Capacity with a pOsitive enviRonmEntal and societAL footprInt: portS in the future era

COREALIS
THE PORT OF THE FUTURE

# D.1.1: Port of the future challenges, enablers and barriers

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# Table of Contents

# List of Tables



# List of Figures

# List of Acronyms

| Abbreviation / acronym | Description |
|---|---|
| ABP | Algeciras BrainPort |
| AEOLIX | Architecture for EurOpean Logistics Information eXchange |
| AGV | Automated Guided Vehicles |
| AID | Automatic Incident Detection |
| AIS | Automatic Identification Systems |
| AIS | Automatic Identification System |
| ANPR | Automatic Number Plate Recognition |
| APCS | Antwerp Port Community System |
| APS | Advanced Planning and Scheduling |
| ATC | Automated Transfer Cranes |
| ATP | Automatic Train Protection |
| AVI | Automatic Vehicle Identification |
| BCG | Boston Consulting Group |
| BoL | Bill of Laden |
| CEPA | Center for European Policy Analysis |
| CITOS | Computer Integrated Terminal Operations System |
| D1.1 | Deliverable number 1 belonging to WP 1 |
| DGPS | Differential Global Positioning Systems |
| DIVA | Dynamic Information on Traffic Volumes in the Area of the Port |
| DPS | Dynamic Planning System |
| DW | Data Warehouse |
| EC | European Commission |
| ECS | Export Control System |
| EDI | Electronic Data Interchange |
| EGNOS | European Geostationary Navigation Overlay Service |
| EMCS | Excise Movement and Control System |
| ENS | Entry Summary Declaration |
| ERP | Enterprise resource planning |
| ERTMS | European Rail Traffic Management System |
| GNSS | Global Navigation Satellite Systems |
| GPS | Global Positioning Systems |

| Abbreviation / acronym | Description |
|---|---|
| HPA | Hamburg Port Authority |
| HPA | Hamburg Port Authority |
| ICS | Import Control System |
| ILU | Intermodal Loading Unit |
| IMO | International Maritime Organization |
| IOS | Inter-Organizational System |
| IoT | Internet of Things |
| IPCSA | International Port Community Systems Association |
| IS | Information System |
| ISO | International Standards Organization |
| ISPS Code | International Ship and Port Facility Security Code |
| IT | Information Technology |
| KM | Knowledge Management |
| KoM | Kick-Off Meeting |
| KPI | Key Performance Indicator |
| LTE | Long-Term Evolution |
| LPS | Local Positiong Systems |
| MCA | Maritime and Coastguard Agency |
| NFC | Near Feld Communication |
| NSW | National Single Window |
| OCR | Optical Character Recognition |
| PCS | Port Community System |
| PoF | Port of the Future |
| PRISE | Port River Information System Elbe |
| RFID | Radio-Frequency Identification |
| RMG | Rail-Mounted Gantry |
| RO/RO | Roll-on/roll-off |
| RTLS | Real-Time Location Systems |
| SBAS | Satellite-Based Augmentation System |
| STS | Ship-To-Shore |
| TAS | Truck Appointment System |
| TEA-21 | Transportation Equity Act for the 21st Century |
| TOS | Terminal Operating System |

| Abbreviation / acronym | Description |
|---|---|
| UMTS | Universal Mobile Telecommunications System |
| UN/EDIFACT | United Nations/Electronic Data Interchange for Administration, Commerce and Transport |
| UNCTAD | United Nations Conference on Trade and Development |
| VAL | Value Added Logistics |
| VANET | Vehicular Ad-hoc Network |
| VGM | Verified Gross Mass |
| VMRS | Vessel Movement Reporting Systems |
| VTIS | Vessel Traffic Information System |
| VTS | Vessel Traffic Service |
| WLS | Wireless Sensor Network |
| WP | Work Package |
| WSAN | Wireless Sensor Actuator Networks |
| WSN | Wireless Sensor Network |
| XML | Extensible Markup Language |

# Executive Summary

This document aims to make a comprehensive and systematic recording of current, mid-term and long-term challenges, enablers and barriers that European ports are facing in the era of digital revolution regarding operational capacity/efficiency, hinterland connectivity, environmental footprint and sustainability concerning climate change, societal acceptance and inclusion in public-private partnerships.

The methodology used to identify relevant challenges, enablers and barriers for European Ports involves i) desk-research, including earlier studies regarding port competitive assessment (e.g. findings from other EC-funded projects, such as SmartPort, CO-GISTICS, AEOLIX, Clusters2.0 and port associations, such as EUROPORTS, ESPO), and b) an online survey and questionnaire.

The result of the desk research is presented in sections 2-4. Section 2 outlines the state of the art regarding the port category/types which will help to provide a comprehensive and up-to-date list of enablers and barriers (technological, business, environmental and societal) for ports to tackle their challenges. Section 3 gives an overview of IT systems used in ports, and provides an in-depth analysis of historical development of seaports with a particular regard to digital transformation categorizing major developments into three main generations of digital transformations. Next, an extensive overview of the technology used nowadays in port operations is presented followed by an overview of information systems largely in use as well as an excerpt on the emerging disruptive technologies possibly used by ports to depict the unfolding innovative framework, including Internet of Things (IoT), data analytics, next generation traffic management and emerging 5G networks, for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. The desk research process concludes with section 4 where a taxonomy on the most significant barriers and enablers is presented, as inferred by the study of several recent EU-funded projects on the field of Logistics.

Section 5 gives an overview of the procedure followed for building the online survey and questionnaire while the analysis on perceived enablers, barriers and challenges is provided in Section 6. The analysis of the responses showed that operational efficiency and sustainable growth are the most important challenges that stakeholders currently face while hinterland connectivity is by far the most significant enabler for port stakeholders compared to other factors examined. An interesting result of the analysis was that as far as barriers are concerned, they are almost equally important.

All methods followed in the framework of this research are fully compliant with the principles described in Deliverables D.8.7 on the Final Data Management Plan and D.10.1 on the Protection of Personal Data Requirements. In this context, a series of measures has been taken to protect the personal data of participants. The collection of such data, especially regarding participants' ethnicity, age, gender, educational level and socioeconomic status has been guided and justified, in order to meet the research goals of the project. Particular care has been taken to ensure the protection of personal data, not only in the data acquisition phase, but also in the data storage, protection and destruction. The EU General Data Protection Regulation

(General Data Protection Regulation, 2016) is taken into account in personal data processing by making licit use of the collected data and guaranteeing participants' privacy.

# 1. Introduction

Ports are essential for the European economy and for economic growth; 74% of goods exported or imported to the EU are transported via its seaports [1]. At the same time, the challenges they are facing are only getting greater: Volumes of cargo are increasingly higher –a 57% rise by 2030 [1] – while they are also arriving in a shrinking number of vessels: the next generation of Post-Panamax vessels have a capacity of more than 18k containers; '…put onto trucks, these containers would stretch in a single line from Rotterdam to Paris' [1]. Cargo volumes are not just increasing; cargo flows types are also changing due to technological trends, such as Industry 4.0. Moreover, cargo port operators need to comply with increasingly stricter environmental regulations and societal views for sustainable operations. Thus, a sustainable land-use strategy in and around the port and a strategic transition to new, service-based, management models that improve capacity and efficiency are paramount. They are key enablers for ports that want to keep pace with the new ocean carriers needs and establish themselves as trans-shipment hubs with a "*societal license to operate*" [2] as well as for ports whose land strategy, hinterland accessibility and operations are underpinned by circular economy principles aiming to achieve sustainability, low carbon footprint and a mutually beneficial relation to the city. Future port strategies must actively engage local stakeholders and strengthen the local (port-city) and international network (TEN-T and ports as hubs).

COREALIS proposes a strategic, innovative framework, supported by disruptive technologies, including Internet of Things (IoT), data analytics, next generation traffic management and emerging 5G networks, for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. It respects the limitations that many European ports are facing concerning the port land, intermodal infrastructure and terminal operation. It proposes beyond state of the art innovations that will increase efficiency and optimize land-use, while being financially viable, respecting circular economy principles and being of service to the urban environment. Through COREALIS, ports will minimize their environmental footprint to the city, they will decrease disturbance to local population through a significant reduction in the congestion around the port. They will also be a pillar of economic development and business innovation, promoting local startups in disruptive technologies of mutual interest. COREALIS innovations are key both for the major deep sea European ports in view of the mega-vessel era, but also relevant for medium sized ports with limited investment funds for infrastructure and automation. Further description on the COREALIS innovations can be found in Annex 1.

## 1.1 Purpose of the Document

The overall objective of the present deliverable is το make a comprehensive and systematic recording of current, mid-term and long-term challenges, enablers and barriers that European ports are facing in the era of digital revolution regarding operational capacity/efficiency, hinterland connectivity, environmental footprint and sustainability concerning climate change, societal acceptance and inclusion in public-private partnerships.

The methodology used to identify relevant challenges, enablers and barriers for European Ports involves i) desk-research and b) an online survey and questionnaire.

## 1.2 Intended readership

The work presented in this report addresses the needs of three potential user communities:

- Container Terminal Operators who are interested in improving the port operational efficiency and embracing circular economy models in the port's strategy and operations.
- Public Authorities (local, regional or national) who are interested in enabling the port to take informed medium-term and long-term strategic decisions and become an innovation hub of the local urban space. In addition they would like to reduce the port's total environmental footprint associated with intermodal connections and the surrounding urban environment for three major transport modes, road/truck, rail and inland waterways.
- Local communities who are interested in lowering the environmental impact of port operations in the surrounding urban space and efficient connections with hinterland transport network and would like to have an updated view of ways to create efficient connections with hinterland transport network.

It may seem difficult to address the needs of such diverse communities in a single document. Nevertheless, the editors believe that the workflow allows us to organize the information in ways useful to all aforementioned communities.

## 1.3 Relation with other COREALIS deliverables

The present document will feed several other key deliverables of the project and WP1 "Port of the Future Needs and Requirements". The current document is in close relation to Task 1.2 on the "Identification of the smart port-city stakeholders and COREALIS Personas" as well as task 1.3 on the "COREALIS User Stories and Scenarios". In this task, the COREALIS user stories and high-level scenarios that will be further on implemented in the five Living Labs shall be compiled.

All the aforementioned tasks give complementing inputs to the task 1.4 "Port of the future needs and requirements" which will provide a list of requirements, properly framed to assist the design and development of the proposed innovations. The task will cover not only technical requirements (functional and non-functional) from the ports' side, but will also seek to identify legal/regulatory, security and data privacy needs for the proper implementation as well as scale-up of the scenario described by the stakeholders.

Finally, all methods followed in the framework of this research are fully compliant with the principles described in Deliverables D.8.7 on the Final Data Management Plan[1] and D.10.1 on the Protection of Personal Data Requirements[2].

[1] COREALIS Deliverable, D.8.7: Initial Data Management Plan, (2018)
[2] COREALIS Deliverable, D.10.1: POPD - Requirement No. 1

# 2. Matrix of container ports

Ports have always functioned as loading centres for cargo, and although historically many ports were pivotal to international trade, many others also failed to sustain their role over time. However, to determine the factors which raise the profiles of ports as centres of international trade and as hubs is not a straightforward analytical exercise. A major challenge for researchers nowadays is to pinpoint and analyze the relationship between a port and its region in view of economic activity. From this perspective, our particular concern is to explore the function and classification of container ports and port cities in relation to the networks that connect them inland and outward.

The existing classifications of ports do not account for the relatively recent changes in shipping and inland transport networks (containerization, globalization and regionalization), nor do they reflect the current diverse trends of economic activity of the maritime and logistic industry. Given these influential trends in port development and in light of the recent economic downturn, the aim of this section is to identify different port classifications.

## 2.1 Traditional Port Classification

In the literature we observe three main types of definition of ports: i) hierarchical, ii) generation and iii) functional. The hierarchical classification refers to the role of ports in the shipping network and partially includes their role as an intermodal linkage, but it neither clarifies the inland network at ports, nor includes the explanation for logistics services and relationships with the region. The generation classification divides ports according to their development or evolutionary stage, and assumes that ports develop from a primitive harbour to a global hub port. The third classification of ports, that of functional, asserts that globalization and regionalization in the world economy promote ports to develop as transhipment hubs or regional load centres in the global logistics chain. The functional approach emphasizes the role of intermodal transport of ports in the supply chain.

### 2.1.1 Hierarchical Classification

Shipping companies have developed the hub-and-spoke system in order to concentrate capacity at a few major nodes connected by many spokes and to benefit from economies of scale. The hierarchical definition of ports relies on the concept of the shipping route. It is mainly based on the hub-and-spoke system, but does not address the interaction between a port and its region. It is therefore a one-sided view of ports, for instance, the shipping trunk line can easily be altered, according to port throughput in each region and each port.

A formalized concept of hub port and port classification was suggested by UNCTAD (1990) after the generalization of the container system in world trade during the 1980s. However, many changes have since occurred in the container shipping business, in which traditional routes have become obsolete, and new routes play a more significant role, as in the case of ship calls in Chinese and Korean ports. Very rapid growth of Northeast Asian container ports which benefitted from the enormous economic growth of the 1990s, meant that feeder ports developed into regional hub ports or into global hub ports. Even though this hierarchical classification of ports can explain the shipping network after containerization, it lacks in its definition an integrated logistics vantage point, that is, a port plays the role of joint operator, and the effects of inland networks on ports may be a decisive factor for the positioning of ports in the shipping network.

### 2.1.2 Generation Classification

The generation classification defines a port's linear development in view of its functional and evolutionary change, for example, from primitive fishing village to developed facility, such as a global logistics centre. This classification, which is widely accepted in the maritime industry, identifies ports on the basis of development generation or as having undergone evolutionary stages (UNCTAD, 1992). Nevertheless, different types of ports and diversified ports carry out numerous functions simultaneously so we can surmise that a port does not always evolve in one direction or through a predictable pattern.

Thus the evolutionary stage of a port can be interpreted as the development of spatial and functional relationships between a port and its corresponding city. This view emphasizes waterfront revitalization as the final stage of evolution and mixed-use operations as a more advanced stage than the containerization and the RO/RO system stage. Even if there is connectivity between globalization and renewal of the port city, it is arguable that every port city renews its function and also enhances its port-city integration.

### 2.1.3 Functional Classification

The functional classification of a port from the perspective of integrated logistics systems and inland transport networks focuses on the regionalization of a port system through a number of stages and on the integration of shipping and land based logistics networks. This functional approach analyses the emergence of transshipment ports and the competition of logistics chains but nevertheless ignores the diversity inherent in port development from a simple function to advanced transport networks and instead regards port logistics integration as the last step of port development.

The port has also been classified as a combined channel system of trade, supply and logistics. This interpretation not only defines the content of traditional port services into the simple services of loading and unloading cargo, but also argues that a port can supply shippers with value-added logistics services as well as related services, including trade, financial, leisure, and property development. However, this does not define multiple types of combination among trade, supply and logistics channels.

## 2.2 New Classification of Container Ports

Differently from the conventional port mainly serving bulk cargoes and general cargoes, a container port is built usually in accordance with the planning on transport networks by governmental authorities. In addition, the demand and the supply of shipping and inland transport networks around a container port would be harmonized by bargaining on port tariff between terminal operators and logistics providers, such as shipping companies, hauliers and freight forwarders, agreement on port planning between central government and local government, collaboration among logistics providers and policy makers and strategic behaviour of logistics providers. Different choice behavior by participants in transport networks will decide each type of shipping and inland transport networks around a container port. Hence there could be different combination by each shipping networks. Decisions on shipping networks by shipping companies could be sometimes suitable for multifunctional inland network by hauliers and railway companies or suitable with simple inland network. Even under immature inland networks shipping companies use a container port as a transshipment hub in continental shipping routes.

Thus, six types of shipping networks have been outlined and a new classification for container ports can be developed through the combination of the definitions of shipping and inland network. Conceptually, we know that ports may develop different functions and impact differently on their regional economies, in accordance with their network characteristics. Based on the mix of shipping and inland network nine different port types can be conceptualised:

- Dominant
- Superior
- Intermediary
- Versatile
- Ordinary
- Developing
- Specialized
- Industrial
- Peripheral

### 2.1.4 Dominant Ports

Dominant ports have a global shipping network and a multifunctional inland network that gives accessibility to regional markets or mega-markets. Most leading shipping companies have a calling schedule in dominant ports. A multifunctional inland network allows a container port to dominate the world logistics market and connect with foreign inland regions. As leaders of new systems and technologies, dominant ports can produce their own movement by activating the economy in their backward areas and hinterlands, where diversified value-added services can be supplied to shippers. By establishing their base for business activity around these container ports, shippers such as manufacturing companies and logistics providers can approach regional markets with abundant human resources and distribution networks.

### 2.1.5 Superior Ports

Superior ports have a global shipping network but a restricted inland network. Most leading shipping companies have a calling schedule to a superior port. In the case of superior port, the weakness of legal schemes for backward areas indicates that only limited logistics services can be supplied. Backward areas of superior ports are small and generally unable to afford warehouse and logistics facilities for value-added service to shippers. The majority of the cargo of these container ports is produced in its hinterland.

### 2.1.6 Intermediary Ports

Intermediary ports have a global shipping network as well as simple inland networks to their hinterlands. The major cargo of these container ports is the transhipment cargo of other container ports, but its industrial relations with its backward areas is weak. Intermediary ports are generally used exclusively by one or a few shipping companies.

### 2.1.7 Versatile Ports

Versatile ports have a regional shipping network but their inland networks are multifunctional. The backward area is well-established and often has a good legal scheme for its logistics service. The major cargo is produced in the backward area and hinterland of the country; value-added logistics services can also be supplied to shippers. At versatile ports shippers can be supplied with strong activity in commercial distribution and may access the regional market through the existing distribution system.

### 2.1.8 Ordinary Ports

Ordinary ports have a regional shipping network and an intermodal inland network. The majority of container ports belong to this category, which generally have slow-growing backward areas and are only partially developed and operational. The major source of cargo for these ports is the hinterland, and only limited logistics services can be supplied, due to the weakness of legal schemes for the backward areas.

### 2.1.9 Developing Ports

Developing ports have a regional shipping network and a simple inland network. Through the shipping network developing ports can connect with regional container ports and other container ports in other continents. Their major movements are domestic cargo and their logistic relations with backward areas are weak, which may be due to their being in the early stages of development, partially built and operational. In smaller backward areas, where present, only limited logistics services can be supplied due to weak legal and aids schemes for backward areas.

### 2.1.10 Specialized Ports

Specialized ports have branch or feeder routes in the shipping lane and a multifunctional inland network. Their major movements encompass cargo from its region to multiple countries, and the logistics relation with its backward area is strong because the region is accustomed to specialization: motor manufacturing, oil refinery, chemicals, steel, and food industries.

#### 2.1.11 Industrial Ports

Industrial ports have branch or feeder shipping routes in the shipping lane and intermodal inland networks. Their major haulage includes cargo from regions within the same country, and their relation with backward areas, which may be industrial complexes, is weak. These container ports resemble specialized ports with regard to their type of backward area.

#### 2.1.12 Peripheral Ports

Peripheral ports have branch or feeder shipping routes and simple inland networks. Through the branch and feeder route peripheral ports connect indirectly with the intercontinental shipping service. Cargo generally comes from the same region in the same country, and their hinterland is restricted to smaller areas in the same region of the port.

## 2.3 Conclusion

A new classification of ports on the basis of shipping and inland transport networks which can provide us with the foundation to analyze the relationships between the port and its region, among ports, airports and inland terminals, and between port's activities and information technology. The classification defined here has examined different functions and impacts of ports on regional economies to which they belong, and in accordance with their networks. The nine types of port, from the port in direct intercontinental shipping routes and multifunctional inland routes, to the port in feeder routes and simple inland routes, summarizes the essential characteristics of container ports or terminals. The new definition of ports adopts both hierarchical and functional approaches. We observe that a container port can balance transport networks between sea and inland by mixing different types of networks according to decisions of shipping companies, shippers and logistics providers.

When we consider how international hub ports have risen to prominence or faded to obscurity since the ancient era, we understand ports as economic entities that respond continuously to internal and external changes and have dynamic relationships with their regions. In so doing, we acknowledge that the economic effect of a port to its region can be differentiated based on its unique characteristics

# 3. Overview of IT systems used in ports

Digital transformation is of utmost importance in the business world with major impacts on any of its sectors. Here we consider ports and logistics within maritime shipping to exemplify those developments. That is, as actors in world-wide supply chains, seaports are particularly affected by technological change.

A scheme of port supply chain operations is given below Figure 1. Due to the high requirements in the logistics sector, e.g., regarding costs, efficiency, security, and sustainability, digital innovation is essential to ports to stay competitive.

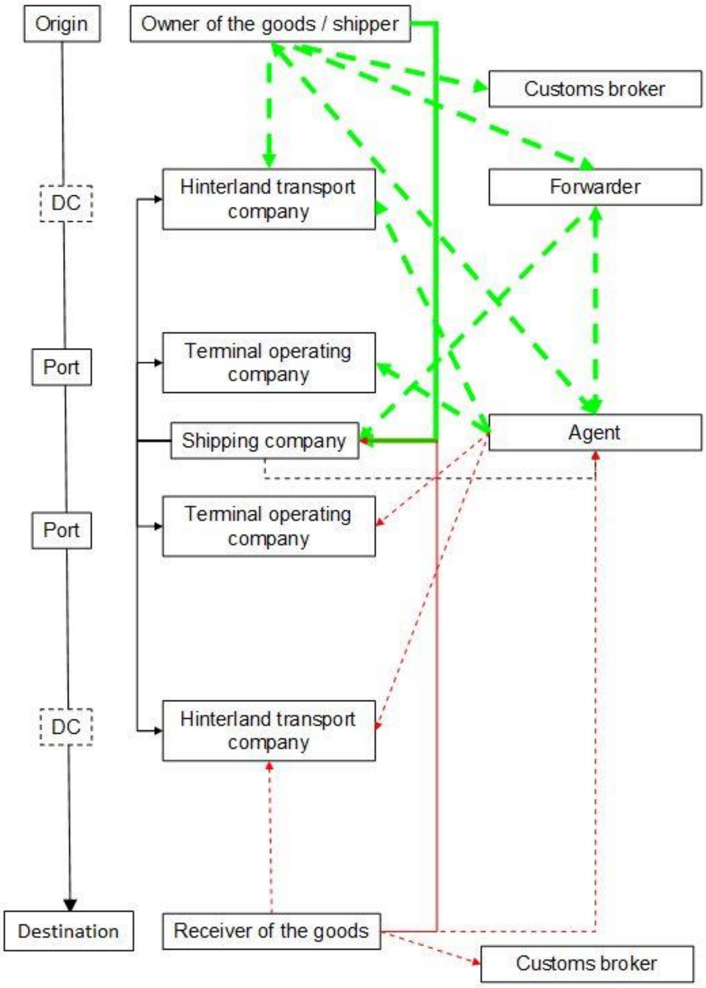


Figure 1. Maritime supply chain

Past developments show how digital innovation can shape the modernization of ports. In order to understand future challenges in this area, it is inevitable to review the outcomes of past developments and their impact on port operations.

The efficiency and safety of related cargo flows is highly dependent on associated information flows. Since the beginning of containerization in the 1960s, the adoption of Information

Technology (IT) and Information Systems (IS) has evolved to an indispensable success factor for the competitiveness of ports, facilitating communication and decision making for enhancing the visibility, productivity, efficiency, and safety in port procedures that are impacted by various conditions [3].

In the first section of this chapter we give an in-depth analysis of historical development of seaports with a particular regard to digital transformation categorizing major developments into three main generations of digital transformations. The second section gives an overview of the technology nowadays used in port operations. Then, the main information systems used in ports and ports operations are also presented. In the last, we give an excerpt on the emerging disruptive technologies possibly used by ports to depict the contemporary innovative framework which is unfolding mid- and long-term perspectives. We include Internet of Things (IoT), data analytics, next generation traffic management and emerging 5G networks, for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges.

## 3.1 History of digital and technological development in ports

Technological development is a continuous and never-ending process. To better understand its features and the contemporary technological solutions applied to ports, we provide an overview on the development of seaports with a particular regard to digital transformation. We categorize major developments into three main generations of digital transformations as suggested by Heilig et al.' (2017) [3].

### 3.1.1 First generation (1980s): Transformation to Paperless Procedures

| | |
|---|---|
| **CALINF** | Call information ( vessel ) / advice of expected container operations |
| **COARRI** | Container discharge / loading report |
| **CODECO** | Container gate in gate out report |
| **CODENO** | Document expiration / clearance ready notice |
| **COEDOR** | Container stock report |
| **COHAOR** | Container special handling order |
| **COPARN** | Container announcement |
| **COPINO** | Container pre notification |
| **COPRAR** | Container discharge / loading order |
| **COREOR** | Container release order |
| **COSTCO** | Container stuffing / stripping confirmation |
| **COSTOR** | Container stuffing / stripping order |
| **DESTIM** | Equipment damage / repair estimate |
| **VESDEP** | Vessel departure |

**Figure 2. EDI Code example of syntax about containers**

The development of the first EDI-based Port Community System (PCS), enabling an electronic document exchange between actors involved in port operations, started in 1983 with DAKOSY1. The development of maritime industry-specific UN/EDIFACT message standards in the late 1980s further fostered this development. In the late 1980s, important paper documents, such as the Bill of Lading (BoL), were transformed into electronic documents (see, e.g., the SeaDocs project starting in 1986; CMI Rules for Electronic BoL in 1990). In the late 1980s, the first commercial Terminal Operating Systems (TOS) were developed and henceforth built the foundation for data-driven planning and automation in container terminals. At that time, customers increasingly demanded VAL (Value Added Logistics) services, requiring an efficient coordination of activities between actors.

By analysing the first periods of dramatic changes in ports, it is possible to say that digital transformation had to take place on several levels (explained at the end of this sub-section). In the context of logistics chains and ports, however, it is possible to notice that the business processes are naturally dependent on efficient information flows in the overall business network. Large port actors, in particular terminal operators, firstly deployed mostly isolated IT systems and applications to provide at least basic IT functionality. The integration of different internal systems and applications was essential to support individual terminal operations like berth and yard activities. Major advances in ERP systems during the 1980s, driven by companies like SAP, gave rise to the idea of developing TOSs integrating data (Time of Shipping) from different business activities taking place within terminals.

Having an integrated view on business processes, overall processes needed to be adopted accordingly to improve the overall planning, management, and coordination of activities. This IT-enabled functional integration allowed more efficient container handling and thus was essential to achieve a competitive edge. The development of off-the-shelf TOSs in the late 1980s may have reduced competitive advantages of individual terminal operators, but led to major advancements in operating container terminals. Knowing that efficient port procedures are highly dependent on the efficiency of all involved organizations and the handover of containers in-between, the need for inter-organizational systems quickly became apparent. As indicated, the development of such systems was highly reliant on common technical standards. The adoption of EDI based on UN/EDIFACT had a strong impact on the overall efficiency of logistics chains by speeding up communications, improving collaboration, decreasing the volume of paper, and reducing costs. The development of EDI systems in the form of PCSs, starting in the early 1980s, focused on the needs of major port communities. The availability and quality of PCSs is still seen as an essential factor for growth and competitiveness of ports. The introduction of EDI systems required community actors to make huge investments in appropriate IT infrastructure and setups, to share information, and to change business processes accordingly. Thus, the development of business networks required actors to firstly transform internal IT in order to comply with those standards. Consequently, actors could again achieve competitive advantages on the local port level by an early adoption of the required IT functionality (level one) and integration of required data from internal systems (level two). Port community actors, who were capable of fulfilling all requirements and adequately adjusting their processes, were then able to additionally benefit from the competitive advantages on a global scale. However, the success of the digital transformation was highly dependent on the port community's willingness to participate.

Generally, we can summarize that one of the major changes in the first generation was the reduction of paper-based processing in inter organizational business processes. However, port operations are often, even today, still highly reliant on the printed version of those documents for handling terminal and administrative procedures (e.g., for the pickup/delivery of containers by drayage firms). This often leads to process errors and inefficiencies, e.g., due to false, outdated, or incomplete information. The major advancement thus was the availability and management of information to better plan and complete internal processes before and after their execution, respectively. Thus, it is seen that the execution of business processes within integrated transportation systems are performed completely autonomously meaning that all involved actors are self-responsible in performing their tasks. However, a lack of actual (external) information during process execution could be another source of inefficiencies. This may also include information on the current situation in ports and the current status of cargo, important for making decisions on when and how to perform subsequent tasks as well as to prevent and react to process errors, which might also occur in preceding business processes performed by other actors. A lack of overall control and visibility may result in cascading errors and delays in related supply chain processes.

It can be observed that the need and degree of digital transformation was highly dependent on the transformation of the port itself. Major ports, consisting of a large port community connecting terminals, authorities, haulage companies, and other stakeholders providing transportation, logistics, and administrative services, urgently required means to better communicate and collaborate. At the same time, those ports could build on existing competitive advantages and had the strength to invest in appropriate IT/IS solutions. In case we regard the overall port as a business, however, the development of a PCS can be seen as just providing basic IT functionality supporting the asynchronous communication in cargo export and import processes (level one) as well as the collection of those documents using a common document platform (level two). This standard IT functionality can be imitated by strong competitors, which is likely the reason for the rapid development of several PCS solutions in major ports during the 1980s and 1990s.

In the following text, we present a summary of the First Generation of Digital Transformation (1980s).

Event: Containerization led to high requirements on efficient cargo and information flows to succeed in the new role of ports as integrated transportation systems and logistics hubs, which had to be supported by huge investments into infrastructure, superstructure, and equipment. IT / IS e.g., EDI, PCS, UN/EDIFACT standards, TOS.

Scope:

- Level 1: Support of individual activities by implementing basic, usually off-the-shelf, and isolated IT functionality (e.g., booking, invoicing, accounting); creation of basic conditions for supporting inter-organizational information exchange using EDI standards.
- Level 2: Integrated view on core business processes within terminals by developing TOS; integration of data sources necessary for supporting collaboration with external actors.
- Level 3: Integration enables planning, management, and coordination of interdependent activities within the terminal.

- Level 4: Paperless interactions between interacting actors in inter-organizational business processes.

Impact:

- Digitalization established the foundation for efficient terminal operations and as well as to expand the traditional business, such as by introducing new VAL.
- Inter-organizational platforms in form of PCSs reduced paper-based processing, but are highly dependent on the port community's willingness to adequately participate; however, in their current form, they are limited to a passive exchange of static documents rather than supporting active interactions among actors.

### 3.1.2 Second Generation (1990s - 2000s): Transformation to Automated Procedures

In the 1990s and 2000s, established and new IT/IS solutions provided an essential foundation to greatly automate container handling procedures, in particular in container terminals. In the early 1990s, laser technologies found their way into terminal operations containing functions such as profiling, locating, distance detection, collision prevention, and damage detection. Providing these functions, laser technologies are regarded as key technology for facilitating automated and safer handling solutions in automated container terminals (some automated port terminal operations are depicted in Figure 3. Automated port terminal operations: a) loading and unloading the ship, b) AGV container operation between quayside and storage yard). This major step towards automated container terminals required a seamless integration between the automated handling equipment and the TOS containing required information including work orders.

The trend of using IT/IS as a backbone to further automate procedures and increase the visibility of port operations continued during the mid and late 1990s. In particular, automatic identification and positioning technologies were introduced in the mid-1990s to improve the efficiency and safety of port operations. Other information systems, such as vessel traffic services (VTS), benefited from the application of automatic identification systems (AIS) in the late 1990s, allowing the tracking of vessels as a means to prevent collisions. To better utilize the capacity of largely increasing vessel sizes while maintaining service quality in liner shipping, the first strategic global liner shipping alliances were formed in the mid-1990s. This required a harmonization of services as well as the IT/IS integration among participating actors. At the same time, the continuous growth in container shipping for the first time seemed to reach the limits of some major ports' infrastructures leading to severe traffic and environmental problems.

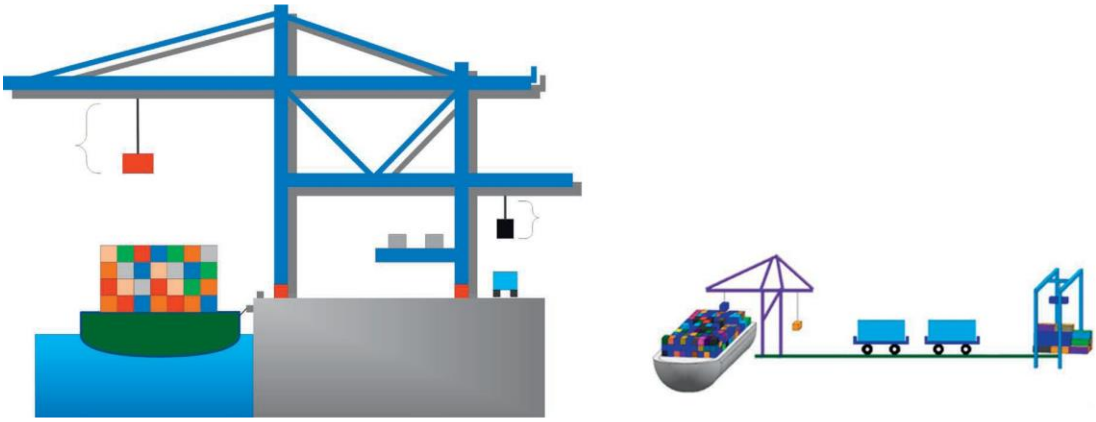

**Figure 3. Automated port terminal operations: a) loading and unloading the ship, b) AGV container operation between quayside and storage yard**

One of the factors was the ever-increasing vessel size leading to peak loads regarding the hinterland transport. Initiatives were formed to propose approaches for addressing those future challenges and imposed state regulations (see, e.g., TEA-21 in 1998, CEPA in 1999). First approaches to address the severe traffic problems were introduced in the beginning of the 21st century. At the Los Angeles/Long Beach ports, the development of the first truck appointment system (TAS) started in 2002 in response to state legislation aiming to reduce truck queuing at terminal gates in order to mitigate vehicle emissions. Again, new information systems were needed to allow the transformation of drayage operations. Terminal operators furthermore asked drayage firms to equip their trucks with RFID (radio-frequency identification) tags in order to allow, for instance, prior identification checks.

We further observe that there was a growing interest in e-commerce systems in the late 1990s, for example, to facilitate trade and shipping management between carriers, shippers, and forwarders. This can be explained by the general euphoric attitude towards e- commerce, today known as dot-com boom, which resulted in new e-commerce platforms. INTTRA, developed in 2000, for example, is still the leading e-marketplace for the maritime industry supporting maritime shipping commerce. Moreover, to streamline the national and cross-national exchange of information with governments, increased demand for single-window systems began to rise in the mid-2000s. The global economic crisis of 2008-2009 led to a more stringent evaluation and selection of ports intensifying the competition among ports drastically. A structural implication was that sustainable performance can be achieved through two key strategies. While the first strategy aims to strengthen the cooperation between ports, the second strategy focuses on improving the coordination between port community actors, e.g., to solve hinterland accessibility problems.

The roles of port authorities and terminal operators in restructuring and enabling an active coordination of actors have become increasingly important. Nowadays it is further crucial to be more responsive to changing circumstances, such as regarding customer needs and process errors. In this context, visibility and decision support based on accurate data are essential. Instead of focusing on exchanging static electronic documents for managing the transport and handover of containers, a new era of contextual real-time data processing for enabling smart procedures was about to begin. In terms of digital transformation, the focus of the second generation was clearly on the integration of terminal equipment and the terminals' IT/IS infrastructure to support automation in terminals.

In the first stage, terminal operators adopted new handling technologies equipped with sensors and laser technologies allowing an autonomous handling of cargo. However, the productivity of automated terminals was highly dependent on the design and development of control software. The final step was to integrate the control software with the terminal's TOS. Thus, the previous generation built a necessary basis, and competitive edge, to support the extension of terminal capabilities with automated terminal equipment.

To successfully utilize the new technologies, automation implied fundamental changes in affected processes. A major change was the collection and allocation of internal information, requiring an alignment of IT/IS with those processes and information management. Moreover, additional checks and control mechanisms needed to be implemented to ensure the performance and safety in those semi-automated processes, in particular when humans are involved. While automation led to labor reductions, a high level of expertise was required for controlling activities. On a more general view, this generation led to an almost complete dependence on IT/IS in container terminals. Besides developments in forming global e-marketplaces as a means to establish trade networks, a major concern has been the growing traffic and environmental issues. Driven by resulting transportation problems and new government regulations, major ports needed to find integrated solutions for the whole port environment.

IT-driven initiatives indicated that a transformation is only possible if a critical mass of actors adapts their behavior, i.e., processes, requiring the willingness to participate and to share information. In the case of the Los Angeles/Long Beach ports, a fine was introduced to influence the – beforehand – autonomous decisions of drayage firms on drayage planning. A TAS was used to integrate port actors and manage terminal appointments. From a port perspective, the resulting network allowed to better control and coordinate port activities (level four) in order to lower the effect of peak traffic periods. Similar to the adoption of PCS, terminal operators and drayage firms had to integrate the TAS with internal IT systems in order to manage their appointments (level two). Moreover, some ports force drayage firms to equip vehicles with identification technologies (level one). A business process redesign was only necessary at container terminals, for instance, to adapt gate procedures.

Redesigning container drayage procedures was not necessary as only the time of activities was affected. Similar to PCS, we observe that the mostly static information constrains the flexibility of port and terminal operations. In a dynamic transportation system, container vessels might be delayed or drayage trucks might be over-punctual, and vice versa; with a lack of actual real-time data integration, however, business processes cannot respond to the current situation and changing circumstances. Another interesting aspect is the used approach to establish the willingness to participate. While some ports exclusively focus on explaining the resulting benefits of a new system for the respective port actors (e.g., reduced waiting times at terminal gates for drayage firms), others make the system mandatory and may also introduce punitive measures, such as fines. In the Port of Hamburg, for example, it was recently decided to make the preregistration and appointment booking mandatory after operating the TAS for several years. The reason may be the new developments towards a smart port aiming to improve traffic flows and coordination in ports.

In the following text, we present a summary of the Second Generation of Digital Transformation (1990s - 2000s)

Events:

- Digitalization enabled a high degree of automation in terminal operations (e.g., ECT Delta Terminal in Maasvlakte Rotterdam, Netherlands, in 1993; CTA Container Terminal Altenwerder in the Port of Hamburg, Germany, in 2002).
- First global strategic liner shipping alliances are formed in the mid 1990s.
- For the first time the continuous growth in container shipping seemed to reach the limits of some major ports leading to severe traffic problems and environmental impacts in the mid 1990s.
- Growing interest in e-commerce systems in the late 1990s.
- Increasing demand for single-window systems in the mid 2000s.
- Global economic crisis of 2008-2009 led to a more stringent evaluation and selection of ports. IT / IS e.g., Laser, VTS, AIS, TAS, RFID.

Scope:

- Level 1: Adoption of new handling technologies equipped with sensors and laser technologies; adoption of automatic identification technologies, for example, to accelerate authorization checks.
- Level 2: Integration of automated equipment control software with TOS; integration of external systems, for example, to manage terminal appointments.
- Level 3: Automation of certain processes required a complete redesign of organizational structures, policies, and business process activities as well as an efficient information management.
- Level 4: Establishment of e-marketplaces supporting trade and collaboration in the maritime industry; port-centric coordination of truck drayage operations using TAS to mitigate traffic and environmental problems.
- Level 5: Global alliances required a harmonization of services and IT/IS integration.

Impact:

- After focusing on increasing the efficiency of terminals through automation, measures for improving cargo flows within ports become increasingly important due to increasing vessel sizes and concomitant peak cargo volumes.
- Port-centric platforms, like TAS, have an impact on the decision making of actors (e.g., drayage companies). Limitations of static information are still experienced; a higher visibility and different forms of decision support based on accurate data become increasingly important to enhance responsiveness during operations.

### 3.1.3 Third Generation (2010s - today): Transformation to Smart Procedures

Terms like internet of things, big data, analytics, mobile computing, and cloud computing are being largely taken into account by the majority of the stakeholders in the maritime industry, and it is possible to find the first implementations of those concepts in ports. In the Port of Hamburg, for instance, the Hamburg Port Authority (HPA) started the project smartPORT logistics2 (SPL) in 2010 with the objective to improve traffic and cargo flows within the port area by investing in modern information systems and port infrastructure.

The main idea is to integrate different traffic control centers (road, sea, railway) into a main port traffic center that allows decision-making and an on-going interaction with actors being actively involved in transport activities based on real-time data. This includes an integration of traffic and infrastructure management thus allowing to route traffic flows dependent on the current traffic situation in the port. A variety of sensors and actuators has been attached to the port infrastructure to facilitate a better adaptability and an eco-friendly use of infrastructure, for instance, by coordinating river and road traffic flows through moving bridges or by controlling the road lighting, respectively. A set of sensors is used to measure the conditions of infrastructure and environmental impacts. The collected set of data is processed in isolated systems and then transferred to a central information system to explore, aggregate, and distribute information over different channels to various involved actors and decision makers. A central cloud-based information system shall facilitate the integration and provides the necessary resources to flexibly fulfill the computational requirements of those applications. The port further aims to improve the accessibility by deploying wireless network hot spots.

Another major step towards an intelligent control of road traffic is the intended use of mobile technologies. The primary intention is to actively route drayage truck drivers through the port by providing driver assistance based on the individual position of trucks in the port. This includes real-time information on the traffic situation and the situation at terminals and depots, estimated time of arrival, and forecasts on free parking space as well as individual recommendations prior to and during process execution. A mobile application and a web application have been developed for establishing the communication link to truck drivers and dispatchers, respectively. In a recent work [4] a solution based on a mobile cloud platform, utilizing real-time traffic and positioning information of drayage trucks, has been proposed for improving the collaboration and coordination of inter-terminal transports, extending current approaches with route optimization functionality. Also the Port of Algeciras Bay in Spain is driving a digitalization program Algeciras BrainPort 2020 (ABP 2020) towards data driven solutions for re-engineering of processes and management tools. These examples show that the maritime industry is undergoing significant changes towards just-in-time logistics, value-added information services, and port-centric decision support. Also other port authorities and terminal operators developed apps to enhance information flows. Moreover, crowdsourcing events were organized in the form of hackathons encouraging students and scholars to create innovative solutions leveraging promising trends. Besides, initiatives between ports and universities were established to support collaboration and to provide educational programs focusing on interdisciplinary education for future decision makers. In Rotterdam, for instance, the Erasmus Smart Port initiative was formed in 2010 with the aim of comprising all different organizations and smart port activities within the Erasmus University Rotterdam and to establish a close collaboration with representatives from the port community in order to bundle maritime expertise and develop multidisciplinary approaches.

In general, the initiatives and projects do not only emphasize the need for a more efficient information exchange, but also the importance of decision analytics. Still, a future challenge is the analysis of data in order to make more efficient decisions and to further automate intra/inter terminal and port procedures that can be characterized by their capability to quickly respond to changes and errors (or operational disturbances). The implementation of this vision requires multidisciplinary knowledge and is highly dependent on a successful collaboration between the maritime industry, the IT sector, and research facilities. At the same time, the success of those initiatives is again highly dependent on the willingness of actors to participate. While traditional information exchange allowed actors to perform activities and decisions almost autonomously, new approaches require an active and on-going collaboration between the port and involved actors to partly contribute to the common good. Although this causes not only enthusiasm, ports need to continue working on solutions for solving major issues. While the first and second digital transformation generations mostly focused on establishing the foundation for improved information flows in terminals and port communities enabling and improving terminal automation, trading, and interaction in a local or global context, the on-going third generation mainly focuses on actively measuring, controlling, and assisting port operations and port infrastructure by an improved exploitation of available data sources and continuous interactions in the port community. It is possible to assume that with the third generation of digital transformation ports aims to actively have an impact on the behavior and decisions of actors in order to increase the efficiency in overall port operations and to address certain issues, such as traffic and environmental problems.

The current innovative development and adoption of modern IT technologies and systems further indicate that ports increasingly extend their traditional business scope by acting as a port information integrator and provider, which can be categorized as a business scope redefinition (level five). Note that the development and implementation of IT solutions is often outsourced to consultancy firms and IT companies. In recent years, the primary focus of many major ports was on the development of mobile apps to allow a dissemination of relevant information to port actors for performing and assisting job orders, for instance, information on booked appointments, available parking slots in the port, and container locations, and information about the current status to support drayage truck drivers. The latter could inform about the release status of containers. For improving the data quality, apps further allow to inform port actors about incorrect or incomplete data entries, for example, during the preregistration of truck operations, in order to accelerate gate and terminal procedures. The adoption of apps might trigger a slight redesign of internal business processes of involved actors (level three) as more accurate status information can be used to optimize activities. However, it requires port actors to adopt the necessary hardware and apps (level one) and to integrate them with their internal systems (level two). Although the adoption barrier and costs are low compared to the introduction of EDI systems of the first generation, it is important that actors understand and highly valuate the benefits of the solution and are able to use it productively. To lower the adoption barrier, major ports have already started several initiatives, for instance, to provide free broadband internet access within the port and to organize workshops to explain and discuss the idea of developing mobile solutions.

It is observed that the sharing of IT infrastructure within the port community, for example based on a cloud platform, builds a common basis for digital transformations in the revolutionary levels. Basic collection and dissemination of information, however, cannot be referred to as smart. Smart port procedures are business processes that are able to make better use of available resources by improving the coordination of actors and responsiveness to changing circumstances as well as by considering economic and ecologic impacts of actions through the use of various integrated sources of information used to support (near) real-time decision making. In this regard, current projects (e.g., SPL) further stress the importance of an integration of available data sources. The port introduces new sensor and actuator technologies to actively measure and control port infrastructure, implements new information platforms, integrates legacy systems, and develops apps to exchange information (level one and two). With the integration of different control systems supporting seaside, terminal, and landside operations, it is possible to better coordinate naturally separated transportation systems. This marks a milestone towards just-in-time and agile logistics operations in ports. To achieve the objectives of this transformation, the port is more than ever dependent on network effects. Thus, port communities need to understand strategic and competitive advantages of participating in this network (level four) and how they are able to adopt new technologies and redesign their internal processes to fully exploit potential advantages, most importantly in terms of costs (level three). In this regard, it should not be forgotten that competition in port communities plays an important role and heavily impacts the willingness to share operational data, which represents a key success factor of current smart port initiatives. Moreover, the integration of several data sources will enable a more precise and active assistance of port actors during port operations. Thus, it becomes apparent that the success is dependent on the willingness of actors to actively follow recommendations during operations; otherwise, the full potential of business network redesign cannot be achieved.

It is important to underline how the success of the digital transformation is again highly dependent on a related redesign of business processes and the willingness of port actors to collaborate with the port (level three and level four). This builds the basis for optimization approaches, using information of data-driven analytics, applied on the port level, referred to as meta-analytics. Finally, strategic cooperation and information flows between ports become increasingly important, in particular, to enhance cargo flows in feeder and short sea operations between connected ports.

In the following text, we present a summary of the Third Generation of Digital Transformation (2010s - today)

Events:

- Current trends and emerging technologies in the IT sector foster an improved gathering, storing, processing, and analysis of various and large data sources.
- Port-centric decision support has become essential to address inefficiencies and bottlenecks on the overall port level.

- Customers increasingly demand value-added information services to get a better insight into related processes.
- Information flows between different ports become increasingly important for establishing successful partnerships.
- IT / IS e.g., Mobile Technologies, Sensors/Actuators, Cloud Computing, Distributed Computing/Processing, Machine Learning.

Scope:

- Level 1: Equipping physical infrastructure and actors with sensors, actuators, and apps.
- Level 2: Integration of real-time data sources, actuators, and external information services.
- Level 3: Improved exploitation of available (real-time) data sources to improve responsiveness and decision making during process execution require more granular process definitions.
- Level 4: Realization of an ongoing interaction with involved actors and controllable physical port infrastructure.
- Level 5: Ports increasingly extend their traditional scope by acting as a port information integrator and provider.

Impact:

- Shift towards port-centric decision support leads to a shift of process control from individual actors to central entities (e.g., port authority, third-party provider) requesting actors to partly give away control and follow instructions.
- May facilitate just-in-time and agile logistics by a better coordination and responsiveness to changes/errors based on different sources of actual data and data-driven decision support solutions.

## 3.2 Current digital and technological developments in ports

We hereby list the technologies that are most frequently being used in any operation connected to ports, shipping, stocking etc. We keep the research work of Heilig and Voß, (2016) [5] as main reference.

### 3.2.1 Global navigation satellite systems

Global Navigation Satellite Systems (GNSS), better known as Global Positioning Systems (GPS), were first installed in port in the 1990s. GPS is generally used to detect and track position of movable objects such as containers, vessels, vehicles, and equipment.

Since then, GPS has become the vessels' primary aid to navigation in and outside the port area (Figure 4). It has become a tool of major importance for getting real-time data on the position and status of objects in order to improve visibility and activities planning and coordinating, especially when multiple actors are involved.

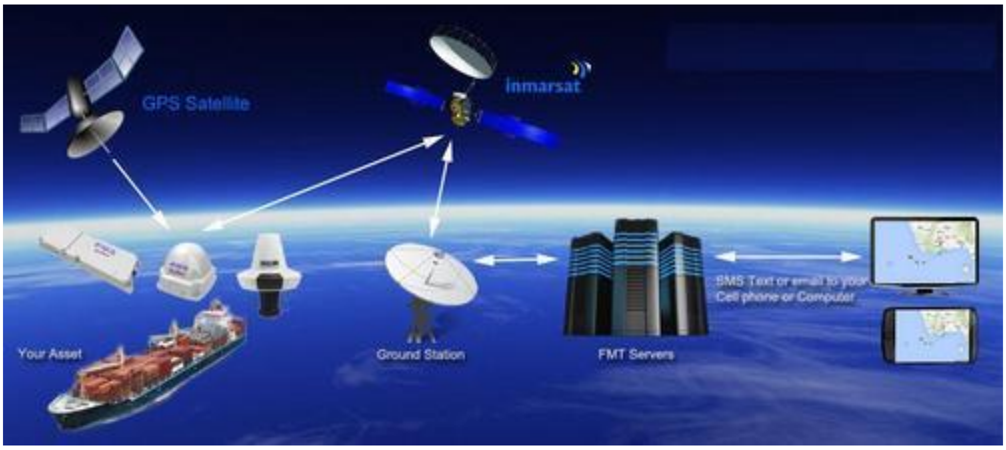


Figure 4. GPS for ship tracking

The retrieved positioning data does not only allow to locate objects, but is also essential for forecasting (e.g., route prediction, arrival times) and for achieving contextual data about the individual object by combining positioning data with other data sources and points of interest. Given this functionality, the implementation of innovative concepts like synchromodality and slow-steaming as well as measures to avoid and handle disturbances may hugely benefit from considering operational circumstances.

The uses of GPS can extend to other areas, for instance measuring tides more accurately. In container terminals, differential GPS (DGPS) technology was initially used to accurately identify and track container yard positions. That is, DGPS extends GPS by fixed reference stations that calculate the difference between the precisely known location and GPS positioning data. This tool defines the exact position of containers as well as locating and tracking container, vehicle, and equipment movements within the terminal. Due to its robustness and accuracy, DGPS can further serve as a navigation system for unmanned vehicles and equipment, particularly for automated guided vehicles (AGVs). Since vehicle-to-vehicle communication is facilitated, the safety in container terminals and ports in general can be improved, for instance, by implementing collision warning systems. According to Ioannou et al. (2000) [6], it is worth highlighting that DGPS installation does not require high costs or major modifications to the port area, thus being accessible to also medium sized ports with relatively scarce resources.

Optical-based systems, especially laser and radar systems, are alternatives to DGPS, which are sometimes combined to achieve an even higher accuracy. As an example, Siemens patented a local positioning radar technology, applied in several large container terminals, this successfully substitutes GPS; real-time location systems are used become a good alternative in particular in areas where GPS cannot be applied (e.g., due to spatial and harsh conditions).

Another tracking tool is satellite-based augmentation system (SBAS), such as the European Geostationary Navigation Overlay Service (EGNOS). This have been developed to complement existing GPS or more generally GNSS. Recently, Favenza et al. (2014) [7] presented a cloud-based SBAS architecture to better support correction algorithms and to provide enhanced localization services.

### 3.2.2 Electronic data interchange

A paperless and standardized communication is a process that started in the 1980s, as we have seen in the previous section. This process is not only a prerequisite for efficient port operations being carried out by multiple stakeholders, but also for improving supply chain integration, coordination, and performance. Electronic data interchange (EDI) technologies are largely used in ports to enable a paperless communication between those stakeholders based on international EDI standards like UN/ EDIFACT (EDI for administration, commerce and transport), which is a standard to structure and exchange data of commercial or administrative transactions. UN/EDIFACT defines several EDI message types supporting port operations, such as for covering berth management, bay/stowage plans, stowage instructions, gate in and gate out reports, stuffing or stripping orders, customs cargo reports, and dangerous goods notifications. The exchange of those and multiple other messages during transportation is essential to enable seamless processes in which different actors can communicate and collaborate efficiently.

However, one of the major adoption problems of traditional EDI systems is still a lack of standardization and high set-up costs, which can be a significant barrier for smaller organizations. To enable cheaper and more flexible communication channels, EDIFACT standard has been improved by adaptation on XML (Extensible Markup Language; referred to as XML/EDIFACT). Other port authorities established new Internet offerings supporting information exchange without the need of expensive EDI implementations. Anyway, EDI and in particular EDIFACT are still in use in many ports for paperless communication and integration of different stakeholders. In fact, the implementation of port community systems (PCS) is commonly based on EDI.

### 3.2.3 Radio-frequency identification

Radio-frequency identification (RFID) is a contactless automatic identification (Auto-ID) technology that enables identification of tagged objects and exchange of information carried by radio waves without requiring a line of sight. RFID systems consist of a data-carrying transponder, the RFID tag, and an interrogator, i.e., RFID reader. The RFID tag contains a radio antenna and an attached microchip incorporating rewritable information related to the tagged object. Advanced transponders are further equipped with sensor technologies facilitating the measurement of physical variables (e.g., temperature, humidity, motion). Within the interrogation zone formed by the RFID reader, a bidirectional communication line between the tag and the reader is automatically established for receiving data. Some readers are capable of reading multiple tags at the same time. RFID readers forward the data to other systems for further processing. For this purpose, a middleware is supposed to filter, convert, correct, and relay the data to a respective information system. The middleware is installed either directly on the reader or on a server. To facilitate the integration, readers offer communication interfaces such as Ethernet, WiFi, and USB. RFID tags can either be active or passive, depending on their source of electric power. Active RFID tags contain a power supply (e.g., on-board battery); passive tags gain electric power from an external RFID reader. Due to the on-board power supply, active tags communicate at higher operating frequencies enabling longer distances. However, the costs for passive tags are significantly lower, mainly due to low tag prices, maintenance costs, and because no batteries are used. In addition, the size of the tag is smaller so that it can be attached to practical self-adhesive labels (smart labels). As indicated, the frequency of RFID systems determines the data reading and transmission speed. At least, RFID readers must support one communication protocol to communicate with standard tags. To protect the data against eavesdropping, different open and proprietary encryption mechanisms are available. Another form is near field communication (NFC), which is based on RFID, but limits its band range to about 10 cm (very short range). It basically enables tag reading and data exchange between two devices. The integration of NFC into mobile devices offers novel application potentials such as for truck driver registration in the terminal gate area. For an extensive introduction to RFID and NFC the reader is referred to. Hassan and Chatterjee propose an RFID taxonomy that can be used to characterize RFID systems. The application of RFID technologies in logistics and supply chain management has been intensively discussed both in research and practice. Although the container transportation industry is still in the elementary stages regarding RFID applications, several application scenarios to improve efficiency of port operations can be identified including automatic coordination and handling of activities. In addition, RFID enables an automated compliance to security regulations important to reduce the costs for fulfilling regulatory requirements promoted by major international security initiatives (e.g., specified in the International Ship and Port Facility Security Code; ISPS Code). In the following, an overview on major application areas is provided.

***Shipping container security:*** Security seals are devices that are used to seal shipping containers. The tamper indication device is attached to the locking mechanism of the container door in a way that an unauthorized or attempted removal can be detected. In addition, a security seal is limitedly resistant against intentional or unintentional physical attacks and intrusion, provide stamper evidence and thus increases the container security. Usually, seals are made of plastic or metal and implement different locking mechanisms for different door designs. The international standard ISO 17712:2013 unifies requirements, procedures for the classification, acceptance, and withdrawal of mechanical container seals. To prove the integrity of containers, the state of each container seal has to be checked during import and export procedures. Manual checking and reporting of the seal status imply high expenditures on personnel along with higher costs and loss of time. To significantly reduce those manual procedures, RFID-based electronic seals (referred to as e-seals or RFID seals) have been developed, which store mandatory data including the seal number, seal status, battery status if an active RFID tag is used, sealing and opening times, and protocol information. The international standard ISO 18185:2007 uniforms the requirements and unique identification mechanisms for electronic container seals.

***Shipping container identification and tracking***: A general feature of RFID in logistics is the automatic identification of tagged objects and their tracking by installing RFID readers at focal points in the logistic chain. Specific RFID shipping container tags may also include data about the transported cargo. The international standard ISO 10374:1991/Amd 1:1995 specifies requirements for an RFID-based automatic identification of shipping containers, such as requirements for the physical location of devices, frequency band, data format, operational requirements, and security features. ISO 17363:2013 defines the usage of RFID cargo shipment-specific tags, attached to shipping containers, for supply chain management purposes. The international standard specifies the implementation of sensors and makes recommendations on the data interface for GPS or GLS (global locating system) services. Further, recommendations about mandatory and optional, re-programmable information on the shipment tag are given. ISO 18186:2011 describes the composition, application requirements, and operational procedures of RFID cargo shipment tags that are used for improving transparency in transportation processes. A standard-conform RFID cargo shipment tag can be used separately or combined with e-seal and license plate tags. A license plate tag, also referred to as container tag, specified in the international standard ISO/TS 10891:2009, is a permanently affixed, read-only tag containing limited data for the physical identification and description of a container. RFID tag data can be accessed either directly with a handheld device or indirectly through an information system. RFID can further be integrated with GPS sensors or other environmental sensors, for instance, to enhance the tracking of containers in storage yards. The automatic collection and verification of truck and driver information based on RFID can further help to improve access controls in the gate area. In some ports, such as in the Port of Seattle (US), drayage trucks have to be registered (with company and driver information) and must affix a dedicated RFID tag on the truck in order to gain access to terminals. To also enhance identification and authentication of individuals (e.g., personnel, truck drivers), a contactless smart card can be used, additionally providing microcontroller processing capability and writable memory, for instance, to verify passwords and store digital signatures and job information. Application examples are given. Moreover, gate in and out controls may also involve checking the status of container seals, which can be fully automated based on RFID electronic seals. In this regard, Choi et al. (2007) [8] propose a non-stop automated gate system based on RFID. Electronic toll collection Once RFID is adopted for identifying and tracking moving cargo and transport vehicles, it may also be used for electronic toll collection.

Tolling is recognized as a means to decongest the port roads and related urban areas, which may result in reduced emissions. The Nhava Sheva Port (India), for example, recently introduced a toll charge for containers and other cargo arriving or leaving by road into or from the terminals. Early RFID implementations such as in the Port of Shanghai (China), however, identified important aspects to be considered regarding the selection of RFID technology, costs of RFID tags, security of RFID systems, and the importance of global standards. Past projects indicate that investment decisions play an essential role for the adoption of RFID. In this regard, Harder and Voß (2012) [9] shipping industry propose a simple cost model for applying RFID in the container shipping industry. By considering relevant factors for evaluating respective business scenarios, the authors show that under reasonable assumptions RFID may provide moderately quick return on investment (ROI). Moreover, Wang et al. (2006) [10] emphasize the importance of information systems in adopting RFID in port operations, providing convenient and practical web-based information platforms that are compatible with existing information systems to efficiently share data with involved parties.

### 3.2.4 Optical character recognition systems

The largely used optical character recognition (OCR) systems enable an automatic pattern recognition of alphanumeric and handwritten characters in scanned documents or images. To improve the text recognition rate, specific fonts have been developed, namely OCR-A (ISO 1073-1:1976) and OCR-B (ISO 1073-2:1976). OCR systems research and development has been active since the mid-1950s and over time those systems are becoming able to recognize human faces, interpret words, and categorize documents. OCR can be for example useful in automatic container number recognition, and is very often present in modern ports (see Figure 5).

(a)

(b)

Figure 5. OCR recognition a) Trucks and b) trains

***Identification of Intermodal Shipping Containers and Loading Units***: OCR systems are often installed at terminal gates to partially automate administrative and checking procedures. Gates can handle more containers without needing extra staff. As terminal entry and exit gates are potential performance bottlenecks, producing congestion in front of the terminal gate, many terminal operators have implemented pre-gates, also referred to as automatic gates or OCR gates, in order to uncouple checking procedures and enable a guided access to the gate. Further, automated OCR-based pre-gates facilitate fast lane procedures thus improving not only the security, but also the management and efficiency of port operations. Also incoming and outgoing rail wagons can be processed through OCR gate systems. This extends to transports of containers between ship and shore and within the yard area, where OCR systems are commonly attached to ship-to-shore (STS) and yard gantry cranes (e.g., rail-mounted gantry crane—RMG), respectively. The real-time exchange of container identification data does not only build the basis for increasing the efficiency of procedures, but also helps to prevent and reduce errors, such as the unloading of a wrong container from a container vessel. To enable the identification of intermodal shipping containers and loading units, such as semi-trailers or swap-bodies, the labeling of loading units is required. The standard for intermodal shipping containers is ISO 6346, which describes a BIC12 code representing the owner, equipment category, and a container-specific serial number. OCR systems are able to capture and recognize such machine-readable codes. In Europe, a new standard, EN 13044, has been introduced for labeling combined loading units (e.g., swap-bodies, non-ISO containers, and semi-trailers) with ILU (intermodal loading unit) codes, which are compatible with BIC codes. Rail wagons can be identified based on unique UIC13 wagon numbers. Although RFID would likely reduce gate time over OCR, OCR has the advantage that vehicles and containers must not be equipped with respective technologies.

***Identification of Vehicle Licence Plates***: In automatic number plate recognition (ANPR) systems, OCR is used to read vehicle licence plates. Usually combined with video surveillance systems, these technologies enable an audit trail of vehicle movements within port facilities and are used for security checks. When a truck enters a container terminal, for instance, the licence plate data is minuted in order to constantly oversee the number of visiting vehicles. In some ports, the data is combined with driver card data enabling an unambiguous assignment of trucks to drivers. Additionally, the entry and exit logs for the vehicles and drivers as well as camera images can be used for forensic investigations in case of intended or unintended frauds or accidents. According to the ISPS Code, a valid identification of load, vehicles, and drivers is mandatory. Damage Inspection The images produced for container identification further provide evidence of the condition of the container surfaces (roof, side, end walls) as they have arrived at or have left the terminal. A reproducible damage inspection is mandatory in order to check claims relating to material damage to goods, especially important for insurance companies. Many OCR systems provide features to document and report container damages. Based on a unique identification, the images of container conditions can be uniquely assigned to the respective container. Some of these OCR systems are combined with laser technology (e.g., 2D/3D laser scanning) to detect damages, such as bulges, tears, and holes.

### 3.2.5 Real-time location systems

Real-time Location Systems (RTLS) are specific Local Positioning Systems (LPS) that enable the identification and constant location tracking of tagged objects located in both indoor and outdoor environments. To detect the position of objects, RTLS often use RFID technology to establish a communication link between a locally installed base station and nearby objects. To determine the position of objects, RTLS readers receive data from the tag, determine the time-of-arrival and forward the data to an RTLS server which determines the respective tag location. Consequently, RTLS technologies are not dependent on satellite systems and thus can be applied in confined spaces including warehouses and road tunnels. Different techniques are proposed to enhance RTLS location estimation. Some research studies specifically explore the application of RTLS technology in container terminals. Park et al. presents an RFID-based RTLS for improving the coordination between vehicles and cranes for loading and unloading operations. Lee and Cho propose a dynamic planning system (DPS) for yard tractors utilizing RTLS technology and analyze its performance based on simulations.

### 3.2.6 Wireless sensor networks

A wireless sensor network (WSN) describes a large-scale system consisting of interconnected wireless sensors deployed within an area of interest in order to cooperatively monitor large physical or environmental conditions, such as temperature, humidity, and position. Sensors communicate with each other and with a base station connected to a remote system propagating sensor data for storage, processing, mining, and analysis. Yet, the application of WSN technology in port operations is mainly explored from a theoretical perspective. Heilig and Voß (2014) [11] present a cloud-based system service-oriented architecture (SOA) that integrates context-aware information on transport vehicles and containers (e.g., to monitor internal and external conditions, such as position, temperature, humidity, status of e-seals, etc.) based on RFID, WSN, and mobile technologies. A METRANS project investigates WSN security and aims to study the application of WSN in a pilot implementation program at one of the terminals of the Ports of Long Beach and Los Angeles. Besides, an increasing number of sensors is used in port related road networks such as in-roadway sensors (e.g., inductive-loop systems, magnetic systems, weight-in-motion systems) and over-roadway sensors (e.g., infrared sensors, ultrasonic sensors) to obtain important traffic measurements. Multi-hop communication can cover large geographic areas, as found in ports, and utilizes the sensors' resources more efficiently (e.g., lower power consumption) in contrast to a single-hop communication on basis of a star topology. Due to multiple constraints of sensor devices that are usually battery-powered, various standards for wireless communication in WSN have been proposed. In contrast to other wireless network standards, such as the well-known IEEE 802.11 family of standards for implementing wireless local area networks (WLAN), communication standards for WSN aim to reduce energy consumption. ZigBee has emerged as de facto wireless standard for the deployment of WSN. In contrast to Bluetooth, which is another wireless communication standard, ZigBee is simpler, uses lower data rates, and is more energy efficient so that ZigBee-based devices can operate anywhere between six months and two years on two common Mignon batteries. Moreover, ZigBee supports a large number of nodes (up to 65.000) and thus can be used to build a large scale WSN. ZigBee is based on the IEEE 802.15.4 standard which defines the lower network layers and furthermore supports mesh networking and automated routing, making it a highly reliable wireless communication standard.

As an interaction with the environment is sometimes required, actuators are used in addition to impact the environment based on environmental conditions gathered by sensor nodes. For example, an actuator might be a stationary fire extinguisher, based on a smoke detector sensor, which automatically extinguishes a fire detected by the smoke sensor. In combination, actuators and sensors form the new generation of WSNs also referred to as wireless sensor actuator networks (WSAN). WSN and its extensions, such as mobile WSN and underwater WSN, may lead to new innovative applications in ports, as seen in a recent project in the Port of Las Palmas (Spain). An interesting application of WSAN is the control of light. In large port areas, lighting consumes a severe amount of energy and costs. A lot of ports operate 24/7 requiring an appropriate lighting. In the context of port related research, however, the optimization of lighting systems (and the corresponding energy consumption) based on real-time data has not been examined so far and thus requires more interdisciplinary research. Recently, the company Philips has developed a solution encompassing several intelligent and interconnected lighting systems that can be applied in the port area. The self-configurable, sensor triggered lighting is responsive to the movement and progression of an object through the area providing an appropriate level of illumination depending on the distance from the object. These approaches could be combined with other technologies, such as with smart video surveillance systems. To further improve the sustainability of lighting in ports, green energy supplied by port-related photovoltaic systems and/or wind power plants could be used, combined with smart grids, which were extensively examined by the research community in recent years.

### 3.2.7 Mobile devices

Nowadays mobile devices, such as smart phones and tablets, are equipped with powerful computing, communication, and sensing capabilities including GPS, RFID, and mobile data services to receive and transmit data over mobile networks. Different standards are used for communication including GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System), and LTE (Long-Term Evolution). The evolution and availability of mobile devices provides many opportunities in the logistics sectors and specifically in the port industry. Yet, the adoption of mobile devices in port communities is still in its infancy, which also applies to research in this area. Heilig and Voß (2014) [11] propose a system architecture that utilizes mobile device capabilities to integrate GPS-based positioning data and WSN sensor data from containers. In this regard, mobile devices act as base stations and data gateways, allowing to forward contextual data from a connected WSN that links one or multiple containers. Other meaningful adoptions may involve the mobile device owner by providing mobile applications that enable not only the exchange of information, but also features to interact with and/or assist the owner, for instance, a truck driver when approaching a port by considering information on the individual position, traffic congestion, parking spaces, etc. Vice versa, individual data from involved actors can be utilized to enhance port operations. Pilot projects, such as the smartPORT logistics project in the Port of Hamburg, demonstrate the growing trend of utilizing mobile devices and thereby support real-time information exchange in port operations.

### 3.2.8 Communication technologies

Without a highly reliable wireless network, it is difficult to scale the deployment of mobile devices, sensors, and actuators requiring an ongoing communication link. Therefore, many ports aim to establish WiFi networks covering a large area with a high bandwidth network while being equipped for harsh environments, such as by a weatherproof enclosure supporting extended temperature ranges. Common routers are equipped with different connectivity options including LTE with backup to UMTS and GSM, and often include redundant routing and meshing capabilities. For connecting specific equipment, for instance STS gantry cranes, dedicated data transmission systems, e.g., to allow the communication of signals between moving and fixed parts of the equipment using mobile transceivers, have been developed.

## 3.3 Survey of information systems in seaports

While the presented enabling technologies are essential for the measurement, collection, and transmission of data, integrated information systems are required to store, manage, analyze, and disseminate information and knowledge to support decision processes of various stakeholders. Existing information systems in the port area can be simply classified according to their scope of operations. In the following, an overview of existing information systems and applied technologies in the port area is given according to the proposed classification.

### 3.3.1 National single window

A national single window (NSW) is defined ''as a facility that allows parties involved in trade and transport to lodge standardized information and documents with a single entry point to fulfill all import, export, and transit-related regulatory requirements.'' (Figure 6). Main objectives of NSW implementations are the streamlining, harmonization, and coordination of reporting formalities and procedures mainly by electronic means. Therefore, the adoption of IT/ IS greatly enhances its implementation.

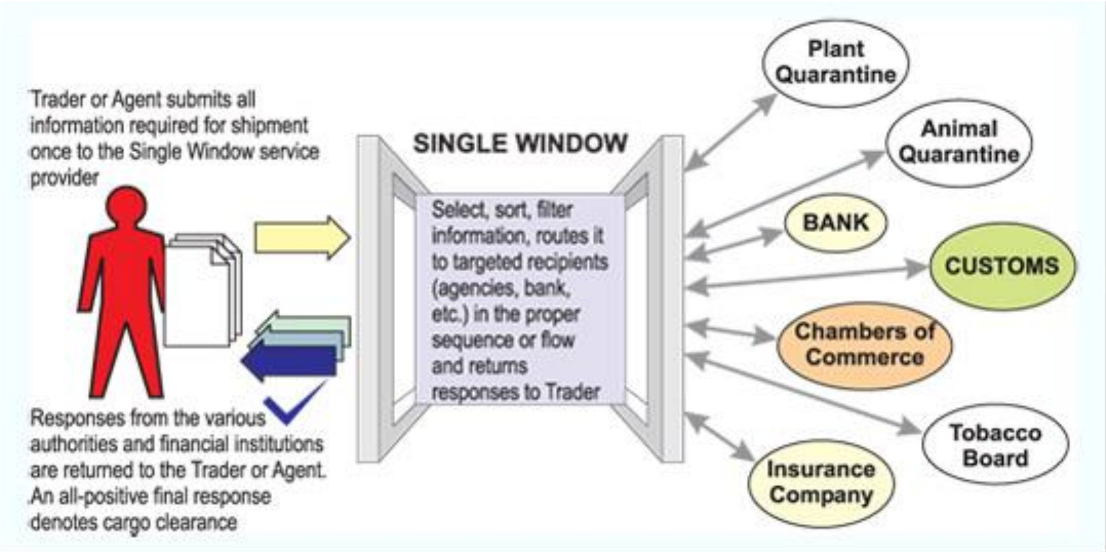


Figure 6. Single window scheme

The stage of an NSW implementation is dependent on its current scope of connecting involved companies, authorities, and countries through the exchange of information. A PCS, which is further described in the next subsection, can be assigned to the third stage of development, providing an information system integration on a local port level. Consequently, a PCS builds a foundation to establish a NSW or can be integrated into one by considering certain standards and interfaces. In the higher development stages, national and transnational information platforms can be established to better facilitate global trade and transnational administrative procedures. In the maritime shipping industry, e-marketplaces (also referred to as e-logistics platforms) have been established to form transnational networks among companies involved in the shipping process, including ocean carriers, freight forwarders, and shippers. INTRAA16 is the leading e-marketplace in the shipping industry, offering various functionalities, e.g., to select ocean carriers, book and track containers, and manage invoicing processes. According to company information, the platform is currently used to handle nearly one-quarter of the world's ocean container traffic. Recently, the functionality of INTRAA was extended to comply with the new IMO17 SOLAS VGM regulations, requiring shippers to submit a verified gross mass (VGM) declaration to carriers before a container is loaded onto a vessel. Besides this large business network, new e-marketplaces have emerged in recent years. The Boston Consulting Group (BCG), for example, developed xChange, a platform to avoid container repositioning by balancing, i.e., exchanging empty container capacities among carriers. A similar platform has been developed by the startup company Find-Box in Santiago (Chile). Following the common approach for empty equipment repositioning, SynchroNet offers a platform for finding inexpensive ways to transport empty equipment to demand locations (e.g., by utilizing otherwise unused space on vessels and vehicles). As problems like empty container repositioning have been extensively addressed in academic literature since decades, it would be interesting to analyze the current gap between industry solutions and scientific approaches. According to Heilig and Voß (2016) [4], studies assessing the value of innovative national and transnational solutions, combining IT/IS with problem solving methods and innovative business ideas, need to be comprehensively evaluated in terms of their economic, ecological, and social impact on port operations. Besides trading, cross-border standards and channels for covering and harmonizing the exchange of information on specific cargo (e.g., dangerous goods, waste, etc.) or other specific requirements of the shipping process between different ports and national authorities have been developed (see, e.g., EDI message standard PROTECT18 for dangerous goods declaration; import control system (ICS) specifications for EU-wide entry summary declarations, etc.). This includes single window approaches to better manage customs procedures. The e-customs initiative, initiated by the European Commission, aims to establish a single EU-wide single window that interconnects local customs systems in order to harmonize and ease customs procedures allowing, for instance, that import/export operations can be started in one EU member state and can be completed in another one without re-submission of the same information. Due to the huge interest and governmental support, such as in terms of funding, the topic has gained much attention in academia in recent years.

Meanwhile, PCS operators and customs-related service providers have formed cooperations (e.g., to exchange customs data via EDI, see, e.g., the DAKOSY-Portbase cooperation) and alliances (e.g., EurTradeNet) to facilitate an effective EU-wide implementation of the envisioned e-customs procedures. Baron and Mathieu (*PCS interoperability in Europe: a market for PCS operators?*, 2013) [12] envision full interoperability among several PCS, especially beneficial for customs authorities, and assume that industrialization of related software systems will lead to a higher market penetration by certain PCS operators linking different ports. In the following, we discuss PCS in more detail.

### 3.3.2 Port community systems

A PCS is an inter-organizational system (IOS) that electronically integrates heterogeneous compositions of public and private actors, technologies, systems, processes, and standards within a port community. Thereby, a PCS provides mission-critical IT/IS services and builds an electronic communication link between organizations that operate in the port environment including shippers, shipping lines and ocean carriers, terminal operators, drayage companies, and various authorities (e.g., port authority, customs authorities, water police, veterinary office, etc.). The number of ports that are connected to a PCS varies from one to many and is often dependant on the size of ports. The core aim of a PCS is to facilitate paperless procedures by providing a common information platform used to exchange port-related information and documents that are required for efficiently managing port operations and procedures, such as related to customs handling, import and export declarations, transport orders, dangerous goods declarations, etc. Thus, the objective of a PCS is to improve administrative and logistics processes on a longterm basis. The value of PCS is dependent on the number of actors using the system, known as network effect, as well as on the quality of information and associated benefits for all actors involved. A fundamental challenge for the success of PCS is the adoption of a single information platform among port community actors and the willingness of those actors to share information. Regardless of different roles, interests, and power structures, it is therefore important to achieve a common understanding between different parties in the port community whereby they agree to adopt a PCS to improve the overall performance. A PCS should be able to promote the autonomy of all involved actors, while incorporating and supporting activities in different port-related business processes. For this purpose, the integration of existing IT/IS plays an essential role, but also leads to several challenges as documented as lessons learned, where also other experiences within the development life cycle of PCS are discussed. Furthermore, special workshops are required to establish a good collaboration and to train end users among the key stakeholders. Carlan et al. (2018) [13] further propose a framework to assess costs and benefits of PCS based on a review of existing literature. In a case study, the authors evaluate costs and benefits of stakeholders using the Export Control System (ECS), providing customs clearance functionality, within the Antwerp Port Community System (APCS). According to the International Port Community Systems Association (IPCSA)[3], key functionality covers an easy, fast, and efficient information exchange and management, customs clearance, dangerous goods declaration, and tracking and tracing for all types of cargo as well as the processing of maritime and other statistics. For a detailed overview on various existing PCS and key functions, the reader is referred to Carlan et al. (2018) [13]. Specifically regarding customs handling, the PCS must comply with certain requirements in terms of information exchange between customs administrations and economic operators, and with national and supranational authorities. For Europe, for example, the PCS must facilitate a single window by implementing a link to the EU-wide ICS, which complies to safety and security requirements of the European community customs code, in order to allow carriers or their authorized representatives to transmit mandatory documents such as an entry summary declaration (ENS) using a single interface. Moreover, national governments may have additional systems and procedures that must be supported by the PCS. In Germany, for instance, this refers to the EMCS (Excise Movement and Control System) procedure for controlling duty suspension within German tax territory. That is, an electronic administration document (e-VD20) under the EMCS is required to move goods under duty suspension. Procedural instructions specify the requirements and conditions for the information exchange over the EMCS between individuals (e.g., carriers) and customs authorities.

### 3.3.3 Vessel traffic services

As one of the most critical information systems at the seaside in terms of both safety and efficiency, a vessel traffic service (VTS), i.e., vessel traffic information system (VTIS), includes functionality to collect, analyze, and disseminate information, in particular to navigate vessels in busy, confined waterways and port areas. One of the main aims is to reduce the risks of accidents, especially the risk of hazardous collisions of vessels with dangerous goods and/or loaded tankers, which increasingly occur in port areas with an increased vessel traffic density.

[3] http://ipcsa.international/

Thus, a VTS is essential to technically support waterway safety in ports. For this purpose, different enabling technologies are used to gather, process, and communicate information to involved actors (e.g., vessel operator). This includes vessel movement reporting systems (VMRS), radar systems, radio communication systems, traffic signals, and video surveillance systems. In this regard, an automatic identification system (AIS) is one of the most used technologies for tracking vessel positions and therefore substitutes radar systems, for example, to avoid collisions on waterways as imposed by the IMO. Recently, new satellites were launched to better support real-time monitoring of vessels based on AIS. GPS-based devices enable an identification and exchange of positioning data between circumjacent ships and AIS base stations, which are commonly connected to a VTS. The application of WSN technologies might be an interesting extension of common AIS. Several screens display VTS information to constantly oversee the vessel traffic situations in a respective port area and beyond. The VTS personnel must be trained according to international standards (e.g., given by the Maritime and Coastguard Agency - MCA). To distribute information (such as water traffic, water levels, dangerous spots, clearance heights and widths, planned underwater operations, and construction sites) not only to personnel but also to actors on the water, the use of mobile devices and apps will play a crucial role in the future. Recently, a mobile app called Mobile Port Monitor has been introduced in the Port of Hamburg, distributing corresponding information in real-time to involved actors. The basis for this mobile app are huge efforts to integrate various information systems into a central control station, i.e., information gateway that will also include road and rail information systems. The availability of more accurate information on vessel movements and sea traffic can be further used to improve vessel scheduling and terminal planning activities, such as berth allocation. By that, the estimated time of arrival of vessels can be refined, which allows a more efficient planning of subsequent port operations, critical for increasing the port’s efficiency and for reducing vessel waiting and turnaround times. For scheduling and navigating vessels, in particular in restricted waterway corridors, tidal windows and turnaround manoeuvres need to be taken into account. Tidal windows are used to schedule vessels with a certain draught and speed dependent on the current time, location of the vessel, and geospatial information. To accommodate flexibility, intelligent decision support systems need to take into account those dynamic aspects, e.g., by incorporating analytics based on real-time data. This might also involve the utilization of favorable tidal window. Vice versa, it might be beneficial to leave the port earlier in case of favorable tides, even though the unloading and loading process is not yet completed. Besides vessel characteristics, information systems and related decision support need to further take into account vessel priorities and appointments. Planning functionality using real-time information is not only important to increase the efficiency of port operations, but also to avoid severe accidents and cascading effects. We further see that the interface between seaside and terminal exhibits several potentials for improving the flow of cargo and information. Regarding the availability of academic works, we see that more research is required in this area taking into account the various aspects, in particular real-world dynamic factors, for developing innovative decision support systems. This is not limited to optimization approaches, but also includes analytics to better utilize various available (real-time) data sources. In the practical context, we already find first implementations of information systems taking into account specific geographic and tidal requirements. In this regard, a port river information system is a specific VTS, also including functionality to ensure a safe entry and exit of vessels through rivers using real-time data. This includes real-time data from sensors and external information providers on the current maritime traffic, weather, and tides. Besides basic VTS functionalities, the information system aims to connect all parties involved in operative and administrative procedures necessary to handle the arrival and departure of vessels in the port. In the Port of Hamburg, PRISE (Port River Information System Elbe) has been introduced to link terminal operators, pilots, shipping companies and shipping agents, tugs, and mooring staff. The objective of the information platform is to improve handling processes, in particular for large vessels, having specific requirements (e.g., regarding the navigation on the river Elbe) and need to be carried out within narrow time windows (e.g., due to tidal time windows). This requires an efficient scheduling of activities and allocation of resources (e.g., berth allocation) according to current circumstances. In this regard, real-time water level forecasts are provided by the German Federal Maritime and Hydrographic Agency.

### 3.3.4 Terminal operating systems

Container terminals manage the flow of goods and materials between the waterside and the hinterland of a port. A container terminal consists of three main operation areas: ship operation area, yard operation area, and truck and train operation area.

Different types of handling equipment (e.g., quay cranes, stacking cranes) and transport vehicles (e.g., automated guided vehicles, straddle carrier, multi-trailer systems) are used to serve different types of container vessels and to satisfy certain requirements. An efficient management of terminal operations, facilities, and equipment requires advanced planning activities. Ship operations involve decisions on berth allocation, stowage planning, and crane split. In the yard operation area, which decouples waterside and hinterland operations, storage planning and stacking decisions play an important role for the performance of a terminal. To enable an efficient flow of goods and materials between all areas of operations, horizontal and vertical transport activities must be planned and optimized. In 2016, for example, one of the worldwide largest container ships, the CSCL Indian Ocean, grounded on the river Elbe due to a failure in the navigation system, which resulted in severe restrictions in the overall port operations for several days.

Vessel, berthing and position data need for optimization has led to a considerable amount of operations research approaches and solutions in recent years. The application of those methods for supporting timely and cost-effective decision making heavily relies on information systems that deliver accurate information on the current situation. A sustainable management of terminals further requires management functions (such as booking, accounting, reporting, etc.), means to measure performance based on KPIs, to facilitate effective information flows and to provide an integrated view on operations and resources/inventory.

Information systems that support terminal-related planning and management activities are commonly referred to as terminal operating systems (TOS). Similar to the concept of enterprise resource planning (ERP) systems, a TOS provides a set of applications to collect, store, manage, analyze, and disseminate information from different terminal activities in order to provide an integrated view on core terminal processes and ensure an efficient use of resources for handling cargo. Thus, a TOS focusses on the integration of other technologies, information systems, and applications being installed in a container terminal. Further, different enabling technologies are integrated to monitor and handle the flow of cargo, such as OCR, GPS, RTLS, and RFID. Moreover, data exchange with external parties (e.g., shipping lines, agents, forwarders, truck and rail companies, and governmental authorities like customs, waterway police, and port authority) must be supported. Common TOS support EDI standards, such as UN/EDIFACT. Often, a link to the port's PCS is established to enable the interchange of certain information over a shared platform. An analysis of existing TOS, however, has shown that many TOS lack of integration with external parties, system integration, management decision support, and information services for customers. Besides ERP functionality, common TOS provide means for decision support, such as simulation tools and advanced planning and scheduling (APS) modules. In general, the TOS can be regarded as a backbone for the automation in container terminals, for example, containing all work orders for (semi-) automated terminal procedures.

In recent decades, several commercial TOS have been developed. The current market leader is Navis SPARCS N4, which provides extensive means to customize the TOS according to individual requirements of terminal operators and has been adopted by many huge terminal operators around the globe. TOS service providers have acquired valuable domain knowledge and developed modules enhancing the planning and management of terminal operations. Another popular TOS is CITOS (Computer Integrated Terminal Operations System), developed by PSA International and implemented in the Port of Singapore. It integrates different modules and expert systems to cover key terminal activities such as berth allocation, stowage planning, and resource allocation. A communication link to Singapore's TradeNet PCS has been established to facilitate cross-terminal communications.

In recent years, a trend towards collaborative planning approaches can be observed in terminal software solutions. XVELA, for example, is a multi-tenancy cloud-based collaboration platform and network linking terminal operators and ocean carriers built upon PowerStow, the stowage planning and management system provided by Navis. Meanwhile, TOS providers started to offer their solutions as cloud-based software as a service (SaaS). In the light of cloud implementations, however, implemented planning components and methods need to be revisited in order to fully utilize cloud capabilities, in particular with respect to computing scalability. This includes making use of big data for analytics. Also in this regard, we see first solutions in the market, for example, Kalmar Insight aggregating operational data from the TOS, terminal equipment, maintenance systems, etc.

### 3.3.5 Gate appointment systems

Gate appointment systems are commonly implemented on the port level to better schedule the handover of cargo by providing a platform to negotiate transport appointments. One of the main objectives is to balance truck arrivals and avoid peak hours at terminal gates in order to reduce congestions at the gate and in the port area. This is not only important for improving cargo flows and avoiding waiting times for drayage trucks within the port, but also for reducing vehicle emissions. Therefore, several terminal operators and port authorities have developed gate appointment systems. The terminal operator uses the scheduled appointments to adjust gate and terminal operations accordingly. Drayage companies serving different terminals use appointment systems to determine cargo availability. Consequently, an appointment system aims to reduce information asymmetries and uncertainties in order to facilitate a smoother flow of cargo. Several theoretic works examine the implementation of gate appointment systems.

### 3.3.6 Automated gate systems

Terminal gates handle landside inbound and outbound cargo flows. Therefore, it is essential that information about container and vehicles movements are recorded and verified accurately using respective gate information systems that are integrated with the terminal's TOS. The gate procedures involve checking container damages and cargo hazard classifications as well as the permissions of the truck driver to enter/exit the terminal with a certain container.

For this purpose, enabling technologies, such as OCR and RFID, are installed to automatically identify vehicle, driver, and container data and check relevant records in the TOS.

External parties can provide that information through a PCS in advance to avoid paperwork. In this case, the gate personnel only need to verify and confirm the correctness of data. Otherwise, gate personnel must record relevant information manually, which is very time consuming.

Especially in peak hours, this may lead to a major performance bottleneck. That is, the availability of prior information is critical to ensure a fast processing of inbound and outbound cargo flows. As a consequence, some terminal operators have subdivided gate operations into two stages. In the first stage, pre-gate operations identify drivers, vehicles, and containers. If prior information is completely available, the truck driver can directly move on to a check-in gate, where gate personnel can verify information and check the container conditions.

Moreover, some ports have introduced self-service stations allowing truck drivers to manually input missing data prior to arriving at the gate (e.g., at pre-gates or dedicated port parking spaces). As depicted in Fig. 10, self-service stations in the Port of Hamburg enable truck drivers to access the system by using a valid trucker smart card. After typing the relevant container number, the driver is able to specify missing data. The application of the self-service stations contributes to a lower workload and processing time at container gates and thus leads to more efficient terminal operations. Recently, mobile applications for truck drivers have been developed enabling a similar registration procedure and further inform the truck driver on the status and errors during the process.

### 3.3.7 Automated yard systems

After identifying the truck at the bay, a safety laser scanner is used to measure the position of the truck and uses light signals to instruct the driver to move forward or backwards.

Additional mechanisms are implemented to ensure the safety of the driver. For instance, the driver must leave the truck cabin and confirm this by pushing a button or swiping a driver's card through a bay station. The latter enables the identification of containers based on job data stored on the smart card. Besides implementing methods to advance re-marshaling and rehandling activities for optimizing the location of containers in yard blocks, an information system is essential to register new containers and track their position within the container yard. Therefore, yard operation technologies are integrated with a TOS.

Automated transfer cranes (ATC) heavily rely on the availability and correctness of job and container data to autonomously perform respective yard moves.

### 3.3.8 Port road and traffic control information systems

After reviewing approaches for supporting seaside and terminal operations, the following subsections are devoted to give an overview on solutions supporting landside operations. Growing international trade volumes, changing patterns of production, and an increasing seaside container throughput due to larger vessel sizes have resulted in significantly increased volumes of freight traffic at and around ports in urban areas. While an increasing freight volume positively impacts the economic development of a country, e.g., accounting for many jobs in respective port areas and significant tax revenues, its impact on urban congestion and environmental problems becomes increasingly visible.

A large portion of import, export, and transshipment goods is moved by trucks before and after, respectively, loading or discharging vessels. An increased truck traffic in metropolitan areas highly contributes to congestion, traffic accidents, and increased vehicle emissions. Besides environmental issues, congestions in port areas affect the productivity of container terminals, lead to frustration and reduced wages for drayage drivers, higher fuel and maintenance costs due to stop and go traffic, cause a higher degree of uncertainty leading to scheduling problems, and increase the transport time of goods between origin and destination.

Some ports have implemented port road and traffic control systems to measure and control current traffic flows within the port area and inform vehicle drivers about the situation. For this purpose, different enabling technologies in form of sensors and actuators are applied (e.g., video/ infrared/laser vehicle detection systems, induction loops, etc.). The collection of real-time data allows more accurate predictions and build the basis to timely react to certain conditions, e.g., by adapting electronic traffic signs and signals. It further helps to determine traffic-related vehicle emissions. The Hamburg Port Authority (HPA), for instance, introduced DIVA (Dynamic Information on Traffic Volumes in the Area of the Port) based on one of the most advanced traffic control systems providing integrated traffic information for the traffic control center, and through LED signboards on the road side.

As current sensor-based control techniques have some considerable disadvantages, such as related to their maturity, installation, sensitivity to weather conditions, and fixed detection spots, research has been devoted to the application of WSN technology enabling a more accurate monitoring and measurement of vehicle numbers and speed in real-time.

The implementation of traffic systems further builds a foundation for truck acceleration programs in the port area. For instance, traffic routing systems can be used to establish an additional communication link between the truck drivers' mobile devices and the road network. While a truck is approaching, nearby traffic lights get a signal to allow the truck to pass without impairment. Given a mobile application, it is also possible to send instructions to the truck driver, for instance, to adjust the current speed in order to enable phased traffic lights.

Strong weather conditions, such as dense fog or extreme winds, increase the risks of accidents and freight damages. More accurate weather data and forecasts could be used to better control the traffic and warn vehicle drivers according to certain weather conditions, e.g., via electronic signboards or mobile apps.

Moreover, the demand for an efficient service area and parking space management is growing. During peak hours with an increased traffic density, truck drivers may prefer to rest at a service area instead of waiting on a congested road. Considering the actual availability of parking space as well as the priority or gate appointment of certain drayage transport activities, an intelligent real-time scheduling could be used to better handle traffic loads.

While access to the port area is given to transports with a higher priority, other vehicles have to wait outside the port in times with an increased traffic volume. By better utilizing those facilities, emissions can be reduced and traffic jams disappear more quickly. According to the HPA, a dynamic parking space management is a valuable component for future traffic management strategies. The HPA currently develops a parking space management system for heavy goods vehicles providing information on the availability of parking capacities and enabling the administration and detection of parking areas. A mobile application informs truck drivers about the availability and supports the booking of parking space.

### 3.3.9 Intelligent transportation systems

An ITS embraces a range of advanced sensor and IT systems applied to transport vehicles and infrastructure to improve the performance of transportation systems. In Europe, a legal framework (Directive 2010/40/EU) and a corresponding action plan were designed in 2010 to accelerate the deployment of ITS in order to contribute to cleaner, safer, and more efficient transport systems. To reduce overall emissions, relieve congestion and enhance productivity based on analytical techniques, a ITS collects and handles data from road-based, vehicle-based, and transport network data sources, for instance, by applying automatic vehicle identification (AVI), FCD, and wireless vehicular ad hoc network (VANET) technologies.

Subsequently, the collected data is verified, transformed into compatible formats, combined with external data (e.g., from external agencies like highway maintenance organisations, police departments), and processed in order to gain insights into several traffic patterns and to offer context-aware services. This includes the prediction of travel times, traffic, electronic road tolling, automatic incident detection (AID), vehicle location and advanced driver assistance that works with and without satellites, and to display location based services. ITS may build a foundation for fully automated transport on individual routes without requiring dedicated roads. Cargo-oriented traffic data is further important to evaluate the performance of truck movements, to explore movement bottlenecks and to determine the frequency, costs, and environmental burden of recurring events, such as traffic congestion or accidents. Thus, the use of ITS becomes increasingly important in multimodal logistics and has the potential to significantly shape the future of port operations. In particular promising are VANET technologies that establish a mobile connection among vehicles as a foundation for enabling ubiquitous and real-time information access and exchange.

### 3.3.10 Port hinterland intermodal information systems

In order to further improve the efficiency and visibility of cargo movements between ports and the hinterland, dedicated information systems shall facilitate the integration of port systems with inland logistics networks. FutureMed is a EU-funded project (futuremedproject.eu) that investigates options to develop a port hinterland intermodal information system (PHIIS) pilot based on interoperable and flexible standards. This involves the development of related PCS services. Consequently, the project aims to extend existing PCS capabilities to better integrate involved parties (terminal operators, railway operators, forwarders, etc.), improve information exchange, and reduce the administrative burden between the port and logistics companies. Such projects are important to implement and extend NSWs that incorporate not only the ports, but also airports, logistics service providers, banks, traders and insurance companies.

Besides the truck transport, a large part of cargo movements is handled via rail transport requiring data access to efficiently manage rail operations and maintain the information exchange between railway undertakings (RUs) and railway operators or other parties in the port area. An example for a corresponding information system is transPORT, which is a new rail traffic management system of the Hamburg port railway. The web-based information system allows, for example, to obtain information on train movements, wagon sequences, track occupations, wagon destinations, loading schedules, and vehicle locations. Furthermore, it can be used to schedule wagons and/or loadings, create transport orders, and transmit dangerous goods data. To harmonize automatic train protection (ATP) systems in Europe, the initiative European Rail Traffic Management System (ERTMS) aims to replace the existing individual member state rail systems with a single system in order to enhance cross-border interoperability. A basic component of this undertaking is an interoperable data communication between the tracks and trains based on standard GSM technology using dedicated rail frequencies (GSM-R). Although the harmonized system has rather the general purpose of improving overall railway operations and safety, it represents an important step towards interoperable and cross-border data access, which is essential for ports that are linked to multinational transport corridors.

Moreover, the planning of hinterland operations needs to be supported by ports. The port authority of Zeeland Seaports (Netherlands), for example, has developed a webbased search engine to support the planning of intermodal transports and provides an overview of intermodal terminals and their connections using dynamic data from transport operations (barge, rail, feeder), terminals, and connections in Europe. As depicted in Fig. 13, the user can specify an origin and destination and gets possible connections in the next step. Once a connection and related operators have been selected, information about the route, including schedules and an estimation of transport times, are provided.

In recent years, many innovative cloud-based applications have been developed to better coordinate available truck capacities and demanded container transports. MatchBack, for example, offers a cloud-based SaaS solution to match the demand for transports of import and export containers in order to reduce empty trips. A solution developed at the University of Hamburg, port-IO, aims to better coordinate truck movements by providing a multi-tenancy cloud-based web platform for managing and planning container transport orders taking into account the current positions of trucks and real-time traffic information in order to minimize costs and empty trips. As the truck drivers are equipped with a mobile app, updated planning results can be synchronized immediately making it possible to react to certain events by replanning truck routes. In general, the development of location-based services draws more and more attention in modern ports.

## 3.4 Emerging disruptive technologies

A disruptive innovation can be defined as an innovation that creates a new market and value network and eventually disrupts an already existing market and value network, displacing established market leaders and alliances.

Notteboom (2017) [14] underlines how the competition across the logistics sector looks set to intensify and at the same time also faces an opportunity offered by rapidly evolving innovations in ICT. The ports and logistics sector has already embraced technology to a certain extent and the operations of many ports have changed dramatically over the past few decades, as we showed in previous chapter about historical technical development. For instance, today scanning technologies can monitor for harmful or illicit substances, and importers can visit a "one-stop-shop" website to arrange an order directly from their smartphone. However, widespreading of automation and increasing of real time operations direction and optimization by sensors and intelligent software will affect the sector with even more substantial changes over the next decade. In his work, Notteboom takes five innovations as particularly relevant and affecting almost all aspects of the trade process (Economist Intelligence Unit, November 2015), and are explained in the next sections. Some of these innovations relate to disruptive technology or applications thereof.

### 3.4.1 Robotics and automation

Ever since the introduction of automated stacking cranes at the European Container Terminal in Rotterdam in 1990, automation in ports has firmly progressed. Automation has developed into almost all terminal functions ranging from water to land side; from ship-to-shore activities straight across the terminal into and including the handling activities on or from the land connected modes.

The extent of automation ranges from remote controlled operations under safe and efficient conditions to fully autonomous terminal operations. Also, in the field of safety, there is continuous progress with research projects such a SaLsa that aim to safely test autonomous transport vehicles in yards that link into the Internet of Things world. Sensors installed in the yard infrastructure enable vehicles to detect other objects and their position which allows the combined operation of automated vehicles, forklifts, and people in an efficient and safe manner.

Software is also used to monitor and optimise the flow of goods through the port, which provides savings in time, fuel and personnel and optimisation of capacity and space. The drivers of automation are cost of labour, land cost and the need for efficient handling of larger sized ships. The trend in ever larger ships, enabled further by such events as the expansion of the Panama Canal, as well as those of the increasing costs of labour and ever more efficient and low cost of technology, will further push the need and desire for automation.

Automation can also play a key role in the transformation of logistics service provision. For example, technological advances make it increasingly possible in real time to dynamically integrate pricing, schedules, bookings, shipment visibility with customers, carriers and marketplaces. Rate automation and shipment visibility technology facilitates online sales.

This can create new opportunities for (larger) forwarders, as the use of these decision tools enable a deeper integration with carriers which will further facilitate shipment and allocation optimization.

### 3.4.2 Autonomous vehicles for port operations

The most advanced and also the most "visible" types of "robot" being developed in all forms are autonomous vehicles, from small last mile solutions to full sized autonomous sea-going vessels. Next to the already described terminal dedicated autonomous vehicles such as autonomous straddle carriers, the type of vehicles being developed will undoubtedly have an impact on the way operations will have to be organised. The development and implementation of these "robots" in the relative short term will entail its own threats and opportunities.

***Autonomous trucks and cars:*** The development of driverless trucks is in full swing and vehicles like Daimler's 18-wheeler Freightliner, unveiled in May 2015, already have been licensed for road tests. It operates on autopilot on highways but switches to a human driver for lane changes and parking. It uses radar sensors, cameras, and servomotors to detect objects around it, and then takes over actions from the driver such as steering and braking.

What does "autonomous driving" really mean?

In 2013, the US Department of Transportation's National Highway Traffic Safety Administration (NHTSA) defined five different levels of autonomous driving. The levels of autonomy describe the system, not the vehicle:

- Level 0: The driver (human) controls it all: steering, brakes, throttle, power.
- Level 1: Most functions are still controlled by the driver, but specific functions can be done automatically by the car (like steering or accelerating).
- Level 2: At least one driver assistance system of "both steering and acceleration/deceleration using information about the driving environment" is automated, like cruise control and lane centering assist. It means that the "driver is disengaged from physically operating the vehicle by having his or her hands off the steering wheel and foot off pedal at the same time," according to the SAE. The driver must still always be ready to take control of the vehicle.

- Level 3: Drivers are needed, but are able to completely shift "safety-critical functions" to the vehicle, under certain traffic or environmental conditions. It means that the driver is still present and will intervene if necessary, but is not required to monitor the situation in the same way as for the previous levels.
- Level 4: "Fully autonomous". These vehicles are "designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip". However, it is important to note that this is limited to the "operational design domain (ODD)" of the vehicle meaning it does not cover every driving scenario.
- Level 5: This refers to a fully-autonomous system that expects the vehicle's performance to equal that of a human driver, in every driving scenario, including extreme environments like dirt roads that are unlikely to be navigated by driverless vehicles in the near future.

Considering the continued investments in the field, it is only a matter of time that in the future fully automated driverless trucks and delivery vans will be used by logistics firms. The main purpose and expected impact of autonomous trucks is increased efficiency and greater safety. For some, a key motivation effectively is to reduce the liability firms face when a human driver makes an error. In this way of thinking, once the technology has a solid track record and a clear safety record, implementation of such vehicles will become self-evident. It is clear that contrarily to what is stated by some proponents, for others it effectively raises awkward liability questions. Does liability lie with the logistics firm or with the truck manufacturer in case of incidents?

Increased implementation of autonomous trucks and vans will effectively reduce transportation costs and result in faster transit times. Considering the expertise and reliance on data driven models to control such vehicles this might change the type of companies running such solutions. Effectively, companies like Uber or Amazon already have plans to expand into the logistics sector.

Considering the fact that autonomous trucks will still be required to carry "drivers" for the foreseeable future and levels 4 and 5 of autonomous driving are still some time away, the immediate impact on port operations will most likely exist of increased efficiency because of assisted manoeuvring, improved planning and synchronized timing, allowing for increased terminal and truck operator efficiency.

***Drone planes:*** Drones are already being used for security surveillance in some ports (such as Abu Dhabi's Khalifa Port), and could also have a role in monitoring port operations and detecting problems requiring maintenance in both port equipment and ships. The main barriers for the use of drones in the ports and port terminals are regulatory, but it may be expected that this will only be a short term obstacle. Still, international harmonization is needed. Technology is developing fast, especially in the field of autonomous flight. These represent the business cases for industry and there is a lot of interest from the logistics sector, but mainly in supporting a range of monitoring and inventorying activities as well as deployment in restricted and secure areas.

Implementation in the public domain such as last mile logistics or public access areas in ports, are highly questionable considering the complexity of implementation in relation to the risks involved. Despite boastful declarations of several service providers' real life proof of concept testing by companies such as DHL clearly highlighted this complexity which somewhat reduces the outlook of intense use of flying drones in the public domain. Also others such as UPS are focusing on understanding how flying drones can be applied.

Considering that most acclaimed applications seem to be developed for use within restricted areas, warehouses, for humanitarian aid and medical supplies to remote areas, inspection activities, and the fact that wide-spread implementations in the public domain seem a long way off, direct impact on port logistics operations where inter-connection with other supply chain actors is involved, is not to be envisaged in the near future.

***Drone ships:*** Drone ships are the least "visible" type of robot being developed and as such hold a large "unlikeliness" factor to them. The main challenges are regulatory considering international maritime conventions have clear specifications on minimum crew requirements. Another challenge is the concern about safety, especially where it concerns the aspects of weather, obstacles and in-trip repair requirements and the uncertainty how such autonomous or remotely operated ships would cope. The main advantages regard a significant reduction in fuel consumption, and therefore emissions, by up to 20% as well as increased cargo capacity and massively (about 40%) reduced operating expenses, all according to Rolls-Royce. Even though safety is currently considered a concern, overcoming the challenges effectively would mean that maritime safety potentially could be improved, as the majority of shipping accidents are the result of human error, often related to fatigue.

In December 2016, Rolls Royce and VTT Technical Research Centre of Finland Ltd have announced a strategic partnership to design, test and validate the first generation of remote and autonomous ships. The new partnership will combine and integrate the two company's unique expertise to make such vessels a commercial reality. In a statement Rolls Royce stated to believe a remote controlled ship will be in commercial use by the end of the decade. The company is applying technology, skills and experience from across its businesses to this development. The VTT Technical Research Centre of Finland will build on its deep knowledge of ship simulation and extensive expertise in the development and management of safety-critical and complex systems in demanding environments such as nuclear safety. On the other hand, more prudent maritime organisations such as the International Chamber of Shipping, predict that the use of drone ships will not be realised for another two to three decades.

The debate between believers and non-believers focuses mainly on the projected costs; reduced operational costs where the absence of a crew can be seen as a liability in case of need for repairs or problem solving and the operational costs this induces, and reduced construction costs where the need for increased quality for unmanned ships is to be taken into the equation. There seems to be some agreement on the possibility to increase cargo capacity that may offset the minor savings in crew costs and questionable savings in construction costs (Roar Adland, 2017).

### 3.4.3 The Internet of Things (IoT) and big data analytics

The ever more rapid development of cheap sensors has resulted in ever more "items" being equipped with such sensors. This effectively means all such items can be tracked and that any activity such item is engaged in, or any circumstances it is exposed to, can be "measured". Thus, the item "senses" an activity, event or an environmental factor. Such item is also capable of receiving information from other "sense-like" items. A network of such communicating items can be labelled as an Internet of Things.

Effectively, the IoT refers to a wide and increasingly large range of physical objects ("things"), that are connected to a system and that are able to send and receive data. The IoT is a development that is rapidly taking place across all industries and throughout society. It is obvious that such a network of communicating "things" opens up a large array of possibilities for logistics.

These "sensorized" items will allow all things, including autonomous and robotized vehicles and equipment as described earlier, port equipment, infrastructure as well as the goods themselves to become connected. This will result in massive amounts of data being produced and being available. It is not hard to imagine this offers an almost infinite array of possibilities for logistics and port operators and stakeholders to optimize and automate processes, and to gather an ever more precise and real-time insight.

In order to effectively and successfully implement applications that build on the IoT possibilities, robust communications systems need to be in place. Ports, with containers and equipment interfering with signals, and warehouses with attenuated and scattered signals, are notoriously difficult environments. Even though many ports and warehouses have network infrastructure available, many of it is about a decade old and is often not suited to the new IoT applications' requirements of high bandwidth and secure protocols. New cloud computing solutions will make data instantly and simultaneously accessible in many locations and across many devices. This massive amount of data requires the collection, curation, analysis and storage of large and complex datasets. This is often defined as the use of big data.

Having discussed the "sensing" of data and the collection and storage of it, the true challenge lies in the use of this data. The data will thus "actuate" new processes or decision making. It can be used in port operations such as preventive maintenance schedules of either infrastructure or equipment, create intelligent inspections systems, sensor track data on speed, direction and driving performance of large numbers of vehicles (UPS) in order to optimize future routes, or support resilience management tools (DHL) in order to adjust routing of supply chains in real time.

The possibilities are almost endless and consequently, the evolution of IoT and the use of big data creates the prospect of logistics becoming a data-centric industry where information takes precedence in logistics services' value propositions over the actual ability to move cargo. The growing interest and developments in the area of IoT and big data analytics gives rise to new business models and partnerships and questions on who is best positioned to lead these partnerships. IoT and big data analytics have an impact on a large number of processes, which implies many stakeholders have to work together to make it work.

There are five key groups of players: device providers, operators, platform providers, systems integrator and application providers (Agarwal, 2017)XX. None of these players can deliver integrated IoT solutions, so partnerships are crucial. Device providers are basically vendors who might capture more value in the chain if they succeed to develop a service model. The operators are very critical stakeholders as they provide the connectivity.

However, they need a partner to go to market and are unlikely to play a leading role in any partnership/alliance. The platform providers bring together the hardware, the connectivity, the service providers and the vertical applications to provide industry with specific solutions. Most of the serious players are eyeing to become platform providers. System integrators make the individual components of IoT to work together in the most optimal way for the customer. They typically are niche players and enter into partnerships with large platform players. The application providers are often small and might be integrated in larger IoT players.

### 3.4.4 Simulation and virtual reality

The availability of big data applications will lead to possibilities for port operators and logistics service providers to fully exploit the advantages of simulation software. Port operations can be modelled in order to analyze operational flows, pinpoint possible barriers as well as define enhancements, and simulate and assess various scenarios of design and throughput. This can be done for existing or newly planned port layouts as well as for terminals. An additional benefit is that such simulation software can also be used to train staff. Already, current proprietary or service based resilience predictive tools are becoming far more powerful and efficient, and such simulation tools are a valuable asset in emergency and mitigation planning.

Considering the previously described automation and robotization of various types of vehicles and equipment, simulation will be important in understanding the impact of these developments as well as how to adjust terminal processes in order to optimally integrate these developments into every day operations.

Virtual reality (VR), defined as the expansion of physical reality by adding layers of computer-generated information to the real environment, will further support such simulations. This is a technology in full development that will become part of everyday life. In a port related environment one can envisage enhanced feeds from infrastructure, port equipment, automated vehicles and various types of drones. It is to be envisaged that VR will have a wide field of applications ranging from operational support of how to execute certain processes to active safety or security interventions.

Other applications could regard more complex VR applications in extending value added service offerings in warehouses, assisting the service providers with product assembly, refurbishment or repair activities.

# 4. Taxonomies of barriers and enablers

Dealing with disruptive technologies is of paramount importance to be aware of the barriers and challenges which may be encountered. Several taxonomies grouping barriers and facilitators are proposed in literature and in previous projects, with methodologies aiming to allow an evaluation of their importance and impact. Zerbino et al. (2018) [16] examine most of previous literature assessing barriers to Knowledge Management (KM) in PCS-enabled ports, collecting 75 different barriers identified in previous reviews and categorize them as organizational, individual, technological, strategic, cultural and knowledge barriers. Their analysis was deepened with focus on a small-to-medium Mediterranean port. Strategic barriers were considered the most relevant. Most actors of the port community are small-sized, and struggled to fund the investment for developing or modifying their ISs for connecting to the PCS and, thus, for sharing and receiving information. Moreover, they are forced to change their strategies and to speed up their decision-making because, since the PCS enables near real-time information sharing, such information has to be exploited quickly, otherwise its usefulness could drastically decrease.

Technological barriers were the second most critical ones. Concerns about data security and privacy hampered the PCS adoption and development. Organisational barriers were ranked as the third most relevant ones. In order to better exploit the PCS, some port operators needed to redefine the internal and external communication flow. The other three clusters of KM barriers – Culture, Individual, and Knowledge – were considered as secondary.

Other taxonomies proposed in literature are presented in two recent deliverables of AEOLIX project. AEOLIX D2.1: “Lessons learned: barriers and enablers of the solutions proposed in the past” [17], focused of previous projects about logistics. The AEOLIX deliverable “Market opportunities, barriers and solutions” [18] focused instead mostly on potential barriers for the deployment and future success of the platform proposed in AEOLIX project. Both deliverables proposed a clustering of barriers and methodologies to evaluate them.

## 4.1 Market opportunities, barriers and solutions

A subset of sixteen recent, mostly EU-financed, projects has been examined in order to reach conclusions on the most significant barriers and solutions on the field of Logistics, as perceived by relevant stakeholders (see Table 1). The set of projects considered was varied in their characteristics, although all are medium/large scale projects and most devoted to create a platform for information sharing within the larger field of logistics. Within the selected projects, people involved at a high level (e.g. coordinator or evaluation work package (WP) leaders) was interviewed and the taxonomy was filled in with their answers.

The macro areas of interest that were examined and are of relevance to COREALIS and the objective of this deliverable, are the ones investigating multiple environmental and organizational factors.

The binary answers (0 or 1) in the macro-areas about structures, objectives and modalities had the aim of creating a possible classification of projects. For what concerns the items in the project success and organizational and environmental factors, the aim was to collect a brief evaluation of various aspects from the interviewed person, in form of a value from -3 to +3. The meaning of such values is presented in Table 2. In this study, after a detailed quadrant analysis of the answers given in the questionnaires the most important barriers were identified as shown in Table 3. Finally, a detailed categorisation of the environmental and organisational factors investigated is provided in Tables 4 and 5, respectiverly.

| Project | Timespan | Topic | Notes |
|---|---|---|---|
| Cassandra | 2011-14 | Risk in global supply chains | Development of integral supply chain data |
| Co-Gistics | 2014-17 | Cooperative mobility services and intelligent cargo | Immediate AEOLIX predecessor |
| CO3 | 2011-14 | Co-modality | Horizontal collaboration. Tools and legal frameworks. Self-assessment workbook. 7 real-life test cases designed to supply information to logistics practitioners |
| Contain | 2011-15 | Container Security | Containers Surveillance system. Set of technology options. Standardisation activities |
| Core | 2014-18. Ongoing | Supply Chain Corridors. | Effectiveness of security & trade compliance. Green lanes and pre-clearance with supply chain visibility and optimisation. Multimodal |
| E-Freight | 2010-13 | Co-modal transport | Information Highways |
| Euridice | 2008-12 | Intelligent Cargo | Information services platform. Combining services at different levels. RFID |
| Icargo | 2011-15 | ICT to support new logistics services | Synchronize vehicle movements and logistics operations. Multimodal. Dynamic planning methods. Open freight management ecosystem. Decentralized ICT infrastructure. Three extensive pilots in end-to-end multi-actor intermodal chains |
| LogiCon | 2013-15 | Logistic Connectivity for SMEs | Data-interchange solutions. Four national living labs |
| Loginn | 2012-15 | Co-ordinating and supporting RTD projects. Intermodal transport. | Bridge the gap between pilot implementation and marketable solutions. Sustainable business plans for European RTD projects |
| Mobinet | 2012-16 | Cooperative Mobility Services | Technical and organisational foundations of an open, multi-vendor platform |
| MODULUSHCA | 2012-16 | Modular Logistics Units. Co-modal Networks | Physical Internet |
| Nextrust | 2015-18. Ongoing | sustainable logistics, trusted collaborative networks, supply chain | Trusted networks, built horizontally and vertically. C-ITS cloud based smart visibility software to support the re-engineering of the networks |
| RISING | 2009-12. | River Information Services For Transport And Logistics | Co-modal transport-logistics processes. Traffic and transport-related information. Standardized IT interfaces to transport-logistics actors and players. |
| Smart Freight | 2008-11 | Freight transport in urban areas | Goods distribution. Integrate urban traffic management systems with freight management and onboard systems |

**Table 1. Projects analysed**

| | Project Success | Factors |
|---|---|---|
| -3 | Complete failure in this particular item | Complete barrier |
| -2 | Mostly failed objective | Severe barrier |
| -1 | Disappointing results | Mild barrier |
| 0 | Not applicable | Not applicable |
| 1 | Positive results | Mild facilitator |
| 2 | Very good results | Strong facilitator |
| 3 | Outstanding results | Huge facilitator |

**Table 2. Scoring system**

| Rank | Description |
|---|---|
| **1** | Lack of cooperative structure between stakeholders |
| **2** | Lack of interest from end-users |
| **3** | Data privacy and IT security |
| **4** | Cost of platform vs. benefits |
| **5** | Technical operation of the system/platform after the project |
| **6** | Compatibility with existing systems |
| **7** | Standardisation gaps/needs |

**Table 3. Top 7 barriers foreseen in other EU projects**

| Macro Area | Elements | Items | Possible values |
|---|---|---|---|
| **Environmental factors** | **Financial issues** (Evaluation of the financial aspects that influence the success or failure of the project) | Fixed costs | [-3,+3] |
| | | Operational costs | [-3,+3] |
| | | Private funding sources | [-3,+3] |
| | | Public funding sources | [-3,+3] |
| | | EU funding schemes | [-3,+3] |
| | **Legal framework** (Evaluation of the current legal framework suitability in fostering the solutions proposed by the project) | Existing supporting regulation | [-3,+3] |
| | | Harmonisation and regulations of laws | [-3,+3] |
| | | Privacy issues | [-3,+3] |
| | | Security issues | [-3,+3] |
| | **Readiness of the environment** (Evaluation of the level of readiness of the environment respect to the solutions proposed by the project) | EU policy trends | [-3,+3] |
| | | Readiness of the technological solutions | [-3,+3] |
| | | Readiness of the physical infrastructures (e.g., road infrastructures, rail infrastructure, etc.) | [-3,+3] |
| | | Workforce expertise | [-3,+3] |
| | | Awareness and knowledge of market players | [-3,+3] |
| | **Technological issues** (Evaluation of the level of readiness of the technological aspects respect to the features of the solutions proposed by the project) | Data availability | [-3,+3] |
| | | Data reliability | [-3,+3] |
| | | Data accuracy | [-3,+3] |
| | | Availability of historical data | [-3,+3] |
| | | Willingness of the private stakeholders to provide data | [-3,+3] |
| | | Operational interoperability | [-3,+3] |
| | | Information sharing | [-3,+3] |
| | | Information standardisation | [-3,+3] |
| | | Proprietary systems | [-3,+3] |
| | | Compatibility between ICT systems | [-3,+3] |
| | | Alignment of the evaluation data | [-3,+3] |

**Table 4. Environmental factors**

| Macro Area | Elements | Items | Possible values |
|---|---|---|---|
| **Organisational factors** | **Stakeholders involvement** (Evaluation of non-technical factors related to stakeholders, i.e. human factors, organizational issues, management issues, dissemination issues, etc., that influence the success or the failure of the project) | Willingness to cooperate | [-3,+3] |
| | | Awareness | [-3,+3] |
| | | Trust | [-3,+3] |
| | | Motivation of the private sector | [-3,+3] |
| | | Variety of stakeholders involved | [-3,+3] |
| | | Involvement of SMEs | [-3,+3] |
| | | Involvement of local authorities | [-3,+3] |
| | | Innovation complexity | [-3,+3] |
| | | Effective communication | [-3,+3] |
| | | Information and results sharing | [-3,+3] |
| | **Administration** (Evaluation of the level of influence that administrative and bureaucratic issues had on the project success) | Time-consuming administrative procedures | [-3,+3] |
| | | Time-consuming negotiations | [-3,+3] |
| | | System governance and ownership | [-3,+3] |
| | | Transparency | [-3,+3] |

**Table 5. Organisational factors**

Resulting sets of answers were compared, taking into account their relative relevance. The goal of this comparison was to identify common issues and trends, and to point out particular factors which were generally perceived as a barrier, or a less successful facilitator by most of the respondents.

In order to analyze the results regarding barriers and enablers identified in the Environmental Factors and Organizational Factors, a further elaboration of answers was performed, with the objective to reduce the bias of the subjective view by the interviewed person. The average of relevant answers from each person was computed in order to see which particular items received a score much lower, lower, higher or much higher than average. The elaboration of collected results is illustrated in Figures 7 and 8.

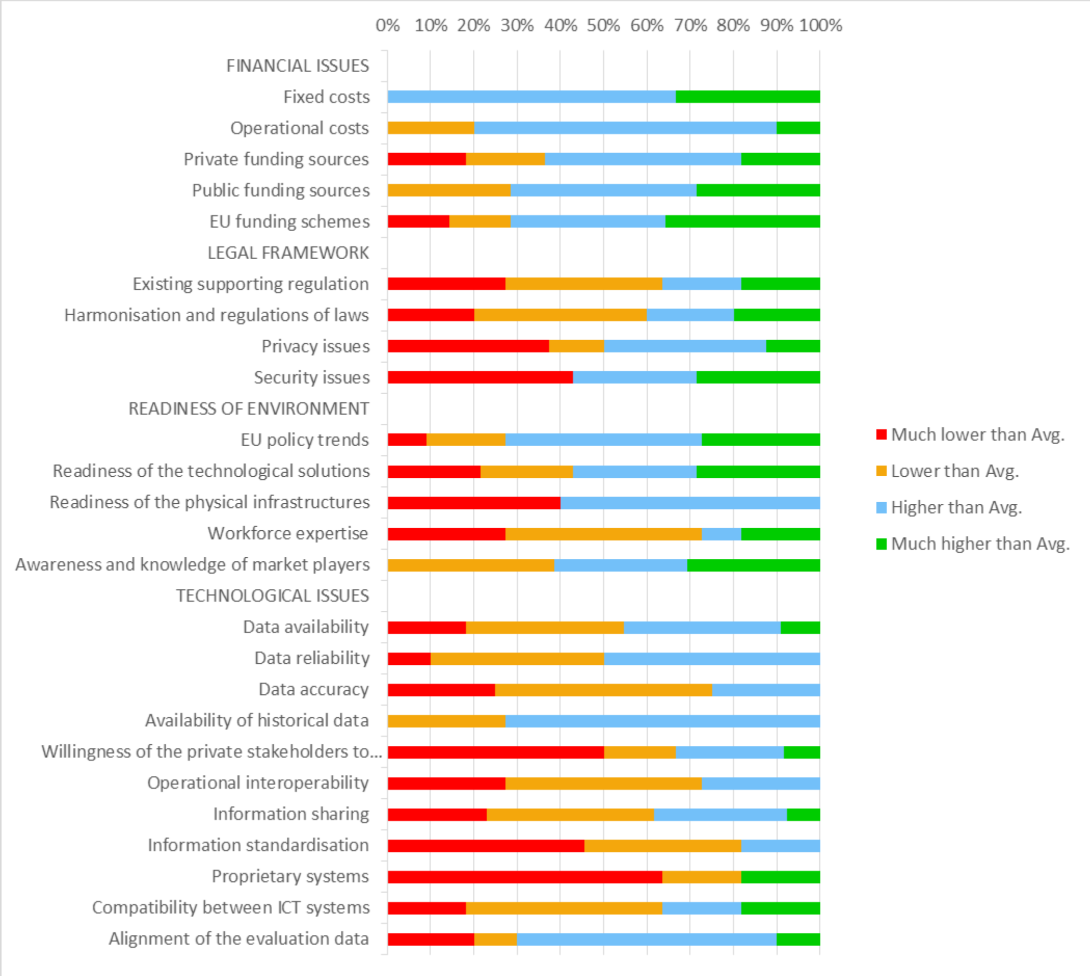


**Figure 7. Bar chart for Environmental Factors relative scores**

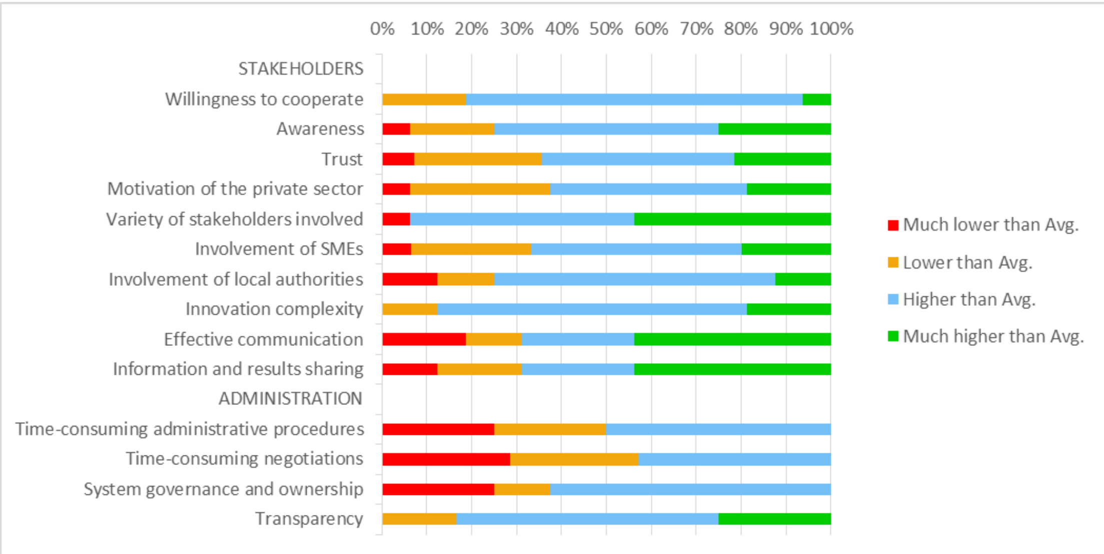


**Figure 8. Bar chart for Organisational Factors relative scores**

In the Environmental Factors macro area, 'technological issues' presents the highest average number of items perceived as barriers. Within this category, willingness of private stakeholders to provide data has been often reported as a problem, often paired with issues coming from use of proprietary systems and compatibility between ICT systems. These issues were also perceived as strong barriers in many of the projects, as well as information standardization.

On the enablers side, the results show that items with more much higher values than the average are EU funding schemes, Readiness of the technological solutions and Awareness and knowledge of market players.

Regarding the organizational factors macro area, a recurring problem is the project partnership collaboration: it has been noted that on some projects, teams have not worked together towards common objectives, as should be desirable. Questions raised regarding awareness of the stakeholders about the issues addressed by the project; the level of trust between the stakeholders involved in the project; and private sector motivation in addressing the issues considered by the project together show an interesting common issue in the need to create a coherent partnership in the project. In addition, the item Effective Communication ("Are the project results disseminated in an effective way?") shows in several projects worse results than other aspects.

On the enablers side, Transparency, Willingness to cooperate, Variety of stakeholders involved, Innovation complexity are the ones with a higher positive overall percentage.

# 5. Online questionnaire

## 5.1 Aim of the questionnaire

The aim of the questionnaire was to gather relevant information from the stakeholders. This information should provide insights on the expectations and predictions of the stakeholders regarding the COREALIS innovations potential impact on their areas of interest. The questions aimed to reveal responses in order to develop a comprehensive and up-to-date list of enablers and barriers (technological, business, environmental and societal) for ports to tackle their challenges.

## 5.2 Establishing the SurveyMonkey questionnaire

An online questionnaire was established on the SurveyMonkey platform (https://www.surveymonkey.com/r/KJ32YY7). The aim of this questionnaire was to gather relevant information from stakeholders related to the ports' operation. This information provides an insight into the stakeholders' perspectives and expectations that they have for their interested impact areas of the COREALIS innovations.

For a more detailed description on the scope and structure of the questionnaire the reader is referred to the COREALIS Deliverable D1.2 on the "*COREALIS Personas and Stakeholder classification*" [19].

## 5.3 Building the questionnaire

The building of the questionnaire started from the idea that stakeholders would have a very good understanding of what the COREALIS innovations could bring as a benefit to them and how they could impact their business. We expected the responses to give a good insight into the stakeholders' expectations. The questionnaire was designed so that stakeholders could fill it in, in about 15 to 20 minutes. Furthermore, the questionnaire was split into two parts.

The first part contains questions that can be answered in a very short time, based on the immediate and natural intuitivity of the respondent, by responding to multiple-choice questions. At the end of this part of the questionnaire, the respondent is asked if they would like to provide further information in an optional second part. This part contains a few questions intended to collect deeper insights and more detailed information. The stakeholder can respond by writing free text responses to each question.

## 5.4 Questionnaire sections

The first section of the questionnaire, titled *'About you'*, aimed to identify participants and to ensure the information collected from them can be used in a legal and transparent way according GDPR rules.

The second section, *'About your organisation'*, aimed identity the company profile and the role it takes in the value chain of the port's business activity.

The third section gathers information on the role the specific organisation takes. It asks for the kind of contract the company has with the port and what type of services and products it delivers to or receives from the port.

The rest of the questions are gathered in the subsequent sections, addressing each one of the major potential COREALIS innovation impact areas. These impact areas are referenced to in the final project proposal that was submitted.

### 5.4.1 Expected impact of the COREALIS innovations

The questions were designed to draw insights from the stakeholders as to how they think the various COREALIS innovations can impact their operations.

Stakeholders are confronted with barriers (or roadblocks) to operate or grow their business. COREALIS innovations might lower or reduce those barriers, paving the way for business expansion.

The barriers were taken as a reference from the initial project proposal. There are three identified barriers:

- *Technical barriers*
- *Legal and policy barriers*
- *Economic and business barriers*

**Question:** *"Indicate which innovations are best suited to address the following barriers for your organisation"*.

### 5.4.2 Enablers, Barriers and Challenges

The following questions were asked in order to gauge the stakeholder's enabling factors, barriers and challenges.

1. *Question on the enabling elements for the operation and business of the port*

**Question:** *"Which of the following do you consider as the most important enablers for the Port of the Future" (*1 - Unimportant, 5 - Most Important).

- Hinterland connectivity
- Automation
- Scalability of operations
- Traceability of Operation
- Logistics Hubbing (Consolidation)

Further explanation of these observed business enablers can be found in Annex 2.

2. *Question on the barriers for the operation and business of the port*

**Question:** *"Which of the following do you consider as the most important barriers for the Port of the Future"* (1 - Unimportant, 5 – Most Important).

The following barriers were listed:

- Legislation
- Societal acceptance
- Technology limitation
- Environmental footprint

Further explanation on these observed business barriers can be found in Annex 2.

*3. Question on the important challenges for the operation and business of the port*

**Question:** *"Which of the following challenges do you consider as the most important Challenges for the Port of the Future"* (1 - Unimportant, 5 - Most Important)

The following challenges were listed:

- Operational Capacity
- Safety and security
- Operational efficiency
- Service digitalisation
- Sustainable growth

Further explanation on these observed business challenges can be found in Annex 2.

## 5.5 GDPR issues applied

In light of the entry into force of the General Data Protection Regulation (GDPR) earlier this year (25 May, 2018), steps were taken to ensure that survey participants' personal data was protected, that the use of their data was clearly communicated and that participants were aware of their rights before starting the survey. This was achieved by including specific GDPR related questions at the beginning of the survey, supported by a specific GDPR background information document. If participants did not agree with the questions put forward at this stage then the questionnaire was designed to end.

The document included in the survey to support the GDPR requirements along with the questions put to participants at the beginning of the survey may be found in [19][.

## 5.6 Dissemination channels

This survey was sent to more than 1400 GDPR compliant contacts via email using the MailChimp platform. The mailing list was comprised of ERTICO network contacts that had opted in to receive information on logistics projects such as COREALIS. The contacts consisted of people, institutions, authorities and industries involved in the smart port-city ecosystem.

Since there was no established contact list of the stakeholders involved in the five Living Labs of COREALIS (Port of Piraeus, Port of Livorno, Port of Valencia, Port of Haminakotka, Port of Antwerp), a supporting survey was established and sent to the related Living Lab Leaders. They distributed the list to their known stakeholders. All of these registered stakeholders received the questionnaire as well.

It was noted that a number of questions in the survey would be the same as the questions raised in a survey needed in Task 1.2 of the COREALIS project Port of the Future challenges, enablers and barriers. Also a number of stakeholders are operating both in the port and externally to the port. Therefore, in order to avoid that a stakeholder would be sent a survey twice, it was decided in a common telephone conference between ERTICO, PCT and the Coordinator that task 1.2 specific questions would be integrated into Task 1.1's survey. ERTICO's newsletter channel was also included on 18/7/2018 as an attempt to enlarge the response hit rate. The newsletter has more than 2400 subscribers.

The questionnaire was also communicated using social media platforms Twitter and LinkedIn by the COREALIS project partners. The Twitter account maintains more than 200 followers while the LinkedIn page maintains 89 followers.

## 5.7 Response rates

The number of respondents in the survey was 107. Out of this number there were answers skipped and some cleaning of the data needed to be done. The final response rate (94/1346 or about) 7% can be regarded as a normal 'response' [4] rate in in on-line surveys.

According to the survey responses, 35% of the overall respondents belonged to the Public sector, 22% came from the Transport sector and 13% of the overall respondents came from the ICT service providers category. Finally, 30% of respondents belonged to the Research, Consultancy and Specialised Companies which has been referred to as "Others" category. For a further categorisation of the respondents, the reader is referred to section 4.1.1 of Deliverable D1.2 [19].

[4] Journal report " The Complete Guide to Acceptable Survey Response Rates by Adam Ramshaw

## 5.8 Analysing the data received

Following the data and information collection, a thorough analysis was performed, based upon the original data received via SurveyMonkey service and its specific visualisation tools, but also by applying selected mathematical techniques which can translate the data into a more comprehensive format. This allowed to build a better graphical representation of the outcomes and provided the Consortium with better options for obtaining clear insights on each result. Interesting correlations between the data were detected and based on them, we useful conclusions were drawn that may provide guidance for the subsequent COREALIS work packages.

# 6. Questionnaire response analysis

## 6.1 Analysis on perceived enablers, barriers and challenges

Stakeholders reported on their perceived importance of enablers, barriers and future challenges for their business operations. For each of the items (enablers, barriers, and challenges), the respondents gave a score on how important a certain policy is related to their business operation. For each policy and each score, the number of respondents was listed. A weighted sum of scores assigned by respondents to each policy has been evaluated and appears on the top of each bar in the following bar charts. This value reveals the perceived importance of each enabler, on a 1 to 5 scale: (1 - Unimportant, 5 - Most Important).

### 6.1.1 Importance of perceived enablers

Based on the responses, Hinterland Connectivity is the most important enabler for addressing current port challenges, followed by the Traceability of Operations. The other listed enablers are considered marginally less important with an average ranking of 4 out 5 and almost equal with each other (Figure 9).

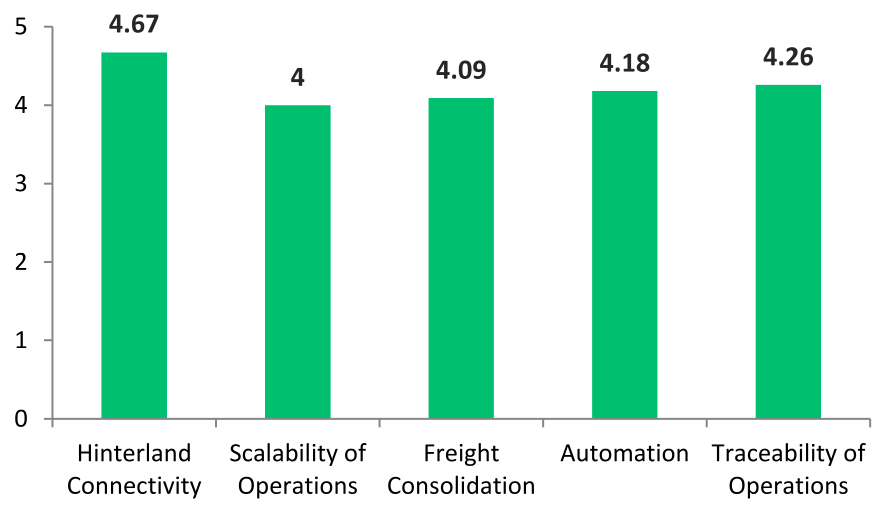


**Figure 9. Ranking of business enablers (1 - Unimportant, 5 - Most Important)**

### 6.1.2 Importance of perceived barriers

Next, the respondents were asked to rate the perceived listed barriers based on their importance. An interesting result that came out was that all of the barriers are almost equally important with legislation being marginally the primary one that has the greatest impact

(Figure 10). This result also agrees with the outcomes of the AEOLIX study (see section 4.1) which identifies 'Technological Issues' as the category with the highest average number of factors perceived as barriers. This factor was also perceived as a strong barrier in many of the projects examined.

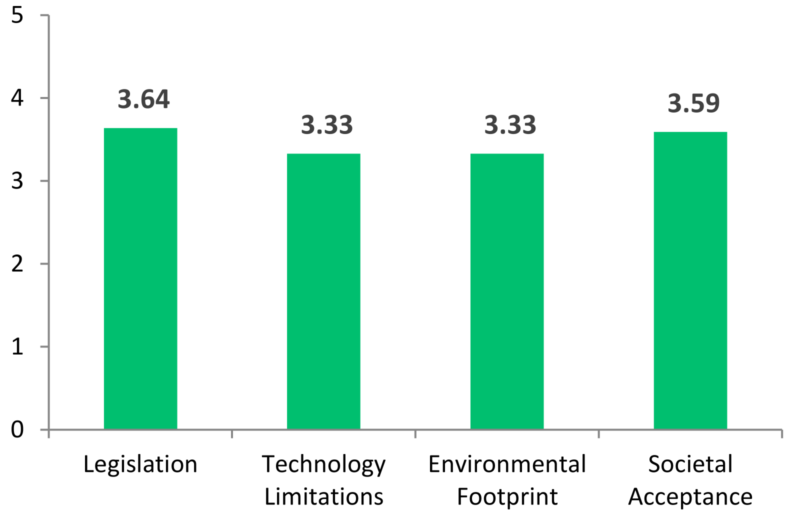


Figure 10. Ranking of business barriers (1 - Unimportant, 5 - Most Important)

### 6.1.3 Importance of perceived challenges

Finally, the survey respondents indicated that Service Digitalisation and Operational efficiency are the most important challenges that ports are currently facing, with Sustainable Growth being marginally less important (Figure 11).

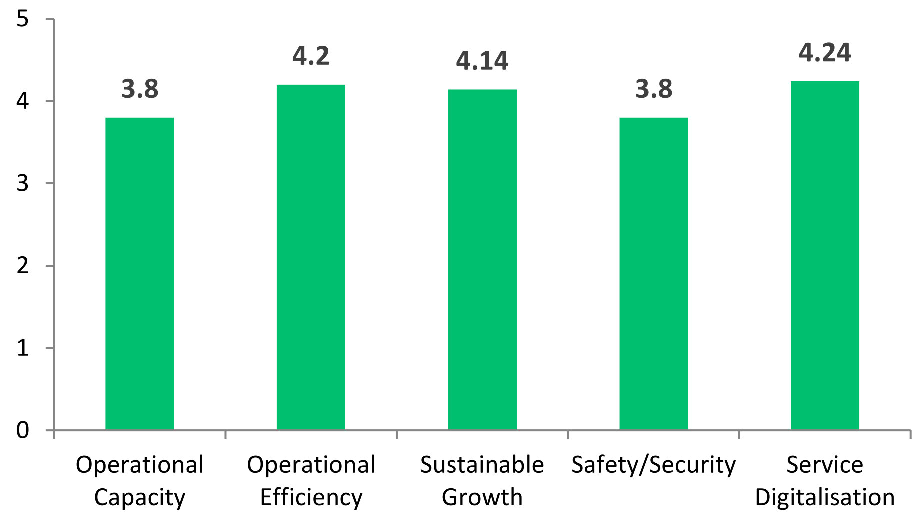


**Figure 11. Ranking of business challenges (1 - Unimportant, 5 - Most Important)**

### 6.1.4 Impact on Technical barriers

Regarding the impact of COREALIS innovations on the listed technical barriers, the survey results revealed that the 5G-enabled smart terminal operations and the Truck Appointing System technologies, seem to be the most relevant and significant ones for addressing them. Indeed, the majority of the respondents (55% and 33%), indicated these two innovations as the most relevant ones with respect to technical barriers. These results are illustrated in Figure 12.

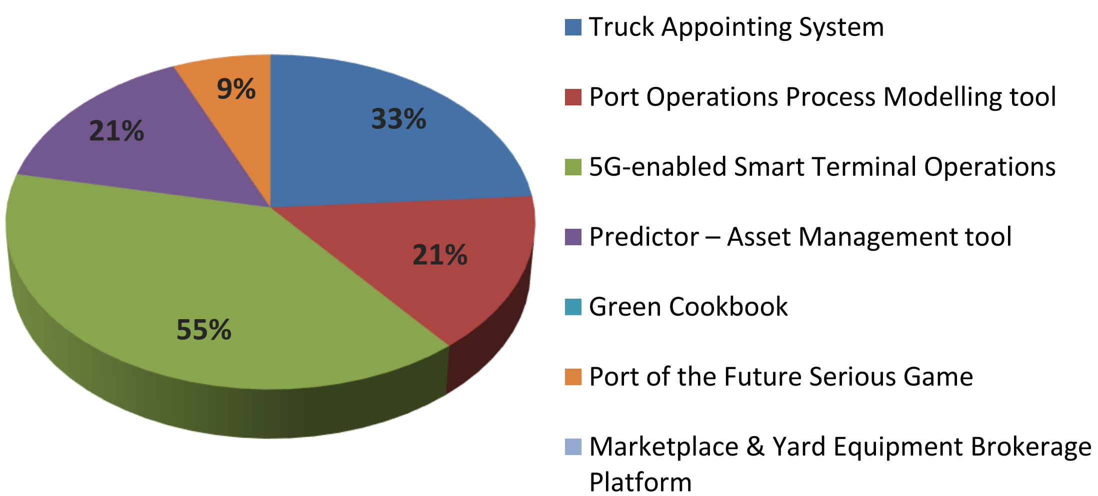


**Figure 12. Observed impact of COREALIS innovations on technical barriers**

### 6.1.5 Impact on Legal and Policy barriers

Regarding the impact of COREALIS innovations on the listed barriers, the Green Cookbook and the Port of the Future Serious Game are considered to be by the majority of the respondents as the ones with the most significant impact on Legal and Policy barriers. This response is visualised by Figure 13.

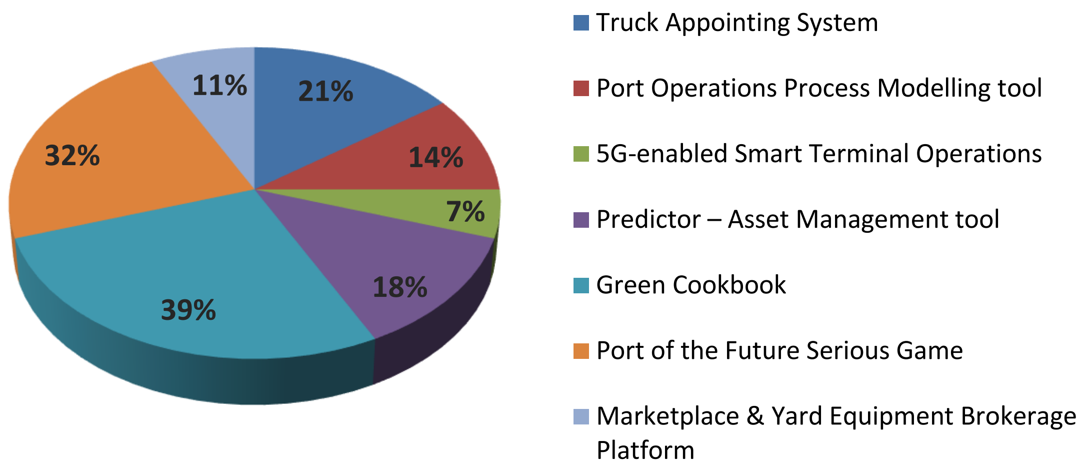


**Figure 13. Observed impact of COREALIS innovations on legal and policy barriers**

### 6.1.6 Impact on Economic and Business barriers

Finally, Figure 14 illustrates the percentage of respondents who have identified the COREALIS innovations as most relevant for addressing the Economic and Business barriers. According to this figure, the Predictor Asset Management tool is regarded by most respondents (22%) as the most efficient innovation, followed by the Green Cookbook (19%).

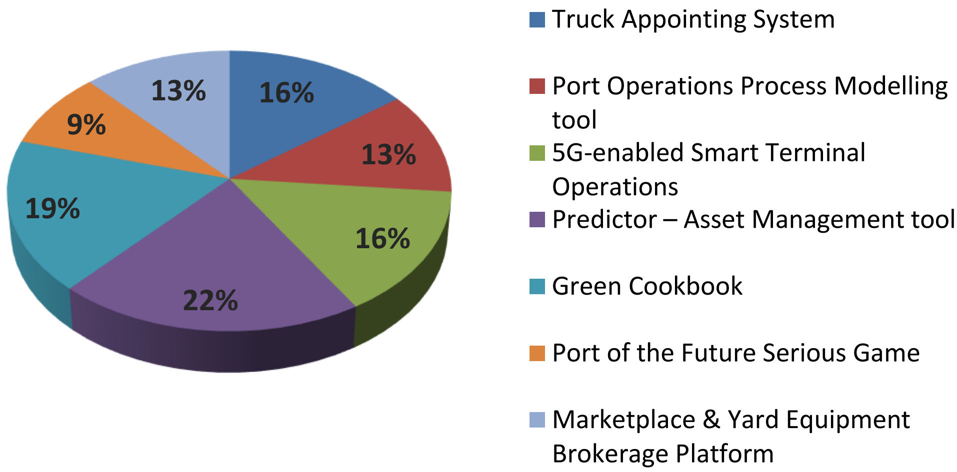


**Figure 14. Observed impact of COREALIS innovations on economic and business barriers**

The following figure summarises the above results by illustrating COREALIS innovations that are best suited to address current technical, legal/policy, economic/business and other barriers, as perceived by the survey respondents. For each category of barriers, the percentages of the three most relevant innovations are highlighted.

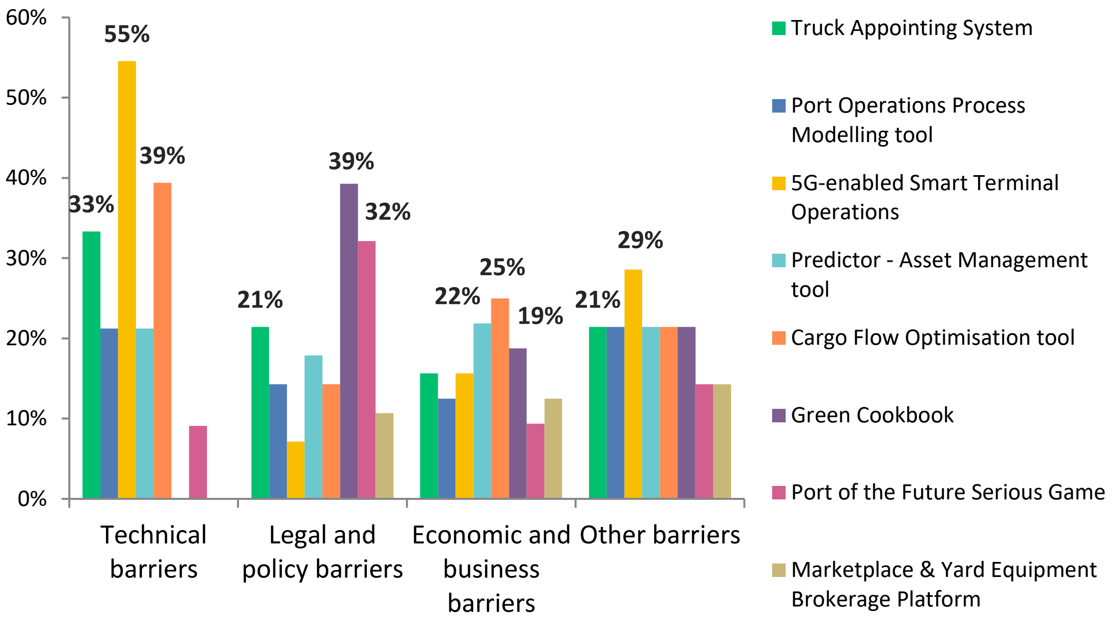


**Figure 15. Innovations best suited to address various barriers for organisations**

## 6.2 Business related analysis

This section is dedicated to a business related analysis, where the most important business related considerations are identified. The following scheme lists the most important items per subject, as perceived by the respondents.

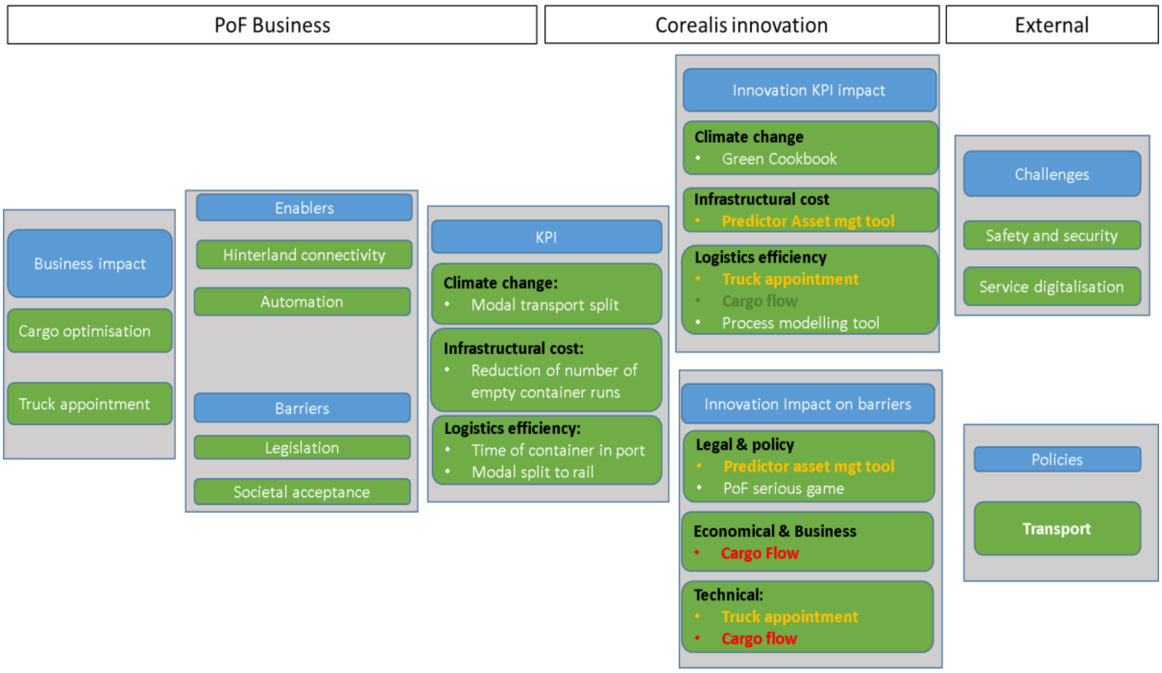


**Figure 16. Business analysis -generic scheme**

As illustrated in the Figure, the Cargo Flow Optimisation tool and the Truck Appointing System tool seem to have the biggest business impact. Their impact on business can be further enhanced if these tools are implemented with emphasis on the Hinterland Connectivity and Automation aspects, which were the most significant perceived enablers by the respondents. The most important policies that influence these business enablers are transport related policies. Any modern business is driven by digitalisation and the care about privacy and security. Although probably not always easy to take care of, these challenges need to be addressed at all times in every innovation implementation.

These tools should define implementations for, or should co-operate with KPI measures that monitor climate change, especially by focusing on how much modal split to rail can be implemented for reaching the hinterland. The modal split to rail will at the same time improve the logistics efficiency KPI. The reduction of empty container runs and idle times of containers can be achieved by the cargo flow and predictor asset management tool.

The respondents identified the legislation and the social acceptance as the most important barriers, which when minimized, can boost the business opportunities. Probably the Port of the Future Serious Game can play an even bigger role in the emulation of transport alternatives and formulate new or modify existing transport policies. The game should especially address the legislation aspects and the social impact acceptance aspects on transport. These can be complementary to the efforts of COREALIS innovations like the Truck Appointing System and the Cargo Optimisation tools.

The above conclusions should not be considered as generic ones applicable to all situations, as they come from the input of specific stakeholders and questions was also dependent to the project objectives. Yet, the results are probably indicative on the current barriers, enablers and challenges of European ports as well as the relevance of the project's innovations to them.

# 7. Conclusions

The adoption of IT/IS has repeatedly paved the way for modernization in seaports. As far as the future modernization of ports is concerned, this study highlights the importance of the interplay between port-centric and local IT/IS technologies, as well as process adaptations. A successful cross-fertilization can lead to competitive advantages for the port as well as individual port actors; vice versa, ignoring trends may lead to disadvantages in the sense of losing important clients or being unable to participate in data-driven port operations. However, the degree of digitalization and inter-organizational integration varies a lot among port actors and may lead to breaks in information flows. An example for recent research activities can be found in the area of inter-terminal transportation, predominantly focusing on optimization and simulation approaches. Approaches on (real-time) data-driven decision support (e.g., meta-analytics) and innovative ways to incorporate them into port operations and training (e.g., augmented and virtual reality, gamification, etc.) are strongly endorsed. These might possibly bring forward successful business innovation, given that current challenges and barriers are taken into account.

Based on the findings of past research and the categorization of ports, an online questionnaire has been established for the characterization of challenges, enablers and barriers to the port's operation within the port-city context. The questionnaire also aimed to capture port stakeholders' view on how the COREALIS innovations may impact their ports related businesses.

It becomes evident that hinterland connectivity and the ability to trace operational status are considered to be the most significant enablers while operational efficiency and service digitalisation are the most dominant challenges as perceived by stakeholders. This outcome comes in agreement with a previous study which identified Technological Issues as the most common perceived barrier in the field of logistics. An interesting fact that was revealed from the responses, is that all considered barriers are important, with social acceptance and legislation as the most hindering ones for the development of the Port of the Future.

The results of the questionnaire have no surprises for the COREALIS project team. The COREALIS concept focuses on raising end-users' awareness of the sustainable port development, from an economic, environmental and social point of view. Through the Port of the Future Serious Game, stakeholders in the port area will gain a better understanding of the multi-disciplinary approach for sustainable port development and port master planning. The COREALIS Predictor – Asset Management and the Marketplace & Yard Equipment Brokerage Platform tools on the other hand, focus on improving operational efficiency while the Green Cookbook aims to reveal opportunities for both operational efficiency and sustainability. Last but not least, the Truck Appointment System aims to enhance hinterland connectivity and operational efficiency.

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# Annex 1: Explanatory list of COREALIS innovations

1. The COREALIS Green Truck Initiative

### a) Truck Appointing System

An innovative Truck Appointing System (TAS) for external trucks that are calling in the port to deliver or pick-up containers. The system intends to minimise waiting time at the port gates, providing to the drivers an optimal time-window to enter the port based on preference, vessel schedules, the traffic expected from other trucks and real-time data from the urban TMC.

### b) The Marketplace and chassis brokerage platform referred as "Marketplace & Yard Equipment Brokerage Platform"

A marketplace/cloud-based brokerage platform will facilitate swift and seamless interactions among the port and the leasing entity, allowing online booking of chassis and serving as a hub for operational data. The marketplace will comprise i) A catalogue of services for ports and their clients so that ports and their clients can book equipment or services for a given time, ii) Yard equipment pool management with emphasis on chassis or other relevant for the CT, iii) Spot booking, and iv) Rating/benchmarking of service providers from the port operators

2. The COREALIS PORTMOD referred as "Port Operations Process Modelling tool"

Process modelling of cargo and data flows in CTs can improve their competitiveness by more efficient operations and better compatibility with regulations. The focus of the PORTMOD modelling tool will be operational efficiency, safety for personnel, emission analysis using LIPASTO database5 and improved data sharing (e.g. via a PCS). In practice, PORTMOD describes in detail the container placements in the container movement chain.

3. The COREALIS RTPORT (Model-Driven Real-Time Control module) referred as "5G-enabled Smart Terminal Operations"

Model-Driven Real-Time Control module (RTPORT) will coordinate and support port operation, providing measurable feedback to the models of PORTMOD. It will perform real time control of operations collecting data via yard vehicles and implanted sensors (including cameras), taking operating decisions based on on-line analytical processing and PORTMOD models.

4. The COREALIS Predictor – Asset Management

An efficient asset management requires an optimal use of port assets, e.g. yard vehicles (forklifts, cranes and trucks), tyres and spare parts. Storing and managing bulky assets takes up significant space of the port. The Predictor tool goes beyond classic ERP static preventive maintenance tools by realising a powerful predictive analytics module; this enables monitoring and dynamic prediction of the total life-cycle cost of port assets that improves over time.

5. The COREALIS Cargo Flow Optimiser referred as “Cargo Flow Optimisation tool”

It is an innovative data-analytics based cargo flow optimisation component; AIS data for the vessel ETAs will be multiplexed with (big) data from the rail operators and barges ETAs so that cargo flows are streamlined; the aim is to minimise containers’ waiting time at the port. This process will improve current land/infrastructure use and the overall supply chain connection to the port. Besides, through innovative machine learning, cargo flow prognoses for short-, mid- and long-term will be implemented so that the port managers and urban planners may be facilitated in their infrastructure investment planning.

6. Green Cookbook – Energy Assessment Framework

The Green cookbook helps ports to lower their environmental footprint and move to cleaner transport modes and cleaner energy sources.

7. Port of the Future Serious Game

The Port of the Future Serious Game (PoFSG) is an innovative and interactive training and simulation tool that is used to assess the feasibility and sustainability of the socio-economic and environmental/physical development of a port within the surrounding coastal and urban area. The tool will visualise the anticipated impacts – positive and negative – related to social, economic, and environmental aspects.

# Annex 2: List of PoF potential Enablers & Barriers and challenges

## Enablers

- **Hinterland connectivity:** Represents the array of transport infrastructure and logistics services that enable an inland centre to be connected to a maritime trade gateway.
- **Automation:** the creation and application of technology to monitor and control the production and delivery of products and services.
- **Scalability of operations:** Describes the ability of operations to grow and manage increased demand. Scalable operations are more adaptable to the changing needs or demands of their users or clients.
- **Traceability of Operation:** ability to verify the history, location, or application of an operation by means of documented recorded identification. It includes the capability and implementation of keeping track of a given set or type of information to a given degree, or the ability to chronologically interrelate uniquely identifiable entities in a way that is verifiable.
- **Freight Consolidation:** Integrated centres for trans-shipment, storage, collection and distribution of goods. Bringing together the key business operators in logistics, e.g. manufacturers, shipping lines, air cargo companies, and logistics support services, etc. Raw material and unfinished goods are stored, processed, finalised and managed in the logistics hub, closer to final consumers. The Hub also provides a clearing house for data, facilitating digital processing and quality management systems to track and trace shipments.

## Barriers

- **Legislation:** act or process of making or enacting laws which have been produced by a governing body in order to regulate, to authorise, to sanction, to grant, to declare or to restrict.
- **Societal acceptance:** public attitude and opinion to accept, support or to tolerate differences and diversity towards a specific situation, technology, topic, etc.
- **Technology limitation:** inability of either computer software or hardware to achieve some functionality.
- **Environmental footprint:** it is a measure of an activity, economy, a person, a community, a city, a town, a region, a nation, or humanity as a whole impact on Earth's ecosystem.

## Challenges

- **Operational Capacity:** port capacity is a measure of the maximum throughput in tons, TEU, or other units that a port and its terminals can handle over a given period.
- **Safety and security:** is the condition of being free from harm or risk. Safety is a condition that is achieved through caution, effort, and common sense. Security is measures taken to guard against espionage or sabotage, crime, attack or escape.
- **Operational efficiency:** can be defined as the ratio between an outputs gained from the business and an input to run a business operation. When improving operational efficiency, the output to input ratio improves.
- **Service digitalisation:** preparing services by adapting their scope, quality and quantity
- **Sustainable growth:** is the realistically attainable growth that a company could maintain a target capital structure without issuing new equity; maintain a target dividend payment ratio; and increase sales as rapidly as market conditions allow.