areas. Safety levels must remain high to hinder the development from failures that could kill the subject at an early stage. For example, the HEAT project in Hamburg`s Hafencity ensures the safety of passengers and pedestrians by additional sensors in the streets and cameras in the vehicle and supervision by an operator. Same is evident for the self-driving bus in Helsinki, Finland, the so called RobobusLine which has gone to scheduled service in spring. These first applications are necessary for testing, gathering experiences and thus for the further development.

Expectations concerning autonomous driving are high: the implementation of the new technologies are associated with more environmentally friendly engines, e.g. electric drives, hydrogen fuel cell or the use of LNG, even though this is not necessary from the technological point of view. Despite the demand for autonomous vehicles still remains unproven, potential for cost savings, increased safety and the shortage of skilled workers in freight transport drive this discussion. Evidently, these autonomous machines can be deployed without any limits of driving hours, which will provide a leap in efficiency.

The realization of a complete autonomy of vehicles, at today's technology abilities, is tied to specific infrastructural prerequisites, which often have yet to be created. This also applies to port infrastructures. This also includes in particular IT infrastructures, e.g. the availability of a sufficient number of sensors or antennas.

There is, however, a big uncertainty, if and to what extend autonomous vehicles demand specific infrastructural requirements. This is also true for port infrastructure where road, rail and sea traffic intersect.

Given the different levels of autonomous driving, in which the lower levels seem to demand more from the infrastructure, mostly reasoned by a less mature technology in the vehicles, ports begin to prepare themselves for the things to come.

As a project of the Port Planning and Development Committee of IAPH in 2017/19, finalized for the IAPH World Ports Conference 2019 in Guangzhou, the Hamburg Port Authority (HPA) reviews the infrastructural requirements resulting from an increasing automation degree of vehicles and transport systems in ports.

3
Goal and Course of the Study

The aim of this study is to provide an overview of the current state of autonomous driving in ports and its consequences for planning and development of ports' infrastructure regarding future requirements. Furthermore, the study aims at formulating recommendations for action that provide support for port authorities to prepare themselves for the technological progress. The study covers four transport modes road, rail, waterway and aerial transportation. To achieve this, the work is carried out in two consecutive steps. The course of the study is illustrated in Figure 1.

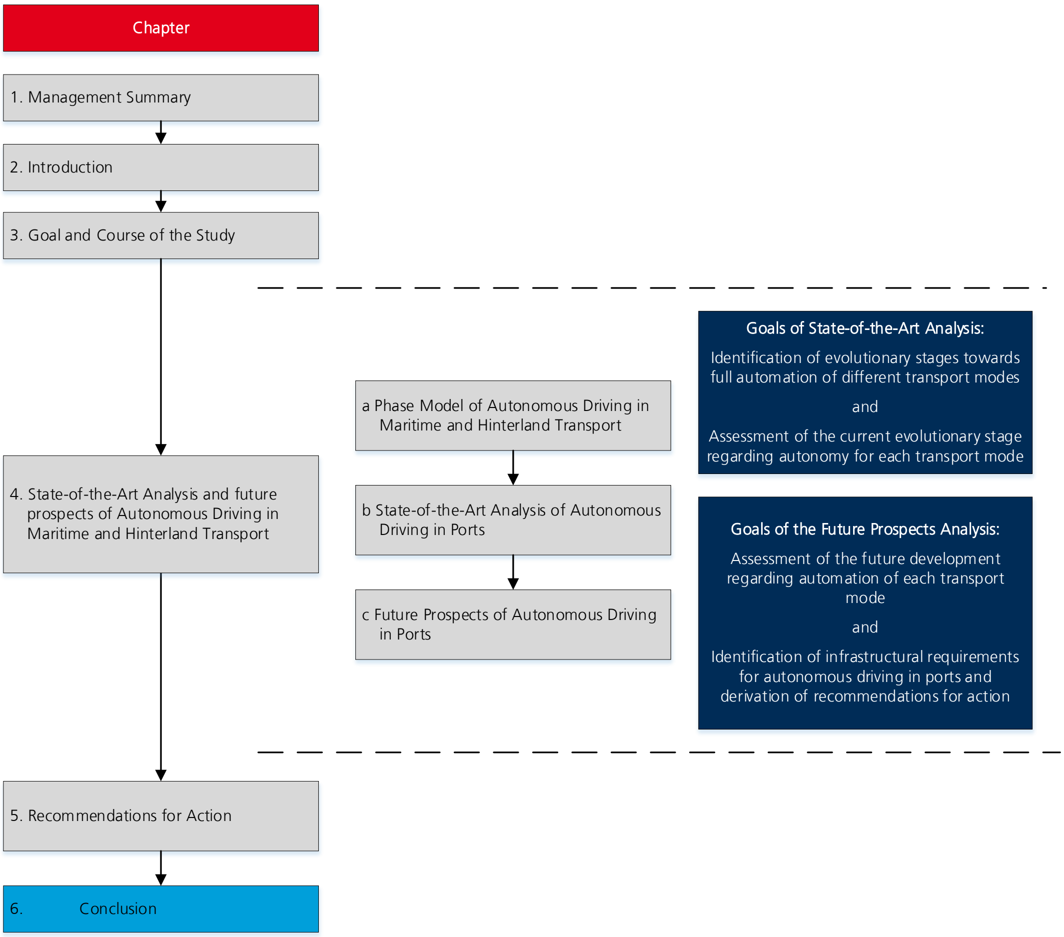

Figure 1: Goal and Course of the Study

Source: Fraunhofer CML (2019)

From Chapter 4, the results of the analysis per transport mode, regarding the status quo and future prospects of autonomous driving, are presented. Firstly, the mode-specific phase models are considered. Subsequently, the current state of driving automation for each mode of transport is described and expected future developments in the field of autonomous driving are identified. From the future developments, forthcoming infrastructure requirements can be derived. These requirements will be summarized with the legal consequences in Chapter 5 following by recommendations for action. Chapter 6 provides a final conclusion of the study results.

4
State-of-the-Art Analysis and Future Prospects of Autonomous Driving in Maritime and Hinterland Transport

This section depicts the development of transport tasks in different phases for each transport mode. To begin with, some terminologies are described to set a common understanding.

Autonomous Driving is generally understood as the shift of full responsibility of performing all driving and maneuvering tasks from a human individual to an autonomous system performing without any need of influence from the driver.
The task to drive can be divided into three categories:

- navigation,
- command, and
- stabilization.

Navigation describes the choice of a suitable route and the calculation of the estimated time. The dynamic driving tasks (DDT) which include the remaining driving tasks such as the category "command" contains all tasks that determine the intended direction and target speed from the current traffic conditions and the planned route. The stabilization is the punctual intervention into the driving process caused by a changing traffic condition. (Maurer et al. 2015, p. 34f)

The expectations of these technologies are improved efficiency, consistent capacity and operation mode, easier management and optimized utilization of capacities as well as an immediate increase of traffic safety (Niessen et al. 2017).

The modes of transportation differ by their automation level. Aerial transport, maritime transport and rail based public transport systems have already reached a high degree of automation in some single applications. The road transport includes a complex interaction with other users and makes the technology development much more complicated. (Trommer et al. 2016)

While autonomous driving describes the completely autonomous acting of sensors and artificial intelligence, automated driving means that an external control center monitors a vehicle, which drives in a separate area (Niessen et al. 2017).

Sometimes it can be questioned, what the motivation for an increased automation in the transport modes really is. For sure, technology companies aim at setting standards and placing their products in the market. Capital strong Silicon Valley IT companies look for other industry sectors to invest in. The automotive sector has got onto their agenda, like many other industry sectors too. While being clearly behind established market players in terms of car and truck manufacturing, they turn to technology – which is their domain. So it is no surprise that Waymo, the Google daughter company, or even Tesla define their competitive advantage via technology systems being it electrical drive or autonomous driving. However, what Uber or Tesla have reached by now is level 2, not more than that.

The technology readiness level of the overall full autonomous vehicles still remains unproven. Experts estimate full autonomous driving within 15-20 years (Prof. Barbara Lenz, DLR) to 30-40 years (Prof. Erich Heltendorf, University of Würzburg). John Krafcik, CEO of the world leading autonomous driving company Waymo Google is quoted with: "It will take much more time then all think" Herrenhäuser Forum Mensch-Natur-Technik

(1/15/2019). What can be observed right now are a number of established special applications, island solution not depending on any compatibility standards in closed areas.

Neither in Germany nor in the USA is autonomous driving legalized nationwide. However, in the USA 29 states of 52 have already enacted legislation related to autonomous vehicles. Most recent developments include commercially operated taxis in Phoenix, USA, by Waymo, however with a driver on-board, a delay of Volvo's ambitions to run autonomous cars in Gothenburg, Sweden, for another 3 years, the withdrawal of Uber from their ambitions to run autonomous taxis in several US states after a fatal accident, as well as ongoing tests of Daimler and other large manufacturers.

4.1 Digital Infrastructure

The development of vehicle systems for environmental perception and detection is still at a development stage. At present, the most promising strategy is the development of an application with simultaneous localization and mapping (SLAM) algorithms. However, these applications place high demands on computing power and data transmission. Moreover, corporate venturing is becoming increasingly important to ensure access to key technologies and knowledge. (Seif and Hu 2016)

With the help of big data analytics, the collected data of autonomous vehicles can be used to implement additional services for users or for government institutions, as well as for port authorities. Such services could include machine learning applications, to improve the behavior in traffic situations of all users, the continuous improvement of intelligent traffic control systems, eco-path finder for pollution control, which is a challenge ports are facing too, or even safety and security solutions based on surveillance (Seif and Hu 2016).

4.1.1 Intelligent Transport Systems (ITS)

Intelligent transport systems (ITS) are regarded as a key to make infrastructure safer and to increase its capacity. Actually, these goals are also associated with autonomous driving (see above). ITS are considered to be the answer to current challenges in transportation such as increasing congestion and energy consumption. (Albrecht et al. 2018) Article 4 paragraph 1 of The European Parliament and the Council of the European Union (2010) defines ITS as follows:

> *"'Intelligent Transport Systems' or 'ITS' means systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport."*

Even though today the term ITS refers to all modes of transport and is a term for intermodal transport, it has its origin in road transportation. (Castelli and Bolic 2013) As stated in the Directive 2010/40/EU, ITS in general is the application of computing and telecommunication technologies in transport and is made up of three core themes (see Figure 2):

- intelligent vehicles,
- informed travel, and
- informed transport infrastructure.

Figure 2: Core Issues of Intelligent Transport Systems

Source: HPA, Fraunhofer CML (2019)

The main function of ITS is to increase the efficiency in the transport system, with special focus on the service and information provision for the full spectrum of users.

According to Leal et al. (2018), ITS is a relatively young discipline, with some references setting "[…] the origins in late 1960s in the United States, with the deployment of the first dynamic messaging signs, and the later-on deployment of first generation bus automatic vehicle location mapping technologies." (Leal et al. 2018) The term ITS was used for the first time in the 1980s, when a new discipline appeared on the market: Telematics – the synergy of the existing disciplines Telecommunications and Informatics. (Cho et al. 2006)

ITS have risen as a key technology and application spectrum. ITS are envisaged to provide an effective answer to the increase in transport demand under tight constraints, and need of dimension efficiently the limited capacity of transport infrastructures while releasing pressure on the environment and energy resources, and providing a higher comfort and security for transport of both passenger and goods. (Leal et al. 2018).

Ports as nodal points in the transportation system suffer from congested infrastructure and often by the limitation to enlarge the infrastructure capacity through extension. ITS as a tool to increase infrastructure capacity and to lessen environmental impact can be the tool of choice for ports.

Within the European Union, the Directive 2010/40/EU provides the legal framework for the implementation of actions required for a coordinated and effective deployment and use of ITS. Article 2 of the Directive defines for priority areas for the development and use of specifications and standards (The European Parliament and the Council of the European Union 2010):

1. Optimal use of road, traffic and travel data;
2. Continuity of traffic and freight management ITS services;
3. ITS road safety and security applications;
4. Linking the vehicle with the transport infrastructure.

Especially point 1 and 4 are of relevance when discussing infrastructure requirements of autonomous vehicles in ports. Autonomous vehicles may need to exchange information with the infrastructure while still not having reached a full mature autonomous technology level, which could cope with anything to happen while driving. Article 4 paragraphs 14 and 15 of Directive 2010/40/EU also mention relevant data types. Due to the fact that the directive focuses on road transport, relevant infrastructure and traffic data is road data only (The European Parliament and the Council of the European Union 2010):

- Road data means data on road infrastructure characteristics, including fixed traffic signs or their regulatory safety attributes (Infrastructure Perspective);
- Traffic data means historic and real-time data on road traffic characteristics (User Perspective).

Cooperative Intelligent Transport Systems (C-ITS) are a specific subset of ITS. C-ITS is "a subset of the overall ITS that communicates and shares information between ITS stations to give advice or facilitate actions with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems." (Horton et al. 2016, p.10) C-ITS are supposed to greatly increase the quality of information. They differentiate from conventional ITS by the type of communication. C-ITS use wireless technologies to enable real-time wireless communication between vehicles, roadside infrastructure, mobile devices and back-office systems, improving the safety and manageability of the transport network while reducing congestion and costs.

According to Horton et al. (2016), C-ITS communication includes communication between vehicles (vehicle to vehicle, V2V), between vehicles and infrastructure (vehicle to infrastructure, V2I; infrastructure to vehicle, I2V) and/ or between vehicles and other transport participants (V2X).

4.1.2 International ITS architecture

Although increasing automation of vehicles is discussed almost everywhere in the world, the interoperability of systems and services allowing smooth cooperation and collaboration of involved organizations and actors are not an obvious matter. ITS architectures address the interoperability issue in particular and provide organizational, functional and technical guidance. According to Albrecht et al. (2018) an ITS architecture in general has the objective to provide guidance and support to the following requirements of intelligent mobility:

> *"Intelligent mobility with consistent and interoperable services for all travelers requires common objectives of the involved stakeholders and mutual comprehension of the tasks in order to define the essential interfaces and processes concerning functional, technical and organizational aspects." (Albrecht et al. 2018, p. 2)*

Different activities for the development of national or cross-border ITS architectures started in the 1990s. The first European ITS Framework Architecture was e.g. published in 2000. However, there is no obligation of using this framework for European ITS projects and deployment, leading to the development of individual national ITS architectures across Europe. This leads to ITS architectures that vary regarding their focus.

The following examples clarify the need for a common ITS architecture: The German National ITS Architecture Framework spotlights strategic aspects, especially common vision and objectives, as the essential elements of each ITS architecture. The new Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) in the USA initially covers relationships between organizations in the so-called Enterprise Architecture and the focus of the European ITS Framework is on functional and technical aspects only. (Albrecht et al. 2018) These differences complicate interoperability of border-crossing ITS services, and therefore also cross-border autonomous driving.

The so-called ITS architecture pyramid is a tool to structure the whole scope of the ITS architecture hierarchically into five layers (Albrecht et al. 2018, p. 4):

- *"The **Strategy layer** describes the goals of ITS and ITS services in terms of general principles and describes the ways ITS goals can be reached.*
- *The **Business Process layer** specifies the ITS roles that are part of the ITS value chain creating added value by means of ITS. It also describes how ITS roles interpret ITS goals and ITS strategies for their own business cases and how the collaboration/ cooperation of ITS roles generates an added value. The operationalization of ITS goals is specified in ITS business processes.*
- *The **Information Structure layer** identifies which ITS information objects contribute to the ITS added value, and it describes the structure of these information objects.*
- *The **Service Structures layer** specifies IT services that are used to generate ITS information objects and interfaces that are used to exchange these ITS information objects.*
- *Finally, the **Infrastructure layer** describes how the services and information objects are provided physically, and it defines the structure of hardware and software components that run an ITS service."*

First steps towards an encompassing architecture framework can be made in each country individually. However, for a broader scope, the individual countries' and regions' activities should be bundled to come to an encompassing architecture framework allowing the collaboration of different ITS services, at least through the definition of interfaces.

Info Box 1: The German ITS Architecture Framework Project

- Principles and approaches regarding ITS architecture in Germany are depicted and related to The Open Group Architecture Framework (TOGAF) Architecture Development Method:
  - Enterprise architecture methodology that offers a high-level framework for enterprise software development
  - 80% of Global 50 companies and 60% of Fortune 500 companies used the framework in 2016
  - De facto standard for developing enterprise architectures
- Basic concepts of German ITS Architecture Framework:
  - The concept of ITS services and ITS added value
  - The concept of ITS roles and ITS actors
  - The concept for the formulation of ITS goals and realization requirements
  - The concept of ITS capabilities and cooperation
  - Means, views and tools for the ITS business architecture
  - ITS reference models and tools for the ITS data architecture
  - ITS reference models and tools for the ITS application architecture

Source: Based on Albrecht et al. (2018)

4.2 Road Transport Automation

To achieve a vehicle capable of driving itself, four basic interdependent functions are required (DHL Trend Research 2014):

1. Navigation: Route planning using a digital map that includes information on vehicle location, weather, road type etc.; tracking relies on GPS (global positioning system); autonomous vehicles are capable of communicating with each other and usually with the given infrastructure via communication systems such as WLAN (wireless local area network).
2. Situational analysis: Monitoring of the environment using visual image recognition techniques; additional positioning data can be obtained using markers embedded in the infrastructure; common sensor technology applied is long-/ medium-/ short range radar, LiDAR (light detection and ranging), camera, or ultrasound.
3. Motion planning: Monitoring of the vehicle's movements by using sensors that determine a course of motion within a defined period of time avoiding any detected static object; decisions have to be made about adapting speed and direction; indicators such as the peoples' hand signals or facial expressions can be analyzed to improve the predictive ability.
4. Trajectory control: Managing the execution of pre-planned changes in speed and direction; observation and maintenance of driving stability; actions in accelerating or braking and in adjustments to the steering are performed by the autonomous system.

In the following sections the stage of road transport automation is assessed based on a phase model of road transport automation.

4.2.1 Phase Model of Road Transport Automation

In road transport, there are different phase models that describe the levels of driving automation. These models describe mainly the same taxonomy. Only the definitions and the level of details varies. The most common phase model is the «Taxonomy and Definitions for Terms Related to Driving Automation Systems for on-Road Motor Vehicles» published by SAE International (Society of Automotive Engineers).

The taxonomy for road transport focuses on the dynamic driving task (DDT). Therefore, the DDT is defined as all of the real-time operational and tactical tasks to operate a vehicle in on-road traffic. The navigation part of the driving task as the strategic function is excluded. (SAE 2018)

The following Table 1 shows all operational and tactical functions of the driving task.

Table 1: Functions of the Dynamic Driving Task

Operational functions	Tactical functions
Lateral vehicle motion control via steering	
Longitudinal vehicle motion control via acceleration and deceleration	
Monitoring the driving environment via object and event detection, recognition, classification, and response preparation	
Object and event response execution	
	Maneuver planning
	Enhancing visibility via lighting, signaling and gesturing, etc.

Source: Based on SAE (2018)

Moreover, the SAE guideline defines two different driving automation systems. The term driving automation system is a general term describing all systems used in level 1-5 automation. The hardware and software of such systems can perform part or all of the DDT on a sustained basis. The systems that are capable of performing the entire DDT limited by its use case are called an Automated Driving System (ADS). This term is used for automation level 3-5 systems.

The following Figure 3 illustrates the phase model of road transport automation as defined by SAE (2018).

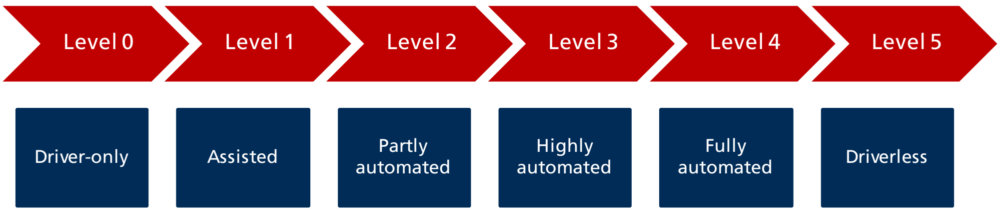

Figure 3: Phase Model of Road Transport Automation

Source: Based on SAE (2018)

Besides the SAE phase model, other phase models exist. (Gasser 2012; NHTSA 2013; VDA 2015). Usually five to six steps are distinguished.

The first step does not involve any driving automation. The so-called "No (Driving) Automation" or "Driver only" depending on the phase model assumes that the driver of the road vehicle performs the strategic, tactical and operational driving tasks while he drives. This means that the driver solely is responsible for the lateral and longitudinal vehicle motion control, monitoring the roadway and for the safe operation of the complete driving task. The level 0 automation does not contain any participation of the driving automation system in the performance of the driving task. Any system only provides warnings and support to the driver.

Warning systems are for example forward collision warning, lane departure warning and blind spot monitoring. Systems that control features that are not part of the dynamic driving task such as wipers, headlights, turn signals and hazard lights can be automated (NHTSA 2013). The vehicle also has active safety systems, which can warn or intervene during a high-risk event, like ESC or ESP (Electronic stability control, also referred to as electronic stability program (ESP) or dynamic stability control (DSC).

V2V warning technology alone is also part of the level 0 automation, even though it can be an important part of the automation because of its capability to provide warnings in several scenarios where sensors and cameras cannot. (NHTSA 2013)

Automation in road transport starts with the **level 1** automation by letting the system perform one of the two degrees of freedom[1]. In this way, the system gets involved into the operational functions of the driving task. The "Driver Assistance" describes the function specific automation where the system performs either the lateral vehicle motion control via steering or the longitudinal vehicle motion control via acceleration and deceleration. However, there are still some events the system is not capable of recognizing or responding. The driver performs the rest of the DDT and remains solely responsible for safe operation. At the same time, the driver needs to supervise the systems behavior and intervenes if it is necessary. The driver makes the decision whether the driving automation system is engaged or disengaged. Moreover, he has to perform the complete DDT immediately whenever he needs to. (SAE 2018) As a result, the driver is always engaged in the operational functions of the driving task and can have either his /her hands off the steering wheel or feet off the pedals, but not both. Examples for level 1 automation systems are cruise control, automatic braking, and lane keeping. (NHTSA 2013)

The third step towards automation is the "Partial Driving Automation". This corresponds to automation **level 2**, which contains the automation of the lateral and longitudinal vehicle motion control. The driving automation system takes over all operational functions of the dynamic driving task for specific use cases and the driver can have his / her hands off the steering and feet off the pedals at the same time (VDA 2015). The system is not capable of recognizing or responding certain events but still needs to be monitored by the driver. The driver decides whether the system is able to perform the operational functions of the DDT and performs the remaining part of the DDT. Moreover, the driver remains responsible for safe operation so the role of the driver stays the same. (SAE 2018; NHTSA 2013) An example for the level 2 automation is the highway assist, which can accelerate, brake and steer in monotonous driving situations on highways (Bosch 2018).

The **level 3** automation is called "Conditional Driving automation" and describes the stage of automation when the driving automation system is able to perform the complete DDT on its own. Because of this, the system is called an Automated Driving System (ADS). The ADS can permit its engagement to the driver if the given conditions allow the system performance. While the system is engaged the ADS performs the complete DDT and detects its own limitations. If the system detects a situation, it cannot handle on its own it timely requests the driver to intervene. The driver now has an active and a passive role to fulfil. The driver must check the operational readiness of the system before the system is engaged in the DDT. The driver makes the decision if the system should perform the DDT too. In case of system's limitations of failure, the driver must be able to perform the DDT or achieve a minimal risk condition. It is the decision of the driver whether or how to achieve a minimal risk condition. (SAE 2018)

[1] Degree of freedom (DOF) of a mechanical system means the number of independent parameters that define its configuration. A car has two independent degrees of freedom consisting of two components of translation.

The "High Driving Automation" **level 4** is the step before reaching the highest level of automation the "Full Driving Automation". At this level of automation the ADS permits its engagement within limitations. The ADS performs the complete DDT by its own and, depending on the observed situation, submits a timely request to the driver to intervene under certain traffic or environmental conditions. Nevertheless, the system is also able to sustain a minimal risk condition when there is a system failure, the driver does not respond the request for intervention or the user requests the system to achieve this condition. At automation level 4, the system only disengages if the driver is performing the DDT or it has achieved a minimal risk condition. Therefore, the system disengages only with a delay when the driver requests its disengagement. The driver at automation level 4 has to verify the operational readiness of the system before the ADS can be engaged. He also decides whether the ADS is engaged or not. When the ADS performs the DDT, the driver becomes a passenger who is only physically present in the vehicle and is not expected to constantly monitor the roadway while driving. The responsibility has shifted from the human individual to the system. As a passenger, the driver does not need to perform the DDT and does not automatically need to intervene when a DDT performance-relevant system failure occurs. The passenger needs not to decide whether or how to achieve a minimal risk condition. They may perform after a DDT performance-relevant system failure when requested or may request that the ADS disengage for becoming a driver or achieving minimal risk conditions. The phase model published by the NHTSA 2013 summarizes the automation levels 3 and 4 as "Limited Self-Driving Automation".

The **level 5** automation called "Full Driving Automation" means that the driver does not need to intervene at all during the entire trip. There are no limitations concerning the traffic or environmental conditions for the system to perform the driving task (VDA 2015). The driver does not need to be able to control the vehicle any time. They only provides the destination. Before driving the vehicle, the operational readiness needs to be checked. The person checking the operational readiness might not be the passenger himself. The driver still decides whether the ADS is engaged or not. While the ADS is engaged the responsibility for safe operation rests solely on the ADS. (NHTSA 2013)

The following Table 2 summarizes the levels of road transport automation based on SAE (2018).

Table 2: Levels of Road Transport Automation

Autonomy Level	Description
0	No assisting technologies
1	Technology assists the driver through functions such as providing information about weather and traffic or even helping to prevent accidents.
2	Cars which can take over and drive autonomously on highways.
3	Cars which can drive autonomously under most conditions.
4	Cars or basically, driverless cars where the car completely takes over the driving from a human being.
5	Cars which can drive autonomously without any human being.

Source: Based on SAE (2018)

4.2.2 State-of-the-Art Analysis of Road Transport Automation

Considering the actual projects developing autonomous vehicles, most of the projects are facing only level 3 or some 4 automation. The key aspect of the projects is on-road testing of vehicle prototypes to improve sensor-processing technologies, adaptive algorithms, high-definition (HD) mapping and the development of V2V and V2I communication. However, there are no indications that level 5 will be reached soon. Most of the "projects" happen in closed environments.

There are however already autonomous vehicles including trucks that operate in a controlled area like mines, industry parks or seaports in Europe, China, Canada and the US (Viscelli 2018; OECD/ITF 2015). Since 2015 the first truck with official road approval using a Highway Pilot is available in the US (Daimler AG 2018). In Germany trucks using Highway Pilot are expected to be available between 2025 and 2030. The trucks being used today have a level 2 automation using e.g. Traffic Jam Assistance (ERTRAC Working Group "Connectivity and Automated Driving"), distance control and cruise control devices.

In the past, utility vehicles have led to many innovations in automotive engineering. The automatic transmission or the automatic emergency braking and braking assistant are examples for such technologies. The digital 3D maps which are used in trucks today are useful for expanding them into V2X-Communication systems. (VDA 2015) For this reason autonomous trucks are expected to be available before autonomous cars. Another reason is the fact that the purchase of autonomous trucks is a business decision and the return on the investment is expected to be very profitable. (Viscelli 2018)

A full legal framework for the deployment of autonomous vehicles in public is not yet in place. Moreover, while the technological challenges are widely the same among trucks and cars, the self-driving technologies for self-driving trucks will be a little bit different. The placement of the sensors and the driving features like longer braking distances must be considered. (Viscelli 2018). Some technologies that are required for autonomous driving already exist. The key technologies and their detection area are shown in Figure 4. These technologies are combined with high accuracy maps. For this reason, the on-board system is able to identify its navigation path, obstacles and signage. In addition to them technologies for V2X communication are needed. (Inninger et al. 2018; OECD/ITF 2015)

State-of-the-Art Analysis and Future Prospects of Autonomous Driving in Maritime and Hinterland Transport

Potential cost savings in road transport will be the most pushing factor to bring these vehicles to market. However, since truck driver's wages differ quite a lot, this effect will become evident in North America and in Western Europe. In other world economies the urge to cut personal costs or to overcome the shortage of truck drivers is less evident.

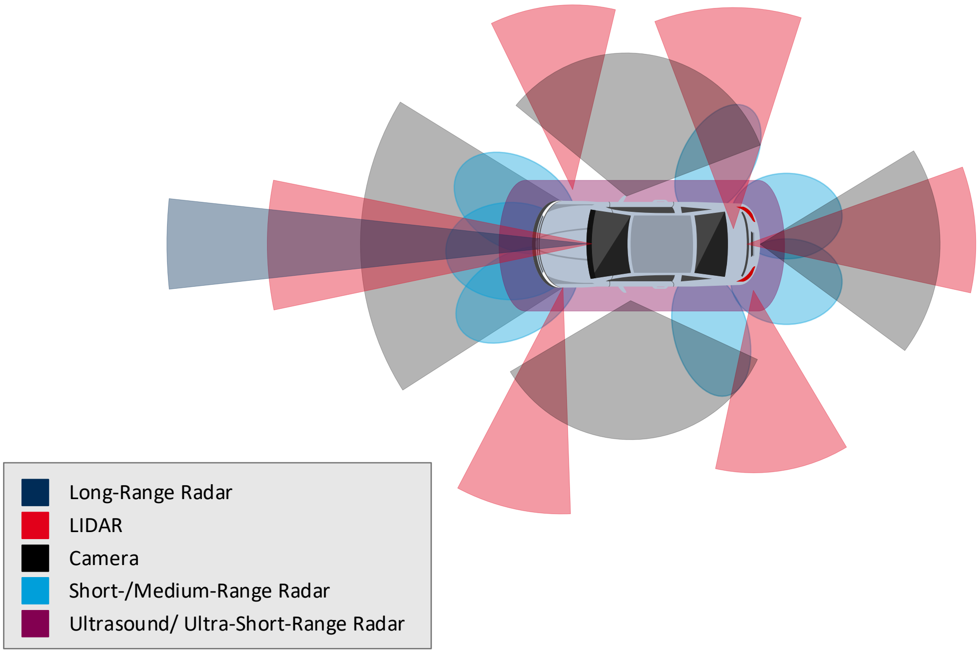

Figure 4: Detection Areas of the Key Technologies in Autonomous Vehicles

Source: Based on Staszewski and Estl (2013); OECD/ITF (2015)

That however doesn't mean that complexity issues in road traffic are solved already. An autonomous system will be required to decide when and how to violate traffic rules. Imagine a level 4 or 5 autonomous car which needs to pass by sloppy parked delivery van but has to cross a continuous lane marking to do so. Will it pass the line or wait hours behind the van?

It is not foreseen in the concept of the fully mature autonomous car that transport infrastructure has to be adopted so that these vehicles can better operate, apart from keeping signs, signals and marks in shape. In the future, the developed technologies should be able to detect road and traffic signs in all conditions. In addition to the static infrastructure, the digital infrastructure will represent the physical surrounding area with which the autonomous vehicle is interacting. (OECD/ITF 2015) E.g. the eCall must be part of all new cars since April 2018, HD maps are expected to be available by 2020 (VDA 2015). It is recognized that autonomous vehicles may need V2I communication But there are no specifications. The V2V communication is already developed and tested in regards to truck platooning. (OECD/ITF 2015) However, regarding platooning, tests by Daimler in the US reveal that savings are so small that the company has decided to skip further investments into that technology.

4.2.3 High Definition (HD) Maps

Autonomous vehicles require maps that are significantly different from the maps that are used in today's navigation systems. The role and scope of digital maps change from being of assistance to the driver to being a data provider to the autonomous machine. In this sense the terminology used as “HD” is somewhat misleading, since this is associated with higher quality of pictures. This is however not the case.

Real time HD maps are supposed to be one of the key technologies for autonomous driving in road transport. HD maps should be able to support autonomous driving cars concerning self-localization, event recognition and reaction, and dealing with other traffic participants. The HD maps are redundant to sensors and provide a high resilience if sensors are not able to detect the environment correctly due to dirt or poor weather conditions. Moreover, no sensor has the ability of localizing and determining a car in reference to its surroundings. (Seif and Hu 2016)

The data source should contain a representation of the road infrastructure, including attributes such as lane models, traffic signs, road furniture and lane geometry, with accuracy down to a few centimeters. Such data sets should be updated in real time, e.g. for construction sites in order to have a real time highly accurate and highly attributed data source. With such a source also lane level accuracy would be achievable since it is a key challenge of autonomous driving to determine the exact location of a vehicle on the road.

The mapping could also help to reduce the reaction time of the system. This might lead to appropriate behavior of the vehicle in traffic beyond the sensors detection area. Additional input such as the exact location, speed, and direction of the car, as well as the current traffic situation and the behavior of other traffic participants, is required. This digital Infrastructure is expected to be a self-updating cloud service. The success depends on the amount of data collected be the vehicles as well as the needed transmission technologies and computing power. (Seif and Hu 2016)

The role of the ports authority as owners of the port road infrastructure could be to provide such maps for the road that they are responsible for and to update them in case of temporary changes immediately.
Additionally, port authorities might benefit from HD maps by offering value added services like parking space allocation. On the other hand the detection technologies of the vehicles could transfer data about the quality of the streets or the traffic light circuit. These data could be used for infrastructural improvements.

4.2.4 Low Latency Communication

Following Blanco et al. (2017) and García Sánchez et al. (2017) autonomous driving, together with virtual and augmented reality as well as tactile internet, have been identified as one of the use cases whose requirements cannot be achieved by current mobile networks but will be met by future 5G networks. According to Panwar et al. (2016) the massive growth of connected devices and in traffic volumes demands the development of 5G mobile networks. However, they are not standardized yet. Therefore, testing grounds are implemented across the world, e.g. in Germany in the Port of Hamburg (see Info Box 2).

Info Box 2: 5G Testing Ground in the Port of Hamburg[2]

- Goal: To test new aspects of the 5G standard using various applications in real-world industrial conditions
- Test area covers about 8,000 ha of port area
- Project involves Hamburg Port Authority AöR (HPA), Deutsche Telekom and Nokia
- Case Studies:
  - Data glasses for engineers
  - Connected antennas
  - Sensors on ships
- Field test is part of the EU-funded 5G-MoNArch (5G Mobile Network Architecture for diverse services, use cases, and applications in 5G and beyond) project (two-year research project), which goal is to establish a basis for defining further aspects of the 5G standard

Source: Based on Hafen Hamburg Marketing e.V. (2018)

As described by Brümmerstedt et al. (2017), 5G is expected to create an ecosystem for business and technical innovation and to enable competitive advantages for industry. It is supposed to be a complete communication ecosystem to enable a fully mobile and connected society (Blanco et al. 2017). 5G networks are expected to serve a wide range of applications and services. Examples include logistics and tracking, automation, smart grids, or personal usages (Panwar et al. 2016).

Info Box 3: Project Green4TransPort

Green4TransPort is a test-project focusing on the communication between infrastructure (e.g. traffic lights) and vehicles

- Content: Prioritization of trucks at intersections to increase traffic efficiency of port road network
- Goal: To optimize traffic flows and reduce emissions by smoothing out the average speed of groups of trucks
  - The system (V2X via ITS-G5 WLAN) that will be utilized is suitable to exchange data between vehicles and infrastructure
  - Thus, it is potentially an important component for future projects of autonomous driving, enabling communication between vehicles and traffic light signals. Autonomous vehicles could then receive information about relevant traffic light phases and could hereby adjust their drive modus and speed.
- The project involves the Hamburg Port Authority AöR, Scania CV AB, NXP Semiconductors Germany GmbH, Siemens Mobility GmbH, Technolution B.V.
- Green4TransPort will be presented at the 28th ITS World Congress, which will take place in October 2021 in Hamburg.

Source: Hamburg Port Authority HPA AöR (2019)

However, autonomous vehicles do not always need to communicate with each other consuming heavily mobile bandwidth. They rather interact with each other, which is something completely different. None of the available concepts for full automation

[2] https://5g-ppp.eu/5g-monarch/

would rely on the availability of a cellular network only. It is one of the most obvious contradictions observed in the current debate about autonomous driving.

Ports however could provide assistance to the recent autonomous driving technologies by providing data communication systems such as 5G mobile networks. Such networks would also be a competitive advantage for ports if it comes to IoT applications of intelligent freight and intelligent containers. In regards to wireless technologies there is quite a rush in the development of new wireless data submission standards, such as G5, not to be mixed with 5G. The new wireless LAN technologies and protocols should enable the communication of sensors and devices, which could also be used by autonomous driving. The role of the port authority can be very different, depending on the national legislation. It could be very difficult and costly to become a telecommunication entity with all rights and obligations.

4.2.5 Future Prospects of Autonomous Driving in Ports

Autonomous commercial vehicles like trucks are expected to be available before autonomous cars for individuals. Figure 5 illustrates the applicable areas of autonomous trucks in Europe and North America. Autonomous driving in ports is expected to materialize between 2020 and 2025. These timeframes are however subject to speculation and could prove wrong.

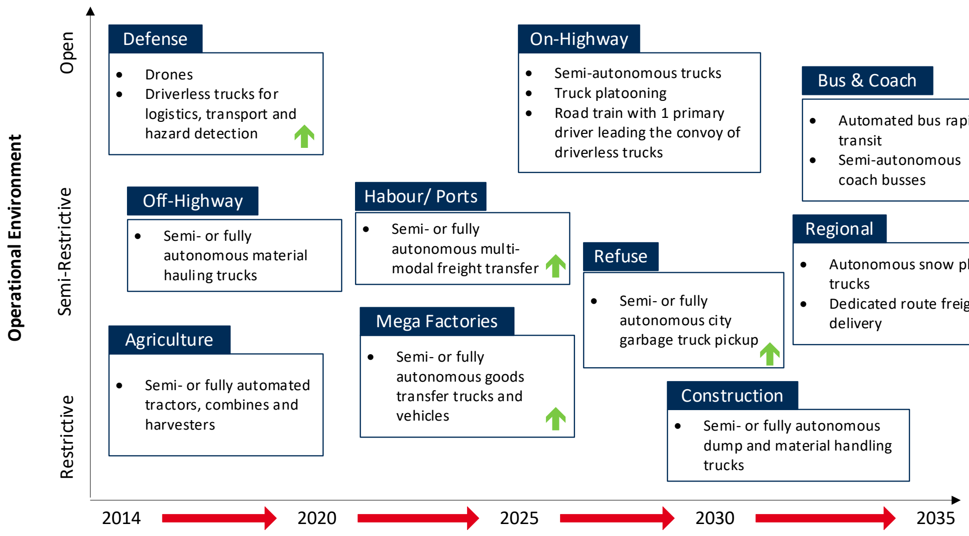

Figure 5: Application Areas of Autonomous Driving Commercial Vehicles in Europe and North America

Source: Based on Frost & Sullivan (2015)

Like in all automation environments, closed areas with homogenous demands for the movements of vehicles are much more suitable for automation than heterogonous areas in which different types of traffic mix. So we will most likely see autonomous transport in gated or private areas in ports (in specialized transshipment areas, i.e. oil, coal, gas, ores) or large factories. The vision of how autonomous driving in Ports could look like is illustrated in Figure 6.

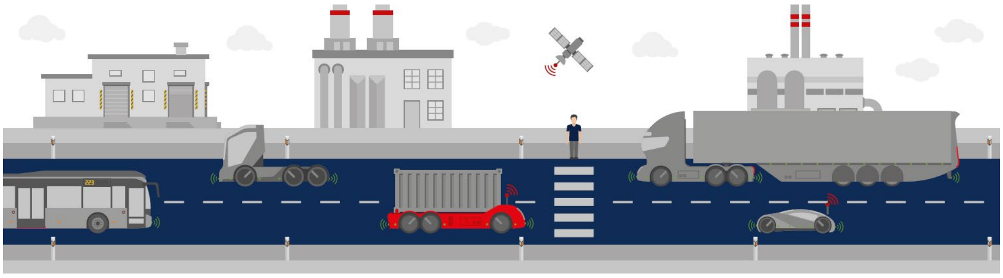

Figure 6: Vision of Autonomous Driving in Road Transport in Mixed Traffic

Source: HPA, Fraunhofer CML (2019)

As illustrated in Figure 7, there will be a long transition period with gradually increasing penetration of different levels of automated vehicles.

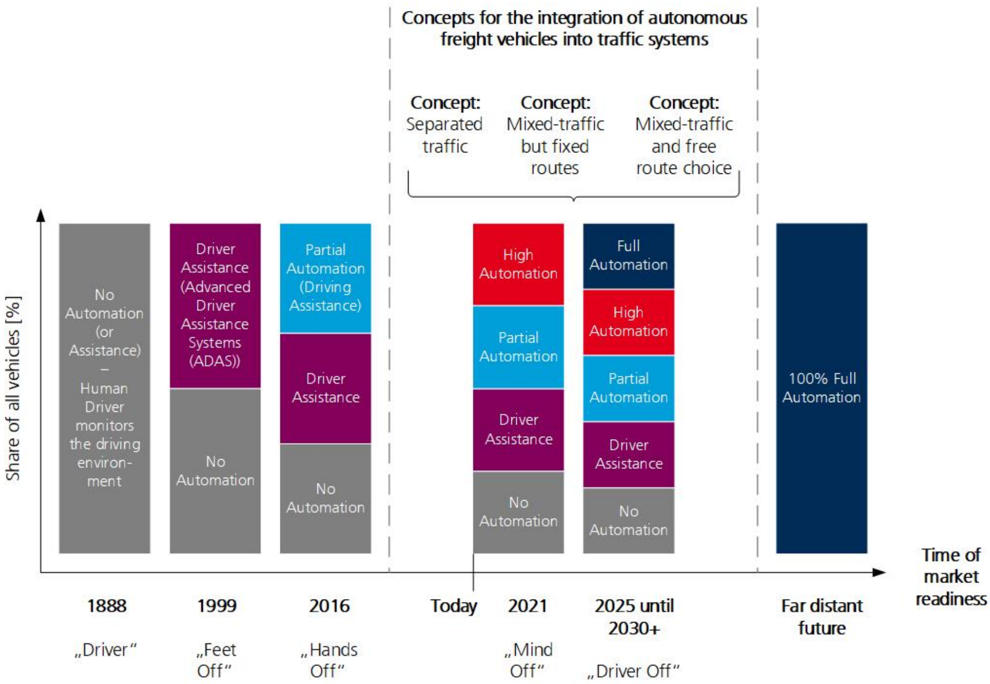

Figure 7: Future Prospects of Autonomous Driving in Ports

Source: Based on TÜV Süd (no date)

The above figure is an optimistic view into the technical possibilities and the acceptance of the autonomous vehicles. As visualized in the figure above, three concepts for the implementation of automated road transportation are most likely for the transition period:

- Separated traffic
- Mixed-traffic but fixed routes
- Mixed traffic and free route choice

The following sections describe these concepts and their individual infrastructural requirements that could be implemented in ports.

4.2.5.1 Concept: Separated traffic

With the help of this concept, self-driving vehicles were first used for passenger transport at the Rivium Business Park in the Netherlands in 1999 (ITF/RPA 2016). Self-driving vehicles can also be used for goods transport. Examples are autonomous vehicles on factory premises as well as regional shuttle transports, such as hinterland port transports or the transport of mined raw materials to corresponding processing plants (Inninger et al. 2018). Transport systems based on the concept of separated traffic share many parameters. The environment in which a transport with self-driving vehicles can be realized has a rather low complexity and can easily be controlled. In this case, a reduction in complexity also involves a minimal interaction with other road users. In addition, the physical infrastructure is adapted by structural measures as a separation between autonomous driving vehicles and other road users. Although there is no driver in the vehicle any more, monitoring of the operational area of autonomous vehicles is necessary, since the vehicles cannot deal with complex events due to the simple environment. The speed travelled in such a system depends on the time required for emergency braking and the degree of separation from other road users (ITF/RPA 2016).

According to Lytrivis et al. (2018) the assignment of a dedicated lane to automated traffic is expected to reduce the safety concerns around the penetration of the automated vehicles to conventional traffic. Moreover, the separation of autonomous vehicles leads to an increasing lane capacity caused by reducing the space left between vehicles and a more regularly traffic flow. This also leads to increasing speed – but not as a result from automation but from concrete infrastructure extension. In mixed traffic conditions, the autonomous vehicle has to deal with human behavior and the manual vehicles are setting the speed. (Maurer et al. 2015; Breden and Kottenhof 2018)

In this concept, all vehicles interacting are capable to provide information to each other via V2V communication. The V2V communication is a supporting technology for autonomous vehicles but not a pre-requisite. Because of the delay between development of autonomous vehicle and inadequate V2I-communication of the infrastructure, separated traffic is the first step towards autonomous driving. The vehicles are protected from conventional vehicles by physical barriers (Breden and Kottenhof 2018) and the infrastructural requirements caused by autonomous vehicle are only relevant for certain lanes. These lanes need to have sensors to provide information on the state of the infrastructure.

The greatest difficulty in implementing this concept lies in traffic management. Intersections between autonomous and commercial vehicles must be conducted without any problems and without disturbing the entire traffic (Inninger et al. 2018). In addition, the space requirement for the traffic area increases due to additional lanes and barriers between the lanes and there are costs for the conversion and new construction of traffic facilities.

Info Box 4: Concept for a Replacement of an Inner Port Infrastructure - Köhlbrand Bridge/ Hamburg

> Since 1974 the Köhlbrandbrücke is one of the most important bridges In the port of Hamburg. Due to the fact that the bridge is not constructed for such a high traffic demand, the end of its operation time will be reached in 2030.
> Possible future replacements are a tunnel or a new bridge.
> When planning such a big infrastructure project with an average lifecycle of 50 or more years the question is how to design the new crossing and which concept should be chosen for integrating the requirements of autonomous vehicles. .
> A tunnel built using shield tunnelling could thus offer advantages for the integration of autonomous vehicles, as additional lanes, e.g. for UAVs, are available above and below the actual roadway.

Source: Based on HPA (2019)

4.2.5.2 Concept: Mixed-traffic but Fixed Routes

In this concept autonomous vehicles are just allowed on dedicated routes, e.g. between terminals within one port or on dedicated routes between two ports. This leads to a reduced complexity of road systems and infrastructure.

This implementation concept enables the testing of newly developed vehicles under real conditions. From a legal point of view, autonomous vehicles can only be used in public on specified routes. Truck Platooning, which is currently undergoing testing and implementation, is also based on this concept, however, with Daimler a major player has just ceased its ambitions regarding truck platooning. Since vehicles up to level 4 automation are not capable to handle all traffic situations, a pre-selected route reduces the probability of such a situation occurring.

In the public transport use case, shuttles will typically operate within limited areas or on predefined tracks, at least in the early application stages. Therefore, the need for operation "everywhere" is less critical, and it may be an attractive alternative to adjust the infrastructure (i.e. by using an electronic track and some barriers to protect from other traffic and to improve the system performance. (Breden and Kottenhof 2018)

4.2.5.3 Concept: Mixed-traffic and Free Route Choice

The essential condition for the use of autonomous vehicles in mixed traffic is that the vehicle can perform all driving tasks under all conditions and in all situations. So this concept can only be applied with level 5 automation. In addition, different requirements are placed on both the physical and the communication infrastructure. For the functionality of autonomous vehicles and the system, provision and the degree of connectivity with wireless technologies such as DSRC and possibly 5G is of elementary importance. However, connectivity is the issue, not bandwidth.

Opinions in this concept differ a lot: It is still not clear, if a communication of V2V and V2I is required at all for autonomous vehicles. Vehicles shall interact, not communicate with each other. Any dependency on external networks should be avoided.

Other experts are of the opinion that even a monitoring system would be needed to ensure reliable communication. The requirements for the physical infrastructure cannot yet be clearly defined, as the necessity of structural separation between autonomous vehicles and other road users is determined by the achievable technological maturity. At present, it is not yet possible to determine which situations can never be handled by an autonomous vehicle and must be prevented by structural measures (ITF/RPA 2016).

For integrating autonomous driving vehicles into conventional traffic without capacity loss there need to be technical solutions for traffic nodes as well as structural and regulatory adjustments need to be developed (Maurer et al. 2015). For urban driving especially the conditional compatibility between crossing traffic flow needs to be changed because autonomous vehicles cannot handle those situations. This could be solved by a separate green traffic light phase for autonomous vehicles which do not need special traffic rules when V2X communication is possible or a separate green traffic light phase for pedestrians and cyclists. (Maurer et al. 2015)

Info Box 5: Hamburg TruckPilot

- Goal: To analyse and validate the exact requirements for customer-specific deployment in a real-world setting and the integration of autonomously driven trucks into the automatic container handling process
- Test areas are the Container Terminal Altenwerder (CTA) and about 70 km long route of the A7 motorway
- Project involves Hamburger Hafen und Logistik AG (HHLA) and MAN Truck & Bus
- Project phases:
  - Preparatory phase until the end of 2018 includes the definition of the technical framework conditions
  - Testing Phase until June 2020 covering the technical development of the system
  - Trial operations between July and December 2020 in a costumer-relevant application context
- The “Hamburg TruckPilot” project is part of the strategic transport partnership between the City of Hamburg and the Volkswagen Group. "Hamburg TruckPilot" is an important project of the ITS strategy in the field of "Automated and Connected Driving" for the city of Hamburg. It will be presented at the 28th ITS World Congress, which will take place from 10 to 15 October 2021 in Hamburg.

Source: HHLA (2018)

4.3 Railway Transport Automation

Rail transport is an important hinterland mode for ports. Even though, railway transport is already highly automated and there are already autonomous solutions in the field of rail traffic, such as numerous metro lines, the complexity of public transportation rail networks and operational procedures and potential risk of extremely high damage makes autonomous driving difficult to realize. Many parties influence the railway sector such as train operating companies and network operators, especially in countries where we find a separation of network and operations. This results in high demands on interoperability. The implementation of autonomous driving solutions can only be realized by using a top down strategy that includes all parties and guarantees a consistent interoperability.
For port authorities, even if not every port has its own rail network, involvement may be necessary for the implementation of autonomous solutions in the first miles of hinterland transport. In the following sections the stage of railway transport automation is assessed based on a phase model of railway transport automation. Moreover, the state of the art of railway automation and its future prospects are considered.

4.3.1 Phase Model of Railway Transport Automation

For describing the automation in rail transport, there is no international standard. In Europe, the EN 62290-1 provides a general concept of driving automation in rail public transport. The automation levels of rail-based vehicles called Grades of Automation (GoA) consider the basic functions that need to be performed while driving. The Grades of Automation describe the shared responsibility of the operating staff and the system concerning the basic functions (see Table 3). The requirements for the operation, facilities, vehicles and operating staff depend on the GoA. In addition, the behavior of external persons must be considered. (EN 62290-1)

Table 3: Basic Functions of the Driving Mode in Rail-based Public Transport

Guarantee a safe train movement	Safe routes Safe distance to other trains Safe speed
Driving	Monitoring the acceleration and deceleration
Monitoring the vehicle	Prevention of collisions with obstacles or persons on the tracks
Monitoring the passenger exchange	Operating and monitoring the door automatism Prevention of the injury of passengers Guarantee of safe start conditions
Operating a Train	Operating at the train station Supervision of the state of the train
Guarantee the detection and accomplishment of emergency conditions	Performing the rain diagnostic Recognizing fire, smoke and derailment Treatment of emergency conditions (emergency call, evacuation/ supervision)

Source: Based on (EN 62290-1)

The following Figure 8 illustrates the phase model of railway transport automation as defined by EN 62290-1.

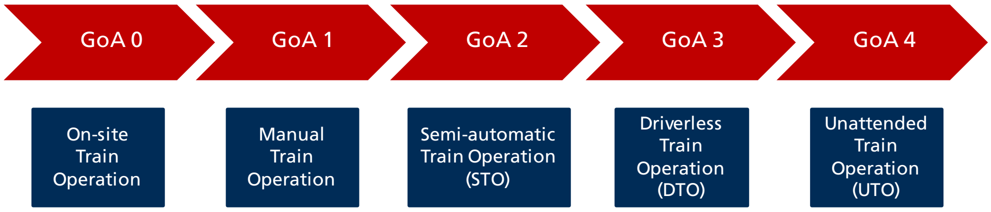

Figure 8: **Phase Model of Railway Transport Automation**

Source: Based on Niessen et al. (2017)

The first Grade of Automation (GoA 0) is called On-sight Train Operation. At this Grade, the locomotive driver has to perform all basic functions and is solely responsible for safe operation. The system does not monitor the performance of the train. Only the switches or routes with single-tracks can be supervised by a system. (EN 62290-1)

The GoA 1 is called "Manual Train Operation". The key element of GoA 1 is the Automatic Train Protection, which is a system performing the safe train movement. The next step towards train automation is the implementation of the Automatic Train Operation. This system is capable to perform the driving function on its own. This semi-automatic Operation corresponds to GoA 2. (EN 62290-1; UITP)

At GoA 3, the system is completely computer controlled and "Driverless" but there needs to be a person in the train to monitor the passenger exchange and guarantee the detection and accomplishment of emergency conditions. In addition, a person performs the supervision of the train's state. By installing the Automatic Train Control (ATC), the train gets completely autonomous and reaches GoA 4. The Automatic Train Operation and Control systems work together and perform all basic functions of the driving mode. (UITP)

This guideline can be transferred to the complete railway transport. The basic functions might differ a bit in transportation of passengers or cargo. It is easier to realize autonomous driving in rail (urban)public transport because of the often separated infrastructure (Niessen et al. 2017). The technical standards are the same and the vehicles using it are all from the same type of service.

Railway however as rail-bound traffic is by definition already one step ahead of road transport since steering is not applicable. Railway infrastructure is largely standardized, however partly different from country to country or even within one country, like in the USA. In Europe the European Train Control System (ETCS) with the European Rail Traffic Management System (ERTMS) overcome such issues like ETCS level 2 or 3. (Niessen et al. 2017)

Especially in freight transport, the train automation is challenging. The freight transport on rail in Europe suffers for its subordinated status, while in North America freight comes first. In Europe, freight trains must make way for passenger trains because of the speed difference between them. This difference in speed makes train automation difficult. (Niessen et al. 2017) Moreover, the freight trains use an international exchangeable wagon fleet and there is no possibility to check their integrity (Randelhoff 2014).

The following Table 4 summarizes the levels of railway transport automation based on EN 62290-1.

Table 4: Levels of Railway Transport Automation

Autonomy Level	Description
0	Comparable to a tram running in street traffic
1	A train driver controls starting and stopping, operation of doors and handling of emergencies or sudden diversions.
2	Starting and stopping is automated, but a driver operates the doors, drives the train if needed and handles emergencies. Many ATO systems are GoA 2
3	Starting and stopping are automated but a train attendant operates the doors and drives the train in case of emergencies.
4	Starting and stopping, operation of doors and handling of emergencies are fully automated without any on-train staff.

Source: Based on Niessen et al. (2017)

4.3.2 State-of-the-Art Analysis of Railway Transport Automation

Rail transport is generally a transport mode with very high safety standards. For more than 100 years, interlocking systems have been responsible for securing rail traffic. Interlockings are responsible for the protection of the track and the train sequence, which includes the closure of the track and the transmission of the correct signal information. Tracks for train and shunting movements are released by the signal box for safety reasons. Exactly one route is set for each journey and the train sequence is thus technically secured. Numerous sensors are used on the infrastructure side and on the vehicle side for implementation in rail traffic. A train is influenced selectively and linearly. (Schnieder and Becker 2007, p. 195f)

Today, autonomous rail systems operate as metros, subways, or light rail, manufactured by Siemens, Alstom, Bombardier, Conductix and others. The developed systems in closed environments have no need at all to be compatible to any standard apart from national security rules. E.g. the autonomous Metro in Paris does not have to share any system approach with the new built train of Pisa, since they will never interoperate. Same is evident for island solutions of automated coal trains running between a mine and a private coal port in Australia or the transit train between the airport terminals in different airports such as Bejing, Birmingham, Munich or London. They do not interact.

Rail traffic in ports can be divided into driving and shunting operations. Both modes of operation differ in their entry requirements, resulting in different requirements for autonomous operation. The degree of automation of both operating modes also differs considerably.

The prerequisite for safe transport is, in particular, compliance with permissible speeds and distances to obstacles during movement. Due to the long braking distances at higher speeds, driving on sight is unacceptable. The distance between two trains is defined as the maximum braking distance at maximum speed. In shunting mode, the distance results from the braking distance difference between the two trains with a safety margin. (Schnieder and Becker 2007, p.198)

The responsibility for safe operation lies with the supervisor, who monitors train traffic and releases the track-blocks if there is no train on them. The driver guides the vehicle and intervenes in emergency situations. This corresponds to the grade of automation GoA 2/3.

During shunting operations, driving takes place on sight and the locomotive driver is responsible for the safety and pass ability of the track sections (GoA 0). In addition, operating regulations stipulate that a person at the top of the first wagon (if the shunting locomotive pushes the train instead of pulling it) must monitor the route. Remote-controlled locomotives already exist to save personnel.

However, most wagons are coupled manually - automatic coupling still remains a niche application. Another manual process is to secure the wagons against rolling away on inclined tracks with brake shoes. There are also so-called local signal boxes in areas with lower traffic volumes where the locomotive driver is responsible for setting the switches.

Two ways of shunting exist

- Flat marshalling
- Run-off hill

Info Box 6: Intelligent Railway Point

The Hamburg Port Authority is constantly developing and adapting smart port solutions. For railway transport operations in ports the frequently used points in in the port railway system like switches are fitted with sensors that transmit data to a central IT system in real time.
The data that is collected by passing over the switching points can be used in different ways. Actually the data is used for supervising the condition and wear of the essential operational intersections.
In terms of autonomous driving these technologies might offer the possibility of value added services for train operators.

Source: Hamburg Port Authority (2019)

4.3.3 Future Prospects of Autonomous Railway Transport in Ports

Most train and shunting services must remain compatible as the infrastructure is used by both modes of operation. Automation of self-contained systems with similar vehicles, such as in metro traffic, is easier to implement due to lower demands on sensors and control technology. Examples of existing fully automated passenger services exist in many places. So the technology is not the problem. For the railway companies however the focus is depending on their market segment not on autonomous trains, even though most large railways like SNCF from France or DB from Germany experiment with it. In the US the focus of the private railway freight companies have been to cut cost and increase efficiency by in general, longer, heavier and less frequent trains. The major issue remains the liability problem of the large cooperations. Having no train driver as the legally responsible person the whole cooperation will be liable in case of system failure for a complete passenger train or a freight train.

There is already a high degree of automation and concepts for further automation in line traffic. The ETCS train control system and digital interlocking systems form the basis for digitalization on the rail. ETCS is also the basis for future technologies such as highly developed sensor technology for object recognition or powerful real-time positioning systems to completely digitize rail operations in the future. A further developed railway system for autonomous driving trains includes sensor and data transfer between trains, tracks and signals (see Figure 9). Technologies for this are mature and open up completely new possibilities to increase the reliability of rail operations and the capacity of the rail network by up to 20 percent (Deutsche Bahn AG 2018). Variable block spacing would be one of the options becoming available through digitalization (Niessen et al. 2017).

Figure 9: Autonomous Freight Train

Source: HPA, Fraunhofer CML (2019)

In addition, the German Aerospace Center is developing a new concept to solve the problem of the last mile and the time-consuming train composition.

Info Box 7: NGT Cargo

The German Aerospace Center DLR develops a future train concept. The Project is called Next Generation Train (NGT).
The aim of the project is the development of innovative and integrated concept. Therefore self-driving NGT-Cargo trains should be developed. The train consists of smart wagons that have the ability to travel the so called last mile autonomously.
The automatic NGT CARGO trains are assembled from individual wagons and powerful locomotives as required and automatically coupled. This is expected to enable the transport a wide variety of goods flexibly, with minimum resource consumption, with low personnel costs and short transport times. It would also replace the cost extensive shunting to a great extent.

Source: DLR (2017)

If autonomous shunting should succeed, the following questions must be answered and the functionality of processes maintained. The first simple but important question is which degree of automation is desired and can be realistically reached. The second question that has to be considered is if the desired process automation can be monitored sole by the vehicle. Another aspect concerning the feasibility is that a mobile solution for monitoring shunting processes at the top must be developed because retrofitting all railcars is far too expensive. If shunting is to be automated, the wagons must also be coupled and secured against rolling away automatically, otherwise the efficiency gains will be questioned.

By instructing the speed adjustment to visibility conditions, a complex control technology of the locomotive becomes necessary. Additionally, requirements are placed on the lighting conditions for checking freedom of movement. In relation to local signal boxes, communication between locomotive and switches or between locomotive signal box and switches would be necessary in order to be able to use the correct route without human assistance. Generally, the system must be highly resilient and fail-safe. Possible failures include system failures to wagon derailments to fires.

Tasks are carried out manually by the supervisor and must be solved systematically. In the case of wagon derailments, the control system of the traction unit must be able to recognize these and accordingly cause the surrounding tracks to be closed. A prerequisite for automated operation would be a reliable locating of locomotives and wagons, as well as functioning communication between locomotive, control system (the system for locomotive control and wagon movements is not always the same system used in the locomotive) and wagons. Redundancy and resilience is also required on the IT side.
According to these assumptions, automation for long-haul and scheduled services seems more realistic than for port railway operations. (Mansholt HPA).

The digital infrastructure will have to meet requirements with regard to performance in the area of data transmission of large data sets and data processing. Infrastructural requirements always arise when the limits of technical feasibility have been reached or when the equipment of the means of transport does not make sense for economic/financial reasons. Combined transport requires uniform data formats and data packages for data exchange between modes of transport.

Info Box 8: RANG-E Autonomous Shunting Project[3]

RANG-E - Autonomous shunting on the port railway
Objective of the study:
To make shunting processes in seaports more efficient through process optimization and automation
The expected effects of autonomous emission free shunting operations to date are the following:

- Simplification of operational rail processes
- Avoidance of empty-locomotive-drives
- Reduction of the overall shunting stock (Savings of about 30 percent are expected)
- Avoidance of communication-interfaces
- Optimization of infrastructure use with savings on future investments
- Reduction of operational efforts and costs (on the locomotive and in the offices) through reduction of personnel
- Safety-Improvements
- Disruptions reduction in port railway operations

Project schedule/ Duration: from 01.08.2017 to 31.07.2019
It is a feasibility study to assess the feasibility of autonomous shunting operations
SHUNT-E examines the potentials and obstacles for the introduction of a more intelligent control of train traffic on the port railway using the pilot port of Bremerhaven as an example. The project tests various automation levels up to complete autonomy and self-control of shunting units.

Source: ISL 2018

[3] https://www.rang-e.de/

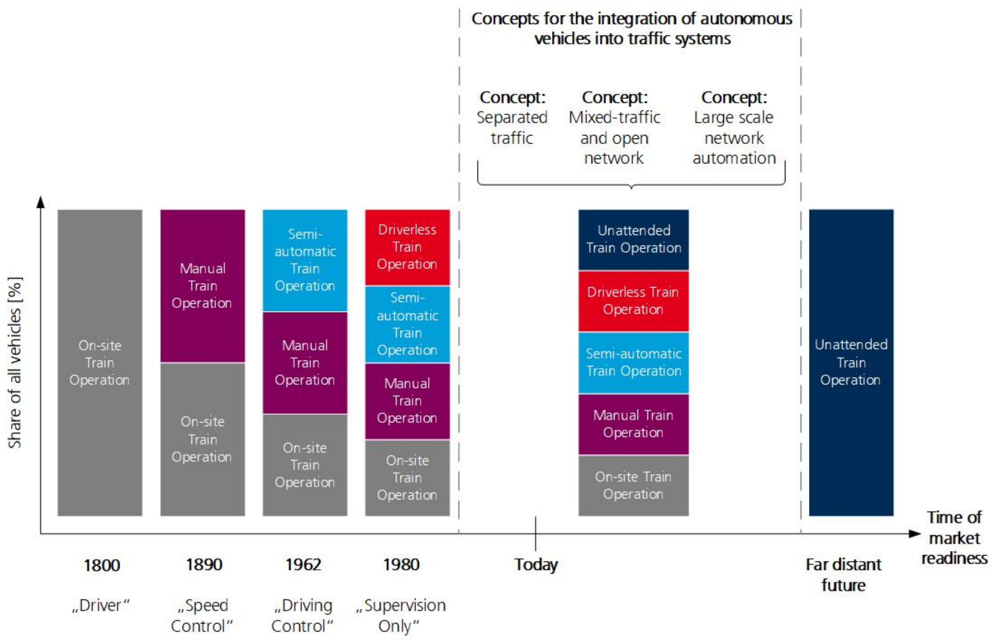

Figure 10: Future Prospects of Autonomous Railways in Ports

Source: Fraunhofer CML 2019

The figure above shows the development of autonomous driving in railway transport. The past developments have shown that depending on the traffic conditions the possibilities for implementation of autonomous driving are different. There are three concepts of railway automation:

- Separated traffic
- Mixed traffic and open network
- Large scale network automation

4.3.3.1 Separated Traffic

These solutions are closed systems in which one type of vehicles moves within the system and no interaction with other vehicles or users is necessary. In addition, the systems used do not have to be interoperable. These solutions can also be implemented for closed systems in Freight transport such as the transport of iron ore between the mine and the port in Australia. The so-called AutoHaul Train from Rio Tinto operates autonomously over a distance of 280 km between the mining place Tom Price and Port Walcott. The line is used exclusively for this purpose. In Europe Alstom tested in 2018 autonomous freight trains on a 100 km track of the Betuweroute between the port of Rotterdam and the shunting yard CUP Valburg.

According to the operational marketing manager for Alstom Digital Mobility, Stephen Shirlaw, Shunting yards are large, closed environments, with no level crossings or passengers, making them ripe for automation. A lot of time and personnel can potentially be saved by automated or autonomous shunting if the aspects discussed above can be technically solved.

4.3.3.2 Mixed- traffic and open network

Mixed traffic generally means traffic which is carried on the same transport route with different types of vehicles, modes of operation, sets of rules or types of rail traction. Mixed traffic in this context focuses on the different types of vehicles with different Grades of Automation using the same network. For mixed traffic, there are no autonomous solutions so far and therefore any identifiable infrastructure requirements yet. Since in multipurpose ports, the main focus is usually on shunting operations and the trains that are formed then leave the port area and enter a rail network, such as the state railway network, autonomous rail travel can only be considered to the extent that the interoperability of both systems must be maintained.

4.3.3.3 Large scale network automation within an open network

This concept requires that all vehicle types have reached the same grade of automation and therefore only one operation mode is used for the entire network. Even though this only seems realistically in a far distant future. The implementation of such complex concept is expected to be very expensive and a lot of different parties are directly or indirectly involved.

4.4 Waterborne Transport Automation

This section illustrates the status of development regarding the evolution of Maritime Autonomous Surface Ships (MASS). Firstly, a phase model of waterborne transport automation is described. Afterwards, the chapter analyzes the status of the development of automation in shipping, including a description of smart and autonomous vessels already in operation.

4.4.1 Phase Model of Waterborne Transport Automation

The Waterborne Technology Platform (2011) defines the 'Autonomous Ship' as a vessel with

> *"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 Technology Platform 2011)*

Bureau Veritas (2017) states that autonomous ships should be capable of:

- *"Managing a pre-defined voyage plan and updating it in real-time if relevant*
- *Navigating according to the predefined voyage plan and avoid collisions with obstacles coming from the traffic or unexpected objects*
- *Keeping a sufficient level of maneuverability and stability in various sea states*
- *Withstanding unauthorized physical or virtual trespassing."*

In paragraph 1.4.1 of the Guidelines for Autonomous Shipping Bureau Veritas (2017) differentiates the following vessel types:

1. Autonomous ships, manned with a reduced crew or unmanned with or without supervision;
2. Smart ships, connected ships capable of collecting data from sensors and having the capacity to process a large amount of data in order to assist the crew during the decision making process. It may be manned with reduced crew or totally unmanned with remote control;
3. Conventional ships, manned ships that may have automated systems to assist the crew by automatically performing some actions, but those systems are always under the control of human aboard;
4. Unmanned ships, ships that do not physically contain a human and is capable of controlled movement. Ship may be remotely controlled, supervised or fully autonomous.

Therefore, autonomous ships have the same capabilities as those of smart ships including autonomous systems capable of making decisions and performing actions with or without human in the loop. The major difference is the human factor.

The definitions given by Bureau Veritas (2017) allow the derivation of even more vessel types: Manual vessels without autonomous functions, smart ships, autonomous vessels with human on the loop, monitored autonomous vessels, and fully autonomous vessels. These vessel types comply with the autonomy levels (AL) given by Lloyd's Register (2016) and Lloyd's Register (2017a), which differentiate even more vessel types:

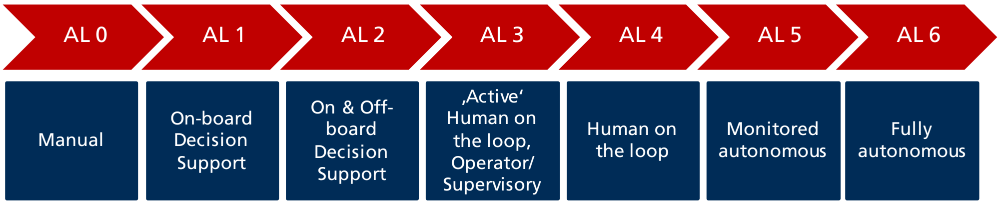

Figure 11: Phase Model of Waterborne Transport Automation

Source: Based on Lloyd's Register (2016), p. 2

Lloyd's Register (2017a) describes the mentioned autonomy levels of vessels as follows:

Table 5: Levels of Vessel Automation

Autonomy Level	Description
0	No autonomous function. All action and decision-making performed manually […], i.e. human controls all actions.
1	All actions taken by human operator, but decision support tool can present options or otherwise influence the actions chosen. Data is provided by systems on board.
2	All actions taken by human operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board.
3	Decisions and actions are performed with human supervision. Data may be provided by systems on or off-board.
4	Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human Operators the opportunity to intercede and over-ride.
5	Rarely supervised operation where decisions are entirely made and actioned by the system.
6	Unsupervised operation where decisions are entirely made and actioned by the system during the mission.

Source: Lloyd's Register (2017a), p. 1-2

However, all these definitions define a ship as autonomous as soon as it is able to conduct a voyage on its own. What`s missing in these descriptions are the information on the infrastructural prerequisites, and the definition of start and end of a vessel`s voyage. There are already research projects that aim at mooring autonomously and what about the loading and unloading process? Such obvious gaps show the novelty of the topic.

To further progress, the topic of MASS has meanwhile even been recognized by the International Maritime Organization (IMO MSC 2017b) and consequently initiated a regulatory scoping exercise to identify:

- IMO regulations which, as currently drafted, preclude unmanned operations (IMO MSC 2017a);

- IMO regulations that would have no application to unmanned operations (as they relate purely to a human presence on board); and
- IMO regulations which do not preclude unmanned operations but may need to be amended in order to ensure that the construction and operation of MASS are.

A recent analysis on this matter was afterwards done by Denmark highlighting in detail where regulatory amendments might be needed (IMO MSC 2018a). Further, IMO defined its own levels of autonomy covering a wide range from "real" autonomy down to simple remote control (IMO MSC 2018b):

- Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with a seafarer on board ready to take control.
- Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
- Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

Similar activities are also happening in the inland shipping domain. One major achievement here is the definition of automation levels by the important Central Commission for the Navigation on the Rhine (CCNR 2018).

4.4.2 State-of-the-Art Analysis of Waterborne Transport Automation

MASS are expected to have major effects on maritime safety, efficiency and sustainability. Just by introducing MASS systems in the existing cargo scheme, latest studies expects an improvement in the ship's life cycle costs already by 5-10% per vessel or even up to 22% per transport unit, mainly by fuel efficiency improvements and crew cost reduction. In parallel, safety is expected to improve (Kretschmann et al. 2017; Rolls-Royce (K. Daffey) 2017). An initial study regarding collision and foundering risk e.g. highlighted, that autonomously operating units can reduce those risks during deep sea transit by a factor of ten, even though this did not take into account detailed system testing due to a lack of data availability at the time (MUNIN 2015).

Small MASS have the potential to provide a flexible maritime transport directly to and from small ports and on underutilized smaller waterways with comparable unit costs to big vessels. Thus, MASS specifically addresses the potential to initiate a modal shift from land-based to waterborne transport. Furthermore, small MASS can also be easily powered by electricity. Therefore, MASS are not just addressing the environmental impact as a side-effect of transport cost efficiency improvements, but as an own topic by aiming to promote modal shift as well. Waterborne transport had a modal share of 31.6% and 4.2% within 2015 regarding the inner-EU-transport, which is a typical share of waterborne transport during the last 20 years (the modal split is measured by cargo-tons transported per kilometer per transport mode divided by the total sum of all modes). (European Union 2017) While waterborne modal share is approximately one third, its share on the energy demand is less than an eighth (10.8% + 1.2%), meaning that it is rather a positive transport mode with regards to environmental-friendliness (European Environment Agency (EEA) 2017). Especially in contrast to road transport, current waterborne transport lacks of competitive transportation times.
Hereby, transportation times must be differentiated between the pure transit times of the vessel and the door-to-door transportation time including waiting and handling

times. MASS are obviously not aiming to increase the vessel's speed so the transit time will primarily be the same as today. Instead, MASS aim for smaller and more flexible ships and thus provides more frequent services. In short sea and during inland navigation, sailing times within the EU are often below a day, but the services often only run on a weekly or bi-weekly basis. Furthermore, ships often call more ports during one service and do not offer a direct connection to ensure a proper utilization rate of the growing vessel sizes. Therefore, average door-to-door transportation times might be in the range of a few days or a week, when waterborne services are included. With MASS aiming for making a weekly service to a daily service, average transportation times are tremendously reduced, as waiting times in ports vanish and loading and unloading times are also reduced due to the smaller ship sizes.

Additionally, by using small MASS there is no need in the long run to (further) deepen European waterways, year by year for the approach of large carriers. This could save several hundred million Euros for infrastructure investment and maintenance, help to protect the environment and be a driver for revitalizing businesses to and from small ports e.g. in the Baltic.

With the increased development of autonomous systems in the automotive and transportation sector, also the marine industry is looking into adopting the technology. (Frost & Sullivan 2017) According to Jokioinen (2014) and Frost & Sullivan (2017), Kretschmann et al. (2016) competitive features for the development of automated ships are:

1. Operational cost efficiency,
   - Reduction of crew costs (e.g. more efficient use of crew and their skills)
   - Performance optimization, more efficient use of fuel, more efficient use of space in ship design
2. Provision of better conditions for the seafarers of tomorrow (e.g. working environment close to family and friends)
3. Improving safety (most marine accidents are related to human errors)
4. Continuous access to any remote location in the oceans

Following Rødseth and Burmeister (2012), the most obvious potential of unmanned vessels is in terms of costs. Labor costs on board are one of the main operational cost categories. According to Gardiner (2015) the share of crew costs of the total operational costs decreases the larger the vessel gets. It varies between 51% for 500-700 TEU vessels and 25% for 10-12,000 TEU vessels (fuel consumption is excluded here). Kretschmann et al (2017) estimated approximated 8% of the overall lifetime costs of a reference bulker are related to crew, while 35% are fuel related. In order to reduce crew costs and because of an increasing efficiency on board of vessels, the number of crew on ocean going ships is declining (Jokioinen 2014, p. 15). Crew number and therefore manning costs can be further reduced if information, communication technologies (ICT) and automation are enhanced.

Further benefits occur at company and network level. According to Rolls-Royce (2016) "remote and autonomous shipping allows improved optimization of operations and processes" based on real-time data. The use of real-time data enables economies of scale at fleet as well as company level and reduces the likelihood of human errors and the number of accidents on the oceans. Hence, the use of real-time data contributes to an increase in safety and service quality.

Autonomous large-scale shipping has not been thought of only in recent years. According to Saarni et al. (2018), notable increase in automation has already taken place in shipping especially from the 1960s onwards, e.g. with processes and regulations for a periodically unmanned engine room already being developed in the 1970s systems or with different auto piloting and positioning systems as well as ECDIS (Electronic Chart

Display and Information System). AIS (Automatic Identification System) further reduced the need for standard conversation. As mentioned by Bertram (2002) concepts for unmanned or autonomous vessels have been envisioned for at least three decades now. However most automation attempts before 2010-2012 focused on capabilities such as equipment monitoring and predictive maintenance (Saarni et al. 2018). Major technological progress has been made since then, especially regarding operation concepts of autonomous vessels. This is illustrated in the following Figure 12.

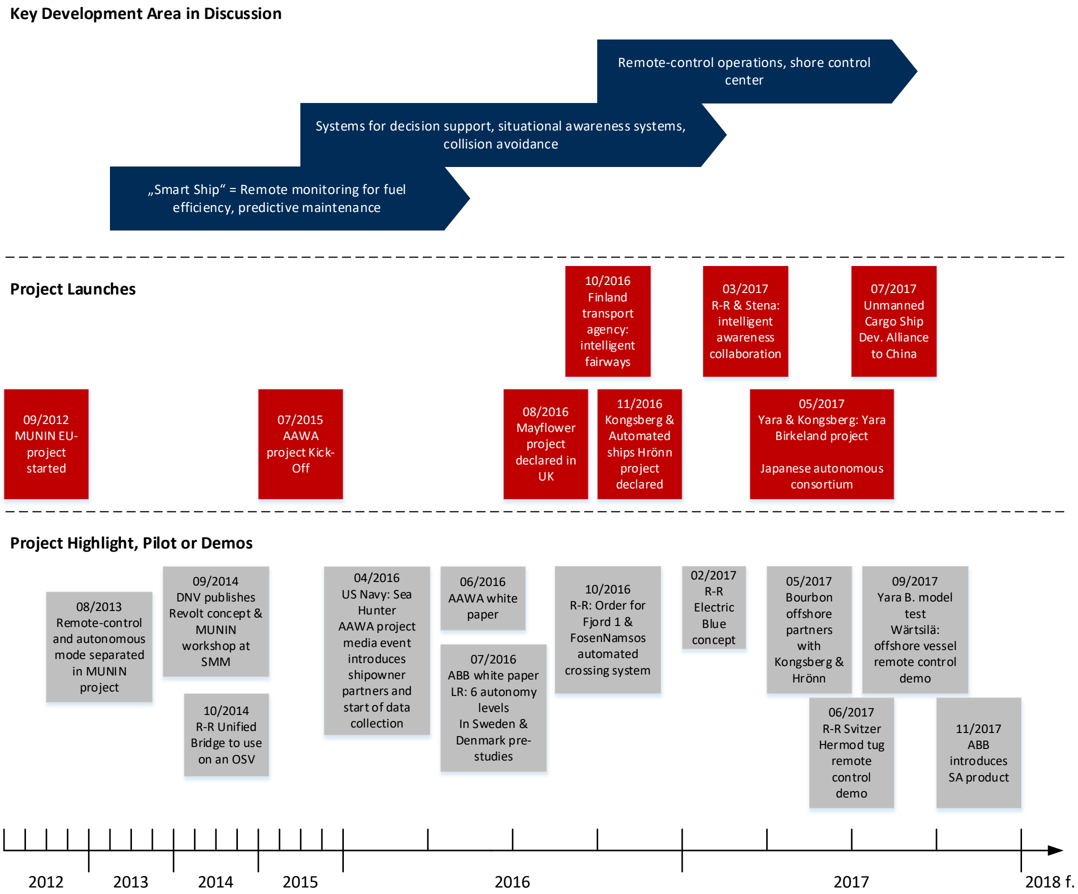

Figure 12: Timeline of Key Events Related to Autonomous Shipping (2012-2017)

Source: Based on Saarni et al. (2018), p. 15

Although there are growing numbers of small-scale autonomous vessels being operated across a wide range of applications (e.g. ocean science, naval operations or surveying and exploration), there are no large-scale autonomous vessels in daily operation so far. (Lloyd's Register 2017b) Info Box 9 gives an introduction to current vessel automation projects that are close entering into use.

Info Box 9: Current Prototype MASS in Operation

Rolls-Royce and Svitzer Hermod Tug[4]

- World's first remotely operated commercial vessel in Copenhagen port

[4] https://www.rolls-royce.com/media/press-releases/yr-2017/20-06-2017-rr-demonstrates-worlds-first-remotely-operated-commercial-vessel.aspx

- On 16th November 2017, a tug master successfully controlled the 2016-built terminal tug Svitzer Hermod from a shore-based operations centre in Svitzer's offices
- Sensors on the tug delivered navigation and situation awareness information to the controller: LiDAR laser scanning, multiple cameras, night vision thermal cameras, dynamic positioning radar-scan, multiple mobile phone network transceivers and satellite communications.

Communication via 3G and 4G cellular connections with the control room.

milliAmpere ferry in Trondheim, Norway[5]

- In Trondheim, Norway, engineers from the Norwegian University of Science and Technology are developing an autonomous (non-cable-guided) electric ferry.
- Ferry will be able to carry at least 12 passengers, along with their bicycles or baby strollers
- Ferry will self-navigate guided by an onboard Global Navigation Satellite System (GNSS)
- Four integrated sensors (radar unit, infrared camera, optical camera, LiDAR) will detect and avoid other watercraft
- Sensors located on the shore will provide additional assistance, by wirelessly transmitting data to the ferry
- Automatic charging of batteries using chargers installed at the docking stations when picking up and dropping off passengers
- Auto ferry may enter use as soon as sometime in 2019
- Currently, a remotely-controlled half-scale prototype is being tested

KoTug RT Borkum[6]

- Remote controlled tug

SVAN Car Ferry Falcon (RollsRoyce)[7]

- Remote and autonomous controlled liner ferry in Finland

ABB's Passagierschiff Suomenlinna II[8]

- Remote control

Source: Based on Coxworth (2018), Wingrove (2018), Rolls Royce Marine (2017), ABB (2018), KOTUG (2018), MAREX (2018), Rolls Royce Marine (2018)

However, so far, the projects listed in the Info Box above are just field trials or construction projects. As of today, no large-scale autonomous vessel is operated on a daily basis. Further test vessels are also currently under construction, as e.g.:

- YARA Birkeland

[5] https://www.maritime-executive.com/article/autonomous-mini-ferry-moves-forward-in-trondheim
[6] https://www.kotug.com/newsmedia/kotug-demonstrates-remote-controlled-tugboat-sailing-over-long-distance
[7] https://www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx
[8] https://new.abb.com/news/detail/11632/abb-enables-groundbreaking-trial-of-remotely-operated-passenger-ferry

- Korean's Smart Autonomous Ship Project[9]
- Japanese remote controlled tug tests[10]
- ASKO Autobarge[11]
- Rosmoports unmanned barge hopper[12]

4.4.3 Future Prospects of Autonomous Waterborne Transport in Ports

As described in section 4.4.2, fully autonomous vessels are still a future vision but maturity has strongly progressed by several research activities in this field, e.g.

- MUNIN Maritime Unmanned Navigation through Intelligence in Networks, 7th RTD Framework Programme, September 2012 to August 2015
- Autonomous Waterborne Applications Initiative, Rolls-Royce, 2015 to 2017
- The ReVolt – A new inspirational ship concept, DNV GL, 2015 to 2017.
- NOVIMAR, H2020, vessel train concept for inland waterways and short sea traffic[13]

In April 2016, Rolls-Royce published a roadmap towards the comprehensive use of autonomous ships (Rolls-Royce 2016). According to the roadmap Rolls-Royce hopes, autonomous ocean-going vessels are a common sight on the ocean by 2030. However, unmanned ships will most likely start with local applications. It is expected that remote controlled unmanned coastal vessels will already be in operation by 2025 (Rolls-Royce 2016, p. 7):

Figure 13: Roadmap Towards the Comprehensive Use of Autonomous Ships

Source: Based on Rolls-Royce (2016), p. 7

A concept for a remote controlled unmanned vessel was developed within MUNIN project (from the European Union research programme) (Maritime Unmanned Navigation through Intelligence in Networks Project). Key information is summarized in Info Box 10.

Info Box 10: MUNIN Concept[14]

- Future autonomous bulk ships complete long oversea legs on their voyages across the world's oceans without a crew
- Vessels (drone ships) are controlled by supervisory shore control centers
- Land-based embarkation crew sets out to take over the ship for the navigation in the port shortly before they approach coastal waters and the port

Source: Based on Burmeister et al. (2014)

9 http://nfas.autonomous-ship.org/events/ow2018/16_Lee.pdf
10 https://www.nyk.com/english/news/2018/1191211_1687.html
11 http://presse.enova.no/news/119-enova-millioner-til-askos-autonome-fartoey-362196
12 http://en.portnews.ru/news/272861/
13 https://novimar.eu/
14 http://www.unmanned-ship.org/munin/

A concept that goes beyond mere remote control is the Yara Birkeland that is expected to be fully autonomous by 2022. The key information of the concept is summarized in Info Box 11.

Info Box 11: Yara Birkeland

- World's first zero emission, autonomous container feeder that is currently being constructed (design finalized in 2017)
  - Cargo capacity: 120 TEU
  - Deadweight: 3,200 mt
- Operational area: Ship will sail within 12 nautical miles from the coast, between three ports in southern Norway
- Three operation / control centers will be operated to handle emergency and exception handling, condition and operational monitoring, decision support, surveillance of the autonomous ship and its surroundings and all other aspects of safety
- Detachable bridge with equipment for maneuvering and navigation will be implemented, that will be lifted off when the ship is ready for autonomous operation
- Ship will be equipped with automatic mooring system - berthing and unberthing will be done without human intervention, and will not require special implementations dock-side
- Vessel will be equipped with radar, LiDAR, AIS, cameras and infrared camera
- Connectivity & Communication: Maritime Broadband Radio, Satellite Communications, Global System for Mobile Communications (GSM)
- Next Milestones:
  - 2019: Testing of autonomous capability
  - 2020: Vessel will be delivered in first quarter and will gradually move from manned operation to fully autonomous operation by 2022

Source: Based on Kongsberg (no date)

But it is not only the seagoing merchant vessels that undergo developments to automatization. Other ships, such as service tugs or offshore crew vessels, with other tasks are also within the focus of researchers.

Info Box 12: FernSAMS - Development and Validation of an Assistance System for the Remote Control of Tugs during Docking and Docking Maneuvers

- Growing ship sizes increasingly require complex docking, casting off and turning maneuvers in ports. The number of service providers involved, and thus the coordination requirements, are increasing, as are costs and risks. The development of remote-controlled tugboats aims at bundling the coordination tasks and pointing out new possibilities for the optimization of maneuvers.
- Development of remote control and technologies for autonomous harbor tugs
- Use of the results by port authorities and pilot companies (tugboat operation)
- Increased knowledge for innovative edge and training for R&D and training partners

Start in 2017; first models expected in summer of 2019

Source: Fraunhofer CML (COMPIT 2018)

Auto mooring systems are currently being offered by e.g. Cavotec SA (MoorMaster™): Remotely controlled vacuum pads are recessed in, or mounted on, the quayside, and moor and release vessels in less than one minute (in comparison: conventional mooring takes 20 to 90 minutes). The system is already implemented in e.g. the ports of Salalah (Oman), Beirut (Lebanon) or Helsinki (Finland). (Cavotec SA 2018) Besides of remotely controlled vacuum pads, automated mooring also requires sensors and cameras equipped to the sheet piling walls as well as communication infrastructure to exchange information.

Info Box 13: AutoMoor in the Port of Trelleborg

- Rope-free, automated mooring system designed and manufactured by Trelleborg Marine Systems
- Use of vacuum technology to rapidly attach to and secure a vessel at berth
- Uses SmartPort tools to continuously monitor all mooring loads acting on the vessel at berth (e.g. DynaMoor, Docking Aid System, SmartHook® Load Monitoring System)
- Provides live data to the operator

Source: Trelleborg Marine Systems (no date)

As can be taken from the above Info Box, the Port of Trelleborg also uses the automated mooring technology – however not for autonomous vessels but for conventional ferries. Furthermore, the Docking Aid System of the port also provides laser and GPS solutions to assist in vessel approach and docking management.

Additionally, updating port approaches and fairways from manned operation for MASS operation should be considered in future development to ease accessibility and improve safety. Potential mid-term developments are e.g. digital upgrades of manual oriented aids to navigation, like buoys and leading lights, to a marine version of an instrument landing system (ILS), enabling highly automated vessels to safely approach ports by shore-based digital positioning assistance.

Due to the long lifecycles of vessels operated today, the transition towards autonomous shipping is slowed down by the existence of an ageing but still functional fleet (Saarni et

al. 2018). As vessels are in operation for a long period of time, there will be a considerable share of autonomous vessels in operation only in the far distant future. In the meantime, it is expected that manned, drone and autonomous ships will use the same waterway infrastructure.
According to Lloyd's Register (2017b), key technology areas for the development of maritime autonomy are artificial intelligence, sensors and situational awareness, connectivity, cyber-security, energy management and sustainability. Therefore, autonomous vessels feature similar technologies to self-driving cars. They use a range of sensors to power autonomous functions, such as Inertial Navigation System (INS), GPS, radar, LiDAR, optical and infra-red cameras, high-resolution sonar, microphones, and wind and pressure sensors (See Figure 14).

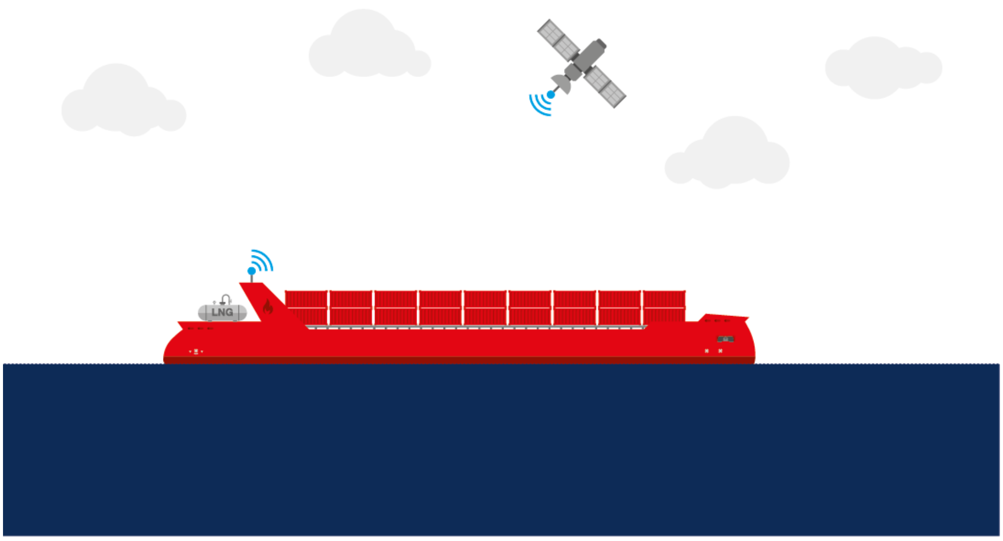

Figure 14: Autonomous Vessel

Source: HPA, Fraunhofer CML (2019)

As can be taken from the Info Box given in section 4.4.2 and the projects described in this section, when finalized the mentioned vessels will communicate with other vessels (V2V) and with the infrastructure (V2I). For V2I communication, port infrastructure needs to provide:

- IoT sensors and devices, e.g. real-time water and weather sensor data
- IoT platform for Big Data analysis and information exchange. Saarni et al. (2018) specify the required IoT platform as a ship-port IoT platform
- Wi-Fi and cellular communications

Further, as the shipping industry does not envision requiring the onboard AI to fully control the vehicle in every circumstance – even not for a long time – ports need to provide the infrastructure for e.g. picking up port pilots to navigate inside the ports (Burmeister et al. 2014).

Info Box 14: Port of Rotterdam

- In order to prepare the Port of Rotterdam Authority for the arrival of autonomous navigation, the Port of Rotterdam Authority has converted a patrol vessel into a floating lab that collects data, including about the vessel's operation and power.
- The first partnership for data exchange from the floating lab has now been signed with Captain AI. They are adding artificial intelligence to the data, which enables computers to be trained as artificial captains to navigate independently through the port; thus building a digital twin.

Source: Port of Rotterdam (2018b)

A first step in this direction, focusing on unmanned surface and unmanned underwater vehicles (USV and UUV) is made by Fraunhofer CML and partners while setting up the research project RoboVaaS.

Info Box 15: Research Project RoboVaaS, Fraunhofer CML

RoboVaaS – Robotic Vessels as a Service

The project 'Robotic Vessels as-a-Service' (RoboVaaS) aims to make maritime operations in coastal waters safer by integrating and networking smaller USV and UUV efficiently and to offer new services for shipping. The system is supported by networked vehicles with special sensors, a reliable data transmission cloud network for surface and under-water communication, a monitoring station and a web-based real-time user interface. During the three-year project period, a live data-based USV grounding avoidance service, a hull UUV inspection service and an automated USV/ UUV data collection service for port areas will be developed.

Source: Fraunhofer CML (2019)

In conclusion ports are facing challenges and requirements due to different concepts of autonomous vessels. In automated mooring processes the communication between the quays as the infrastructure and a vessel would require V2I communication. Moreover shore control centers might be required. For remote controlled applications the control centers need to have the possibility of on sight navigation. This might require new buildings in the port area like observation towers. As long as autonomous navigation in the ports area is not possible yet, coast water crews might be required to board the autonomous vessel to perform the inner-port navigation and the mooring. Port authorities could also provide HD Maps for autonomous ships to support their navigation.

4.5 Unmanned Aerial Vehicles (UAV) Automation

Unmanned Aerial Vehicles (UAV), also known as Unmanned Aircraft Systems (UAS) or drones, were firstly developed in the 19th century and in these early days mostly used for military purposes. Today, UAV are rapidly gaining in popularity also for commercial and recreational use.

UAV are unmanned aircrafts or flying robots that use onboard sensors and software to fly remote controlled, autonomously or in a combination of both modes. As they show the flight characteristics of small helicopters or propeller-driven airplanes they own the following strengths: UAV are able to access remote areas, they are faster and move more individually than comparable transport vehicles, and they are independent of transport infrastructure and thus are not influenced by congestions. Not least, they are financially favorable compared to airplanes or helicopters in a spectrum covering the same transportation capacity.

On the other hand, today´s UAV can only conduct a limited number of transport services. They have a high specific energy consumption and comparably high noise emissions. Not to forget their low load capacity. The use of UAV is quite expensive and thus focuses quite naturally on special tasks that have a high value. Nevertheless, today's UAV deployments are more influenced by the development of new technologies and innovative use cases then by economic considerations.

4.5.1 Phases of Development and Levels of Autonomy

Since the beginning of the 1990s, UAV with rotorcraft using electric drive provide automated steering components almost as a standard (see Figure 15). Since then, the development of small UAVs, also for private use, took in. And twenty years later, the combination of micro video devices and the internet economy led to a huge increase of number and use of UAV worldwide.

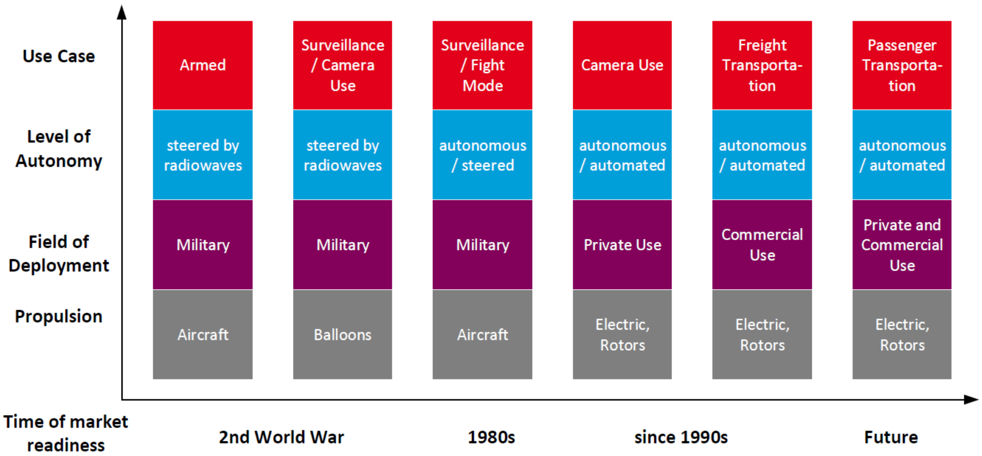

Figure 15: Phases of UAV Development

Source: Fraunhofer CML 2019

It is possible to steer UAV remotely, e.g. via VHF. This mode enables the pilot to choose a route individually which may be interesting to explore an area or to monitor an unclear situation. But for most pilots it is much easier to let the UAV start, land and fly by itself so the pilot is enabled to focus on e.g. the camera footage and to keep the UAV flight in the visual line of sight (VLOS) mode.

Looking at automated flight modes of UAV, a distinction can be made between self-piloted and autonomous control modes: in order to depict complete autonomy, due to Feist (2019), a UAV would have to be equipped with artificial intelligence and not only fly independently specified routes, but would also have to plan these itself in terms of time, report unexpected events directly, and evaluate and secure the video recordings and/ or observations itself. The status of self-piloting then means, that a UAV flies by itself, but in a range of given parameters, like time frame or waypoint track.

However, definitions of autonomy or automation vary due to the fact that the technology is still quite young, however developing rapidly. The definition above obviously extends the definition of automation not only to the flight, but also to the tasks a UAV is dedicated to fulfill. Other experts state, that an autonomous status is already reached if the UAV follows a person independently or flies home, conducts figures or follows given waypoints. Scientific definitions use a more systematic approach to define “autonomy” regarding UAV.

Different degrees of autonomy can be described according to ISO 8373 for Robots and robotic devices. Using the vocabulary of this standard – that is also valid for UAV - by Floreano and Wood (2015), “Sensory-motor autonomy” then describes a UAV that performs an operation by remote commands based on available information signals such as GPS. For this purpose, only a few sensors and onboard computers are needed, and for the operation of this type of UAV monitoring is required. This type of UAV is already available today and can be used for any type of propulsion (fixed wing, rotorcraft and flipping wing). This definition matches the “self-piloting mode” described above.

“Reactive autonomy UAV” can independently maintain their position or continue a path, even if external or internal influences act against it (e.g. weather, electrical faults). They can independently maintain distances to the ground and to other flying objects as well as take off and land independently. Their equipment consists of a few sensors and medium computer power, for which they do not have to be constantly monitored. UAV of this autonomy level are already partly available.

“Cognitive autonomy UAV” can simultaneously record e.g. geodetic information and localize their position. Contradictory information can be resolved by the intelligence of these UAVs. These UAVs are characterized by a large number of sensors and great computer power. They do not require surveillance, so they operate autonomously. These UAVs are expected to fly with rotor power, but are not yet available.

These levels, defined by different parameters, are depicted in Table 6 in detail.

Table 6: Levels of Autonomy

	Exteroceptive sensors	Computational load	Supervision required	Readiness level	Validated on UAV type
Sensory-motor Autonomy	None or few	Little	Yes	Developed	All types
Reactive Autonomy	Few and sparse	Medium	Little	Partly developed	Fixed wing, rotorcraft and flipping wing
Cognitive Autonomy	Several and high density	High	None	Not yet developed	Mostly rotorcraft

Source: Based on Floreano and Wood (2015)

Over all, different definitions of "autonomy" have been developed due to the need of describing the subject from different points of view, e.g. operative like the fulfillment of tasks, or technologically with a view to sensors and computational load.
For this study, the definition of the NATO Working Group is chosen as a good starting point to describe the different concepts. The NATO Working Group focuses on the necessary input a UAV needs to fulfill a given task and defines four levels of autonomy to classify UAV:

- Level 1: Remotely Controlled System - System reactions and behavior depend on operator input
- Level 2: Automated System - Reactions and behavior depend on fixed built-in functionality (preprogrammed)
- Level 3: Autonomous non-learning system - Behavior depends upon fixed built-in functionality or upon a fixed set of rules that dictate system behavior (goal-directed reaction and behavior).
- Level 4: Autonomous learning system with the ability to modify rules defining behaviors – Behavior depends upon a set of rules that can be modified for continuously improving goal directed reactions and behaviors within an overarching set of inviolate rules/ behaviors.

Level 1-autonomy is in use since the 2nd World War in the military field, steering airplanes loaded with explosives by radio waves. In the leisure use, this kind of autonomy is used for model airplanes since the 1930s. Autonomy of Level 2 was reached in the 1990s, when UAV for leisure use learned to start, fly, return, and land autonomously. Level 3-autonomy can be compared to the above mentioned self-piloting. This mode is already pre-programmed in a couple of modern UAV. It was used for military UAV in earlier years, where UAV in BVLOS (beyond visual line of sight) mode needed to operate at least partly automated to fulfill surveillance or other tasks. Level 4-autonomy is reached by only a few UAV today.

Today, high-end UAV for leisure use start and land autonomously, conduct pre-programmed flight figures and use cameras to film their pilot. Of course, they are controlled via the pilot´s smartphone. In the commercial sector, first developers (e.g. Accelerated Dynamics) provide autonomously operating UAV (or even swarms) that make use of AI at surveillance or inspection tasks. Nevertheless, autonomy in a technical way may not be confused with autonomy when it comes to regulation, because in most cases today it is not allowed to let a UAV fly autonomously, e.g. out of sight.

4.5.2 State of the Art of UAV Development and Purposes

The historical outline already shows a wide range of UAV applications in the military sector. As carriers of weapon systems or radar and video electronics, UAV are used successfully in combat and surveillance situations. In the USA, more UAV pilots are already being trained than conventional pilots.

In the commercial sector, UAVs can implement logistics processes in areas that are difficult to access, outdoors as well as indoors, and used to transport small load sizes and weights. In addition, the possibilities of aerial photography are used for marketing as well as for inspection, surveillance or security purposes. The idea of using UAVs for inner-city and short-distance passenger transport is also very popular (but not yet implemented).

And in the private sector, UAVs are intensely used for filming sports, leisure time and holiday activities. UAV are designed according to their very different application possibilities. These are represented, for example, in the technical parameters, the kind of propulsion and the sensor equipment. Due to the rapid development in the field of UAV, the following illustrations must be valued as it is: a state of the art.

4.5.2.1 Technical Parameters and Capacities of UAV

The application possibilities of UAV are largely determined by their weight. Their size determines various regulatory requirements and application parameters.

- Small UAV for private and commercial use weigh up to 250 g: for this purpose e.g. in Germany a labeling of the UAV or a proof of knowledge of the pilot are not necessary.
- Small UAV up to 2kg must follow the labeling obligation. UAV up to 2kg are mostly chosen for leisure use; carrying not more than a camera and the necessary IT- and sensor technology. In the commercial field, these small UAVs might be used for the counting of stockpiles (indoors), and making films and pictures.
- Small UAV over 2kg are mainly used for commercial purposes, as they combine a bigger weight, payload and an extensive sensor equipment with a namely higher price. These UAVs have to follow the labeling obligation and the pilot needs to proof his knowledge. UAV weighing more than 2kg are dedicated for the use outdoors, carrying more elaborate camera equipment and sensors for surveillance, gathering of geodetic information or study of weather patterns.
- Medium-size UAV weigh over 5 kg to several hundred kg. They are also mostly used for commercial purposes. These UAVs need additionally to the pilot's proof of knowledge an ascent permit from the responsible aviation authority. And UAV weighing more than 5kg are able to provide rescue items in SAR situations and support in firefighting, not to mention transport capabilities.
- Large UAVs used for military transport, for reconnaissance purposes and war missions need a regularly educated and approved pilot to conduct remote control and take over the responsibility if need be. Large UAVs need the same certifications as regular airplanes do.

4.5.2.2 Power Supply and Kind of Propulsion

UAV for private and commercial use are mostly electrically powered rotary-wing aircrafts that combine many advantages as quadro- or octocopters: they are comparatively inexpensive, can land and take off at many locations and are relatively easy to remote control. In addition, their operation is inexpensive and mostly harmless due to the limited weigh and the given regulation. Practical training is not required in many cases, and control has so far been almost completely remote.

UAV used in the military sector for reconnaissance and war operations are necessarily designed for long ranges and greater payload capacities. They can fly at great heights and over long distances. For this reason, military UAVs are usually equipped with fixed wings and a pusher propeller configuration.

There are also hybrid UAV that combine rotary-wings with pusher propeller configurations, the so-called VTOL UAV, VTOL meaning vertical take-off and landing. This form combines the advantage to start and land on small patches with a high speed in flight mode.

4.5.2.3 Sensor and Camera Equipment

Due to the task a UAV is needed for, different sensors and other equipment play an important role. Usually a UAV is expected to "know" its position and height. For this information, a GPS receiver as well as other sensors are necessary. To be able to "find home", the connection to the remote control of the pilot is necessary. To transfer information during the flight, of course cameras, eventually HD, infrared or thermal cameras, are deployed and need storage capacities on the board computer as well as a capable transmission connection to the pilot. This is mostly enabled using 4G, 5G and VHF, sometimes even WLAN. Only very good and stable data connections provide the useful First Person View (FPV), showing the pilot the camera picture on a screen, as if she or he would fly himself.

4.5.2.4 Legal Issues – Regulation and Administration

With regard to the legal framework applicable to the use of UAV, a distinction can be made between comparatively small UAV used predominantly for private and commercial purposes and UAV used for military purposes. While the latter have to comply with international regulations due to their large radius of operation, purpose and similarity to conventional civil and military aircraft, other local or regional regulations apply to small UAV (up to 5kg).

In **Germany**, UAVs must not fly higher than 100m without a special permit; in the vicinity of flight control zones they are not allowed to fly higher than 50m. The flight is usually only permitted within sight of the pilot (VLOS mode: visual line of sight) and only in daylight. Flying at night and within a radius of 1.5 km of an airport is generally not permitted. It is also forbidden to fly over residential areas, nature reserves, industrial sites and most public infrastructures. A distance of 200m to residential areas, crowds etc. must be maintained; manned aircraft must also be avoided and rescue measures must not be obstructed.

According to the rapid recent spread of UAV for photo and film purposes in the private and commercial sector, the jurisprudence is in default. In the **United Kingdom**, UAV only led to the closure of air traffic in January 2019. In the UK, UAV may be flown outside a radius of 1km around airport premises. UAV manufacturers want to ensure these and other restrictions through geofencing technology. By geofencing, areas which are not allowed to enter with a UAV are marked accordingly using GPS data, so a UAV may not cross this digital fence (UVA Expert News 2019) (Taking Flight: The Future of Drones in the UK Government Response).

European regulations are developed by EASA (European Aviation Safety Agency). Three different categories of operations have been defined: Open, specific and certified: These categories refer primarily to the operations and current purpose of the UAV, not to its technical specifications (which, however, are often related to the operations). These are explained in detail in the "Introduction of a regulatory framework for the operation of unmanned aircraft" to change the existing UAV regulations that hinder the development of UAV use and services.

- 'Open' category (low risk): safety is ensured through operational limitations, compliance with industry standards, requirements on certain functionalities, and a minimum set of operational rules. Enforcement shall be ensured by the police.
- 'Specific operation' category (medium risk): authorization by National Aviation Authorities (NAAs), possibly assisted by a Qualified Entity following a risk assessment performed by the operator. A manual of operations shall list the risk mitigation measures.
- 'Certified' category (higher risk): requirements comparable to manned aviation requirements. Oversight by NAA (issue of licenses and approval of maintenance, operations, training, Air Traffic Management (ATM), Air Navigation Services (ANS) and aerodrome organizations) and by EASA (design and approval of foreign organizations).

A number of definitions are standardized in the draft, but individual conditions such as no-fly zones around airports are left to the individual member states. (European Union Aviation Safety Agency 2018)

To compare these regulations with other countries developing and using UAV quite intensely, the actual regulation is described below:

In the USA, the registration of any UAV with the FAA is obligatory. Flight mode VLOS must be ensured, and the UAV must weigh under 55lbs. Operation near aircrafts, airports, and emergency situations is prohibited. For commercial use, the UAV needs a certificate from FAA, and the pilot needs additionally a remote pilot certificate. The weight of commercial UAVs also must be less than 55lbs.
For all UAV operations the following rules are obliging:
The UAV must be kept within VLOS mode and flown at or below 400 feet. Flight time is only during daylight or civil twilight. Flight speed is limited to 100 mph and flights are not allowed directly over people.

In China, UAV weighing more than 250g must be registered with the Civil Aviation Administration of China (CAAC). For commercial use, licensing is necessary, and only VLOS mode is allowed. UAV must fly not higher than 120m and not in populated areas, not around airports, or military installation, and in general not in no fly zones.

In Israel, UAV for recreational use need two permits from CAAI (Israel Civil Aviation Authority) and from the ministry of communication. There are the following general rules for leisure use applicable: only VLOS mode is allowed, flight height is max. 50m, the distance to airfields or airports must be larger than 2km, and not closer than 250m to people and buildings. In Israel, flights in no fly zones are forbidden. For commercial use, a licensing is necessary.

4.5.2.5 European UAV Strategy

The EU Commission realized early the enormous potential of the development and application of UAV for the European economies. On the other hand, a look at the UAV regulation in Europe makes quite unclear how a prospering economy might evolve on a basis limiting and restricting nearly every move of UAV in populated areas.
Two major concepts are thus set in place to initiate the joint development: The SESAR Joint Undertaking is the technological pillar of the European Single Sky Initiative and its task is the coordination of all EU research and development activities in Air Traffic Management (ATM) since 2017. This includes European-wide high-performing airport operations and ATM network services, but also the development of the ATM Master Plan

Drone Roadmap. This roadmap foresees a new framework, the U-Space, to support "the management of safe and efficient UAV operations and address the proper interface with manned aviation and Air Traffic Control (ATC)" (ATM Masterplan). U-Space shall enable aircrafts of all kinds and sizes, be it (remote) piloted or automated, carrying people or goods, to operate safely and efficient. To reach this ambitious goal until 2030+, it is important and necessary to engage a reliable network of communication and IT infrastructure, emerging technologies and AI.
To ensure the European people privacy and safety, and to enhance the cyber security of these operations, U-Space demonstrators all over Europe develop use cases for UAV with different parameters and for leisure, commercial and governmental purposes. These demonstrators shall act as showcases as well for the technical and regulatory implementation as for early business use cases to engage the economy into further development of new ideas and services for UAV.

Info Box 16: Urban Air Mobility (UAM) Initiative of the EU in Hamburg[15]

The Urban Air Mobility (UAM) Initiative of the European Union[16] aims to

- contribute to the creation of a market for urban air mobility
- that brings together cities and regions with companies,
- allows urban air mobility showcases and
- support their replication by scale.

Hamburg was one of the first cities to join the UAM initiative in May 2018

- The city with its strong aviation industries such as Airbus and Lufthansa is an official demonstrator region for the deployment of air mobility solutions
- Industry, universities, authorities and the public cooperate in the Windrove network
- Test cases are the time-sensitive transport of medical goods or the inspection of large infrastructure facilities

Source: European Commission and Urban Air Initiative Hamburg (2019)

4.5.3 Future Prospects of UAV in Ports

For the use of UAV in ports, the situation is different compared to other transports modes. As there are only a few small UAV in ports in service today, and all UAV in service provide nearly the same sensor and computer equipment, the danger of colliding is comparably small. Furthermore, the view on the integration into existing traffic systems is not of relevance today. Nevertheless, for the development of UAV use in ports some thoughts might be helpful.

[15]https://www.hamburg-aviation.de/urban-air-mobility.html
[16]https://ec.europa.eu/transport/media/news/news/2018-05-30-commission-welcomes-european-cities-joining-urban-air-mobility-initiative_en

4.5.3.1 UAV for surveillance and security purposes

In future, the use of UAV for surveillance and security purposes in ports may become much more intense then today. The deployment of high-definition cameras on UAV combined with enhancing autonomous flight performance makes it easier to conduct regular inspection of infra- and suprastructure in ports (as long as inspection by vision is sufficient). Especially cranes, bridges and quay walls are usually hard to reach, so the use of UAV that record the condition regularly may bring a nameable benefit for the maintenance department (See Figure 16).

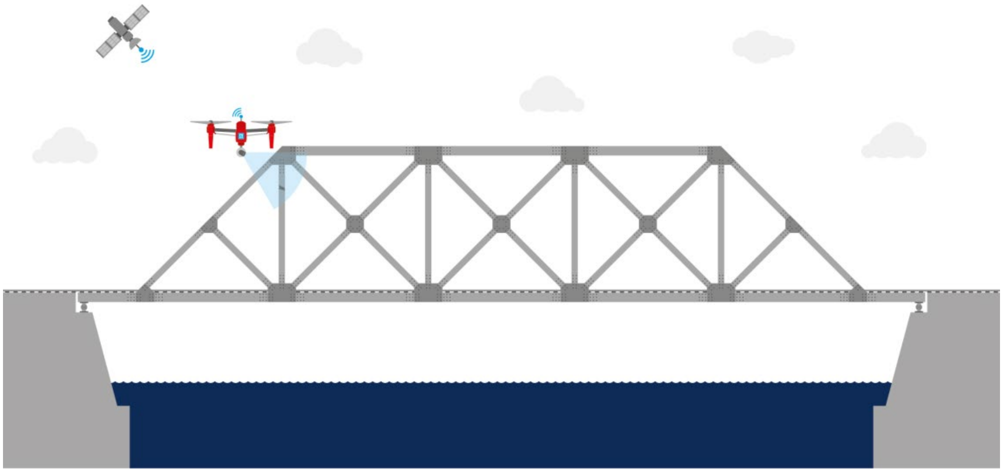

Figure 16: Autonomous UAV used for Inspection of Infrastructure

Source: HPA, Fraunhofer CML (2019)

Furthermore, UAV can be deployed in making inventories on container terminals, scanning container IDs to cross-check their storage place with the Terminal Operating Systems.
Another situation, where the birds eye-perspective of a UAV might be a nameable gain is the support of maneuvers with pictures from above (See Figure 17).
And the use of special cameras can detect thermal anomalies at an early point of time.
With a view to security issues it is obvious that UAV can provide a supplementing intelligence compared to the procedures making a port safe today.

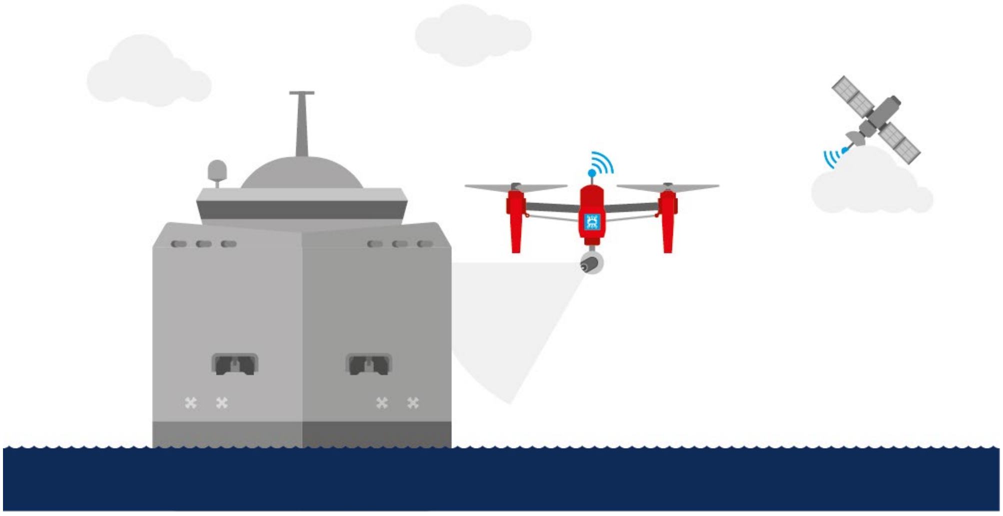

Figure 17: Autonomous UAV Supporting Maneuvers

Source: HPA, Fraunhofer CML (2019)

4.5.3.2 UAV for transportation purposes

Still, there are few possibilities for the application of UAV for transportation purposes. As long as nothing more than information is carried by the UAV, there is no need for dedicated start and landing platforms, although they are of help with a view to navigation of the UAV and for security reasons. As soon as bigger UAV are implemented into this system, that transport goods and even people, interfaces with the terminal and/ or port infrastructures must be developed.

There are already concept studies to transport units as big as containers, but a next step may rather lie in the transport of smaller goods, as e-business companies plan already today. Use cases for small goods in a port are possibly the supply of documents between office buildings on different terminals, the distribution of spare parts or even a flying kitchen to provide terminal workers at their work places and spare time and effort to drive long distances for the coffee break.

To ensure a high efficiency of aerial transport in the port, the implementation of flight slots, schedules and airways as in the commercial aviation, thus will gain on importance.

Info Box 17: AIRBUS-Skyways in Singapore[17]

AIRBUS-Skyways project: shore-to-ship trials in Singapore

- AIRBUS plans to deliver parcels to vessels at the Singapore anchorage, e.g. essential spare parts, medical supplies
- Up to 4 kg payload, up to 3 km distance from shore
- Navigation autonomously in predefined aerial corridors
- Successful first trials mid of March, 2019
  - Distance 1.5 km
  - Flight duration 10 minutes
  - Payload 1.5 kg
- Project Partners: Airbus Skyways, Wilhelmsen Ship Services

Source: Airbus (2019)

Transport UAV are still in their infancy. Prototypes, often developed for the military, are currently mainly designed like helicopters with combustion engines to cope with large payloads and long missions. For these UAV, the ability to land and take off at any location is crucial. As a special case, vertical take-off and landing (VTOL) aircraft are developed. Due to their similarity to conventional aircraft, their pilots require extensive training.

Info Box 18: Concept for an Unmanned Aerial Vehicle for Military Transport Use [18]

Aerial Reconfiguration Embedded System ARES

- The hybrid transport concept ARES was developed 2013 by DARPA (US Defense Advanced Research Projects Agency) together with Lockheed Martin (basing on the DARPA Transformer Program from 2009)
- ARES combines a vertical take-off and landing (VTOL) system with different types of detachable mission modules up to 1 ton payload and purposes:
  - Transport containers for material
  - Containers for staff
  - Modules for medical assistance
  - Modules for SAR purposes
  - Tactical support
  - Intelligence, surveillance and reconnaissance
- ARES shall be able to land and take of vertically in nearly every surrounding and situation
- ARES shall be operated unmanned in an action range of 250 miles
- Status: Building of the prototype started in 2014, actual status unknown
- Project Consortium: Lockheed Martin, Piasecki Aircraft Corporation

Source: Lockheed Martin (2018)

[17] https://www.airbus.com/newsroom/press-releases/en/2019/03/airbus-skyways-drone-trials-worlds-first-shoretoship-deliveries.html
[18] https://www.lockheedmartin.com/en-us/products/ares.html

Info Box 19: Concept Study: Use of a UAV for Container Transportation

> Companies in the container handling business like Terminal Operators and the Logistics Service Industry think of using UAV for transportation of empty containers. Some concept studies already exist.
> However, as of today, these visions are still far from realization. Although it might be technically feasible to lift empty containers with UAV, as a study of the Fraunhofer entities IML and CML for the Hamburger Hafen und Logistik AG HHLA shows, the use of combustion engines and rotors would lead to nameable emissions of exhaust gas and noise. Probably, the economic view of such a project does not permit any meaningful implementation in the near future.

Source: Fraunhofer CML (2019)

The transport of people with automated aerial vehicles is a popular concept in different studies; nevertheless it is yet a way to go until local Aviation Administration permit passenger transportation by UAV. Nevertheless, in future ports passenger transport by UAV may be of use for manned inspection flights on terminals, vessels or infrastructure. Pilots and specialists may be transported from shore to vessel and vice versa. And of course, regular passenger transport need in big ports would be another use case to speed up mobility in congested ports.

Info Box 20: Transport of Passengers in UAV: Ehang 184 and 216

> Autonomous Passenger Transport by Beijing Yi-Hang Creation Science & Technology Corporation.
> Ehang 184 took flight firstly in 2015. The UAV flies autonomously and is constructed for one to two passenger/s and a flight speed of 100 km/h.
> Another UAV, Ehang 216, is built for two passengers.
> Farthest distance flown is 8.8 km, with a height up to 300 m, even in bad weather conditions like storm and bad sight. 30 to 40 prototypes of Ehang UAV conducted more than 1,500 flights until today.
> The Ehang was firstly shown in Europe in Amsterdam in 2018.
>
> Other companies, like e.g. Airbus ("CityAirbus") work on UAV for passengers as well.
> Developers think that the operation of UAV for passengers is technically feasible, but will probably not be a standard before 2030.

Source: VTOL Investor (2018)

When it comes to UAV, there might be still many more occasions where UAV are of more use than vehicles used today, and also occasions, where there is no vehicle available today at all. UAV are already engaged in firefighting situations, where manned aircraft cannot be exposed. The same goes for other emergency situations, where experts, food and other supplies are urgently needed, e.g. to sustain a wrecked vessel. Even paramedics and medical equipment can be provided in such a situation. Though these situations fortunately do not describe every day's status in ports, these examples show the breadth and variety of use cases of UAV, not only but also in ports.

4.5.3.3 Technical Prerequisites

The operation of UAV needs three main prerequisites: UAV must be able to orientate themselves in their environment. There must be space to conduct safe flight and start/ landing operations. And energy refill must be provided.
For a port or terminal these prerequisites are very similar to those at any other place where UAV shall be deployed.
UAV make use of a GNSS receiver (Global Navigational Satellite System, such as GPS, GLONASS or Galileo) to receive detailed information on their position. The exact flight height is determined by sensors. E.g. the use of radio waves enables the information exchange between pilot and UAV. No Fly Zones will in future be integrated in a UAV´s flight controller, and updated through firmware release, to ensure that e.g. airports and other relevant infrastructures cannot be compromised by unauthorized UAV operations. For the operation of UAV in a port, this means that navigational information must be provided and ensured by any means. The signals from the global satellite systems must not be hindered by infrastructure or operations of any kind and the possibility of GPS jamming must be surveyed and minimized. The need to exchange big amounts of data during the flight can be enabled by providing powerful communication services, such as 5G, VHF but also WLAN, to support data transmission.
To operate safely in the space given, UAV use obstacle-detection sensors to identify objects like buildings and other UAV. For example, the SLAM (Simultaneous Localization and Mapping) technology develops 3D images to sense and avoid objects. The flight controller then makes use of these signals and initiates proper maneuvers. As actual information on near objects, flying or not, might provide to the safety of a UAV, the communication infrastructure of a port or Terminal is also helpful for UAV operation.

Depending on the kind of propulsion, the kind and setup of energy reloading is determined. UAV that are electrically powered need other facilities to charge or change battery packs than gasoline or kerosene fueled ones. For transport UAV, additionally space for loading and unloading might be required whereas the start and landing infrastructure for small UAV can be quite flexible and vary due to the individual task.

5
Recommendations for Action

As described in the previous sections, autonomous driving is getting increasingly more attention for all transport modes. Ports begin to prepare themselves for the arrival of autonomous vehicles at their gates. The crucial question is if and how the ports should be pro-active in making themselves fully accessible for such vehicles, being it road, rail, air or waterborne vehicles. Infrastructure planning requires a long-term vision of transport demand and services. The appearance of autonomous vehicles may demand new infrastructure investments from the ports. The recent challenge is that only few technologies that are required to realize autonomous driving already exist. Many technologies are prototypes or not fully developed yet.

While comparing the lifecycle of a vehicle and the related infrastructure it is obvious that the infrastructure has a longer life time, and decisions that are made have long-lasting impacts. There are two possible choices:

- The first option to deal with the challenges is to do nothing and wait until the autonomous technologies have reached a level of maturity which enables them to use any given infrastructure.
- The second option is that ports actively sustain their competitive position by investing in bridging technologies that support (semi-) autonomous vehicles, even though some of these investments might become obsolete soon.

The decision must also be weighed against the background of a port's existing infrastructure, its size and importance, and other parameters such as labor and operational costs. The most important challenges to be tackled for the ports include

- The infrastructural requirements
- The vehicles' technological requirements
- Regulatory requirements
- Data protection requirements (PKI-Public Key Infrastructure)
- Requirements in possible connection with additional services und business cases

5.1
Infrastructure

The set-up of physical transport infrastructure is determined by the vehicles using this infrastructure and vice versa. Most demands towards infrastructure are reasoned by the dimension and weight of the vehicles.

Previously any demand for a change or a reconfiguration of transport infrastructure have been reasoned by the demand of transport companies to be able to use scaling effects by using longer, higher or/ and heavier vehicles. This includes e.g. even in the somewhat harmonized European Union trucks over 4 m height in Norway and the UK, heavier trucks (60 tonnes) in Sweden and Finland, longer trains over 700 m between Germany and Denmark or the demands from larger container vessels to port infrastructure and navigation channels.

With autonomous vehicles it is not crystal clear if from these vehicles new and additional demands for transport infrastructure originate. However, this will obviously be the case, if less mature autonomous systems require supporting technology to run error-free. Vehicle to vehicle communication and vehicle to infrastructure communication could help to supply such requirements. However, the overall vision of autonomous vehicles remain, that they should be able to cope with any demand, which means that they can operate on any infrastructure.

The physical infrastructure as designed and visualized today is based on the capabilities of conventional vehicles and the cognitive abilities of human drivers.

5.1.1 Road Infrastructure

Proposed measures:

- Prepare the road with high quality road surfaces to minimize irritation
- Ensure a high quality of formation, contrast and regular maintenance of road markings
- Provide as further support road guidance systems and road demarcation markers

Road surfaces should be prepared in a good quality to support the movement of (semi-) autonomous road vehicles in ports. The road markings should be clearly readable, also by optical sensors. Which contrast in which weather conditions and illumination should be advisable, is not clear and depends on the maturity of the technology built into the vehicle. Same is true for any additional road guidance systems such as magnetic guidance systems.

The camera-based detection relies on visual detection of road markings and lane borders. Therefore, the road markings must be available in good quality in the ports at all time. Moreover, the variable textures and colors of the pavement are challenging the detection of the drivable road regions. A uniform pavement on the roads would be preferable. More challenging factors are illumination conditions that cause shadows and the road curvatures. (Cai et al. 2018)

According to Lytrivis et al. (2018), the average road vehicle age is about 10 years. The average lifecycle of the road is 20 to 30 years. The truck fleet is renewed even every 5 to 7 years. Thus, road transport infrastructure does not innovate as fast as the vehicles using it. “In addition, new and existing, physical […] infrastructure elements […] need to be designed and adapted in order to allow the current infrastructure to address the introduction of automation in a flexible, fast and cost effective way, while being understood by all traffic participants, automated or not.” (Lytrivis et al. 2018)

One of the key aspects of environment perception is road detection. The most important elements of the road are markings and lane borders. For detection the most commonly used sensors are LiDAR and cameras. (Cai et al. 2018)

5.1.2 Railway Infrastructure

Proposed measure:

- Preparation of the port's own railway infrastructure in such a way that developments in the main railway network are tracked with regard to the technologies used, such as sensors and additional data transmission systems.

This would allow the (autonomous) trains to run seamlessly from the main network onto the port rail network. Since railway transport is usually controlled and governed by railway infrastructure authorities almost in real-time, it depends how much the port railway infrastructure is integrated into such regimes.
In the case of isolated single applications, where either a special train e.g. between a mine and a port is operated or port railway traffic is not fully linked to any other network

traffic; such systems may include technological solutions not applicable on mixed networks.

As regards shunting, it would be again the question, if the shunting operations only take place in a closed system. In a closed system autonomous shunting locomotives may use a dedicated system to navigate on the network and to perform their task.

5.1.3 Waterborne Infrastructure

Proposed measures

- Prepare the appearance of shore control centers for remotely controlled vessels.
- Depending on the responsibility of the port for the navigation within its coastal waters prepare the integration of advanced data transmission technology systems to support autonomous shipping within Vessel Traffic Service areas.
- Prepare for auto-mooring facilities if MASS sail completely unmanned to the terminals.
- Plan for training the involved personnel with the new processes arising.
- Since MASS aim for smaller and more flexible ships and thus provides more frequent services such vessels are also an issue for smaller ports.

Following Lloyd's Register (2017b), automation of vessels will transform on-shore elements of shipping, from port infrastructure and cargo handling through to the land-based logistics chain. Besides a Port-IoT, infrastructure needs to adapt to autonomous vessels, e.g. the mooring system for autonomous vessels. According to AAWA (2016) the mooring system for an autonomous vessel can be fully or semi-automated:

- Fully automated: complete mooring and unmooring operation can be remotely controlled or is automatically executed by the autonomous vessel;
- Semi-automated: Connection to the quay can be made automatically but crew is needed to secure the docking (i.e. using conventional rope-based systems).

5.1.4 Infrastructure for UAV

Proposed measure:

- Develop or contribute to a concept for the regulation of aerial corridors (concept for lower airspace) or zones for UAV.

Especially for the case of emergencies, but also for the setup of regular UAV flights it is helpful or even necessary to set up a network of aerial corridors. This network should connect start and landing places of UAV and ensure that flying in these corridors is following the regulation. The corridors enable a rapid implementation of new ideas for the use of UAV, and above all a use in emergency cases.

5.1.5 Digital Infrastructure

Proposed measures

- Provision of low latency communication networks such as 5G or wireless standards such as G5.
- Prepare how to handle the issue of data generated by V2X infrastructures to be compliant with national or international law.
- Prepare HD Maps of the relevant port transport infrastructure.
- Take into concern the most likely increasing demand for IT security of the ports' IT systems.

As the autonomous vehicles will require connectivity and bandwidth in their introduction phase, ports should ensure the availability of communication networks. They are considered as a prerequisite also for the IoT applications to come in freight transport, so ports will be obliged to invest in these systems anyway, or depending on the individual setup, engage telecommunication companies to provide the respective infrastructure. If they do it themselves or leave it to a telecommunication company is depending on the regulations and capabilities of the involved companies.

Another important prerequisite for autonomous use cases is the development of digital twins of a port in all dimensions. Data provided in such a twin are crucial for developers and future users of the port.

There is, as stated previously, a high relevance of data/ 3-D visual environment acquisition for autonomous driving. The vehicles record the environment by means of sensors and regularly compare this with the basic data (such as geodata, HD Maps of the road image). Therefore, for autonomous driving an inventory of the road image in digital form (Digital Twin) is most likely necessary and useful. Infrastructure operators and ports could also provide support with regard to their own transport network or hold adequate digital material available.

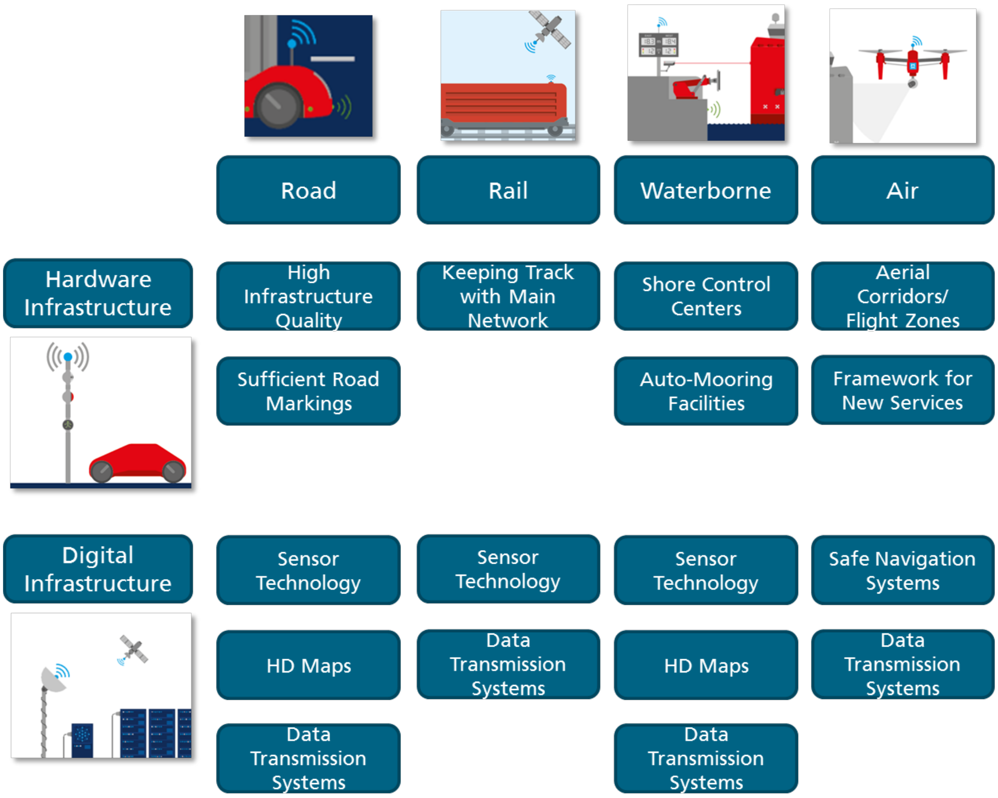

Figure 18: Recommendations at a glance

5.2 Regulation and Legal Challenges

The development towards autonomous driving in ports requires adjustments in the applicable regulations. Regulations must ensure that in the years to come, when steered and remote controlled, automated and autonomous vehicles use the same infrastructure, the development is not hindered on one side, but on the other side no persons' rights, or any other assets are harmed by the new technology. This chapter deals with the fundamental problem of the speed of regulation and legislation, addresses the specificities of regulation for infrastructures and vehicles and finally adds some thoughts to the challenges data protection policies might add to the setup of communication infrastructure for autonomous driving.

5.2.1 Speeding up the Regulation for New Technologies

Regulatory institutions and administrations are faced with the key challenge how to protect citizens best, ensure fair markets, and enforce regulations, while allowing new technologies and businesses to develop. According to Lloyd's Register (2017b), there is a crucial mismatch between the time taken to develop and exploit technology and the ability of regulators to develop codes and practices. Eggers et al. (2018) state, that existing regulatory structures are often too slow to adapt to changing societal and economic circumstances, and that regulatory agencies are generally risk-averse. Accordingly, rapid adaptation to emerging technology is supposed to pose significant hurdles. The authors argue that traditional regulation faces the following challenges:

- Business challenges:
    - The pacing problem: Regulation may reflect an understanding of yesterday's technologies instead of what is currently emerging;
    - Disruptive business models: Evolving products and services can shift from one regulatory category to another, therefore regulation needs to be as flexible as business models;

- Technological challenges:
    - Data, digital privacy, and security: The growing use of smartphones, connected devices, and sensors has created a vast digital footprint in consumers' lives. So, who is responsible for the protection of the data and who actually owns the data? Only in 2019 a data protection regulation was put into force in the European Union - 13 years after the first iPhone.
    - AI-based challenges: AI and the underlying algorithms is a black box for the regulators. The question to be answered is, how to deal with incomplete information based on AI? Who could be made responsible for a wrong decision?

In order to decide on the need for the adaptation of existing regulations, four questions should be answered (Eggers et al. 2018):

1. What is the current state of regulation in the area? (Current state of ecosystem that could apply)
2. What is the right time to regulate? How can regulators avoid the too-fast or too-slow speed of implementation?
3. What is the right approach to regulation?
4. What has changed since regulations were first enacted?

Many actors are involved in regulating and law-giving when it comes to autonomous driving in ports. Not only the national and EU-regulations must be taken into account, but also demands of international organizations and trade unions.

Experts suggest the setup of "regulatory sandboxes". Ports and other interested parties in the port environment could suggest to prototype and test new approaches by creating sandboxes and accelerators. By doing so, the technological prerequisites of the new technologies could be tested in a safe surrounding and valuable input for the design of new regulation is gathered. Furthermore, the ports' stakeholders could act in the direction of a collaborative regulation. The aim to align regulation nationally and internationally could be reached by engaging a broader set of players across the ecosystem. Thus regulators can benefit from working directly with businesses, innovators, and other players to define rules for emerging technologies.

This approach setting up test areas and communicating with regulation bodies may accelerate the speed at which legislation is adapted to new requirements and also to sharpen the design of new regulation. At least these activities have the potential to evolve ports and their respective stakeholders to experts and valued partners in the development of regulation and legislation for the installment of infrastructure and operation of automated driving in ports.

5.2.2 Evolving Infrastructure Regulations

Legal consequences for infrastructure providers have changed severely lately. While previously a provider was only responsible for sufficient road surfaces and analog traffic signs, today, complex intermodal traffic management systems have become reality. This development is accompanied by increased investment and responsibility of infrastructure operators. For infrastructure operators, this means that they must be alert to value their services with a view to new risks. The development of automated vehicles, supported by digital infrastructure, must mirror responsibility and liability of the providers.

For ports this means to face legal responsibilities when it comes to the infrastructure use by third parties, e.g. by using risk management tools and systems. Ports that are engaged in the development of testbeds or are involved in other kind in the development of new technologies may make use of the information gathered from own experiences or the exchange with their competitors.

The changing infrastructure requirements, together with the necessary investment, may also lead to new insurance needs and thus to rising fees for the use of the empowered infrastructure. Recommendations to cope with regulation and legal challenges are:

- Ports should develop a risk management system that includes possible damages arising from automated or autonomous driving in ports.
- New and already known risks should be taken care of in the further development of the infrastructure as well as in the coverage of the respective insurances.
- Contact and exchange of experiences with involved institutions and organizations could help to further maintain an overview on upcoming developments and expectations, but also of legal and regulation affordances.

5.2.3 Designing the Prerequisites of Autonomous Driving

Regulations and laws that design the process of autonomous driving focus on the safety of all traffic participants. They take care of the topic of liability in any case of damage occurring. The question of safety of traffic is already tackled successfully in traffic rules applied in all transport sectors and is mostly comparable between different nations. To ensure the safe operation of automated or autonomous vehicles the obvious solution should be to ensure that they must obey the rules in force. However, that is easier said than done.

In daily traffic situations we observe drivers that violate traffic rules knowingly to conduct their journey, e.g. while crossing a blocked area or closed line to pass a bottleneck or while overtaking a (wrongly) parking delivery van. These are situations in which it is not clear how automated vehicles should react. Also the so called Trolley-Problem is a subject for regulation, situations, in which a damage of one or more persons cannot be avoided and a machine has to decide what to do and who to injure or even to kill to avoid the damage of others.

How is the liability in the case of an accident or damage regulated? According to Vellinga (2018), a novel interpretation of some regulations might provide a solution, meaning that the driver does not necessarily need to be a human driver. According to Yadron (2016), Google raised this issue in the United States on the interpretation of the American Federal Motor Vehicle Safety Standards (FMVSS) and has managed to persuade the US National Highway Traffic Safety Administration (NHTSA) that the company's computers should be defined as the drivers of autonomous vehicles.

Another important legal topic that needs to be taken into consideration is the topic of personal data or data recording in general. Automated or autonomous driving vehicles can be expected to exchange more data than modern cars today. And these vehicles will not only exchange data with some kind of steering and controlling entity, but also with each other in V2X-situations, which makes the protection of data complicated, especially if the infrastructure owner is public and has to follow regulations about publically gained data.

6 Conclusions

Ports should prepare themselves for the demand of their customers to use (semi-) automated vehicles, being it road, rail, air or waterborne. The required steps to prepare for autonomous driving and flying depend on the existing digitalization degree of a port and on its responsibility for the port infrastructure. The following degrees can be differentiated:

1. None to a very low level of digitalization: ports in less developed economies where only basic IT infrastructure is available
2. Medium level of digitalization
3. Highly digitized ports: Large and competitive container ports in e.g. Asia, the USA or Western Europe

As described in the previous sections, automated driving is getting increasingly more attention for all transport modes. Most quoted reasoning for this technology includes an increased efficiency of transport which brings alongside better capacity utilization and less negative environmental impact. Safety issues are also quoted quite a lot, while at the same time this safety concerns are the most questioned regarding acceptance of such systems.

The most important challenges to be tackled for the ports include

- The infrastructural requirements
- The vehicles' technological requirements
- Regulatory requirements
- Data protection requirements (PKI-Public Key Infrastructure)
- Requirements in possible connection with additional services und business cases

There can be hardly any doubt, that it will the lower operating costs that once evident will make the transport industry use these systems. These vehicles will then arrive at the gates of the ports. Transport departments, infrastructure providers and port authorities prepare themselves for the technology leap to come. For the time being, test applications are carried out testing the technology of autonomous driving in ports.

UAV play a special role in this context. There have been no comparable transport solutions so far, and the range of services offered by UAV extends transport solutions into completely new areas. For example, tasks can be performed in the security of terminal and port facilities, in the case of SAR operations, or in the detection of leaks or thermal anomalies, which have not been performed in the past.

Interesting enough, ports and cities, the parties responsible for the transport infrastructure, take the lead in this development installing technology to their infrastructure e.g. mainly sensor, communication devices like W-Lan. Some cities and ports want to go ahead, but face some immaturity of the autonomous vehicle technologies. The immaturity of the technology for autonomous driving remains evident.

There is only limited evidence that transport infrastructure providers like port authorities will gain any competitive advantage fostering the development towards autonomous driving. If autonomous driving of freight vehicles will lower the transport costs per ton-kilometer depends on the wages of the drivers in the specific regions. However, if this is the case, and the avoidance of driving hour regulations and a noise reduced operation is a strong hint into this direction, it will be no question that forwarders will shift to use autonomous trucks. Also the scarcity of qualified driving personal in some western economies for road, rail and waterborne transport could be overcome this way.

As a direct consequence ports will increase their competitive advantage making autonomous driving possible at that early stage.

This means that ports should make themselves known to the technology and start, advisably together with the vehicle industry, test sites so called sandboxes. The test sites will have to use supporting systems such as additional sensors and wireless or mobile networks to ensure their feasibility.

Port Authorities could use and steer with the trend towards autonomous driving the digitalization within their domain and develop new business models sustaining their role as responsible societal partners and port business facilitators to ensure the port regions' economic wealth.

Road infrastructure planning should take into account the requirements for autonomous vehicles also in the emerging phase. Even though the overall idea of autonomous vehicles is that they should be able to cope with any infrastructure condition, in their emergence phase they will require additional aid also from sound physical infrastructure – high quality pavements, intact (road) markings, and digital infrastructure as networks.

While the development of the autonomous vehicles still remains in a development phase, todays recommendations to ports include:

For road infrastructure:

- Prepare the road with high quality road surfaces to minimize irritation.
- Ensure a high quality of formation, contrast and regular maintenance of road markings.
- Provide as further support road guidance systems and road demarcation markers.

For railway infrastructure:

- Prepare the port owned railway infrastructure in such a way to keep track to the developments on the main network in terms of deployed technology such as sensors and auxiliary data transmission systems.

For waterborne infrastructure:

- Prepare the appearance of shore control centers for remotely controlled vessels.
- Depending on the responsibility of the port for the navigation within its coastal waters prepare the integration of advanced data transmission technology systems to support autonomous shipping within Vessel Traffic Service areas.
- Prepare for auto-mooring facilities if MASS sail completely unmanned to the terminals.
- Plan for training the involved personnel with the new processes arising.

For aerial vehicles:

- Prepare the installation of aerial corridors for the flight of UAV.

Regarding the digital infrastructure a definite answer what to install and what not cannot be provided, since the autonomous driving systems are still immature and e.g. need supporting networks or sensors that might become obsolete soon. Proposed measures however may include

- Provision of low latency communication networks such as 5G or wireless standards such as G5.
- Prepare how to handle the issue how to deal with partial public data generated by V2X infrastructures according to national or international law.
- Prepare HD maps data collection of the relevant port transport infrastructure.
- Take into concern the most likely increasing demand for IT security of the ports' IT systems.

Regarding the legal aspects the suggestion is to set-up of "regulatory sandboxes". Ports and other interested parties in the port environment could suggest to prototype and test new approaches by creating sandboxes and accelerators. By doing so, the technological prerequisites of the new technologies could be tested in a safe surrounding and valuable input for the design of new regulation could be gathered. Furthermore, the ports' stakeholders could act in the direction of a collaborative regulation.

In any case the time to act is now, autonomous driving will emerge and ports should be well prepared for these vehicles.

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