Technology gaps and regulatory challenges in Danish case studies

Deliverable D10.4

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Summary

This report is part of Work Package 10 of the AEGIS project. This Work Package is focused on Use-Case C, which is about the revitalization of small and medium enterprise ports and terminals and their relocation out of city centres. This report on technology gaps and regulatory challenges in Danish case studies shows how port terminal infrastructure development plays a key role in the development of a new waterborne transport system for Europe. This report highlighted the impact of the AEGIS concept as experienced by Port of Aalborg and by Port of Vordingborg, as small and medium enterprise ports. On the side of technological gaps, the report analyses gaps related to digitalisation in communication and standardisation, cargo handling and infrastructural support for new autonomous vessels, namely the capabilities of small and medium enterprise ports. It is concluded that the biggest technological gap in port terminal automation is the ability for a system to react constructively to unknown and uncontrolled objects i.e., manually controlled equipment vs. automated equipment. On the side of regulatory challenges, the main conclusion is that the ownership structure of Danish ports politicizes some of the decisions of the management, which may hinder on efficiency for the sake of social sustainability. The lack of a clear incentive structure to develop port infrastructure is another regulatory challenge, as it introduces lack of foreseeability for terminal operators. This report generally concludes that there are gaps and challenges that cannot be addressed at the local level alone.

Definition and Abbreviations

CCU	Cargo Carrier Unit
CEMT	Classification of European Inland Waterways
DKK	Danish Kroner (currency)
ECS	Equipment Control System
EDIFACT	United Nations Electronic Data Interchange for Administration, Commerce and Transport
EU	European Union
FAL	Convention on Facilitation of International Maritime Traffic
ICT	Information and Communications Technology
ISPS	International Ship and Port Facility Security Code
IMO	International Maritime Organization
IWW/ IWT	Inland Water Way / Inland Waterway Transport
RCC	Remote Control Centre
RORO	Roll-on/roll-off ship
SME	Small and Medium Enterprise
PFSA	Port Facility Security Assessment
PFSP	Port Facility Security Plan
TOS	Terminal Operation Systems
VDES	VHF Data Exchange System

1 Introduction

This document reports on findings associated with research on the introduction of the AEGIS concept to revitalize regional ports and city centre terminals in Denmark. The report gives a brief overview over the AEGIS Danish use-cases, namely some contextual information on Port of Aalborg and Port of Vordingborg, and then delves into the relevant details associated with the possible implementation of the AEGIS concept in practice. The reported is structured around two main axes of analysis.

The first axis looks at technological gaps encountered in both ports when considering the implementation of the AEGIS concept. This includes gaps in digitalisation, namely the automation of ships and especially of terminal operations, and the underlying gaps in communication and standardisation. Some further details are presented on technical gaps associated with cargo handling and the relationship with vessels. And finally, the technical gas in terms of energy efficiency, namely in view of alternative sources of energy for ships and for terminal operations.

It is important to underline that technological gaps may not only be the lack of available technologies at port or in the marketplace, but also eventually the operational and organizational challenges associated with access and usage to those technologies. This broader understanding of technological gaps justifies the link between the two axes of analysis of this report: it is expected that regulation ay assist in overcoming such organizational issues that materialize in technological gaps.

The second axis thus looks at regulatory challenges that may constrain the introduction of the proposed new waterborne transport system in Denmark, namely by reference to the two regions where the use-case ports are located. These will not be exclusive to the technological gaps identified above, but also consider more context dependent issues such as the port ownership structure and the requirements for licensing a port expansion project such as those required under AEGIS.

It is expected that this report assists in understanding the difficulties of implementing AEGIS from a port terminal perspective, and how port related issues should not be underestimated in short sea shipping and inland waterway transport.

2 Methodology

This report is based on work undertaken at different levels in the AEGIS project and consolidated under several tasks of the Use Case C work package

Technological gaps are here understood as missing developments necessary for the implementation of the yet still conceptual AEGIS solution. These are not calls for the industry to develop such technologies, but rather a warning to policymakers that such gaps exist and that they may delay or hinder the introduction of the proposed waterborne transport system, not only in the context of Denmark, but also potentially in other locations.

Rules, namely legal norms, play a fundamental role in not only allowing new technologies and setting a level playing field between all operators, but also, in some cases, in delivering incentives for them to take risks necessary to invest in the missing technologies. For that reason, it is not sufficient to identify technological gaps but also the challenges of a regulatory nature proper of the Danish context.

The first step was to request the technical work packages to identify, in abstract, the technological gaps associated with the introduction of the AEGIS concept in the two Danish ports.

The second step consisted of the identification by each one of the two port managerial structures of the gaps existing in the context of their own operation. This step was done by using “simulation”. Simulation is a known technique for testing the capabilities of systems before building them, and is often used to test logistics systems, to see if the configuration can handle the expected throughput. The success of a simulation is about how precisely a system can be modelled, to find bottlenecks and inconsistencies in the setup. The details level needed to do this is also depended on the type of system being modelled and where the issues are most likely to arise. In a logistics system, the most critical points are modality changes, handling costs and bottlenecks, either physical or organisational. To model a logistics system there are no real technological gaps, as the creation of a simulation tool is based on known technology, but applicated in a novel context. The focus is on the supply chain and the used transport systems and aims to deliver a tool for deciding between existing solutions and the ones developed in AEGIS’ other work packages.

The third step was to identify regulatory challenges associated with the technological gaps in the context of Denmark, based on data collected at Aalborg and Vordingborg. This data was collected also for the purpose of work undertaken in the *Policy Support* work package.

The reviewing process of the report and involvement of the industry stakeholders of the AEGIS project was key to ground the data in actual and not hypothetical issues. This report is thus a qualitative assessment of experiences from the two use-case ports. The occasional generalization effort is illustrative of broader trends known by the participant stakeholders and not the result of an inquiry into other experiences.

This report does not enumerate the public policy recommendations resulting from a dedicated task (T10.5), but rather reports those findings to the Deliverables of Work Package 6.

3 Description of the use-cases

AEGIS is structured around three use cases, each featuring a different approach to intermodality. While short-sea shipping is approached based on the Norwegian case and inland waterway transport is approached based on the Belgium case, port terminal development is approached based on the Danish case, namely the study of two SME ports.

3.1 Purpose of the case-studies in AEGIS

The purpose of this use case is to consider how concepts and solutions developed in AEGIS can be applied to increase efficiency to the value chain and thus increase competitiveness towards road transport in small and medium sized ports. The two selected ports are Aalborg (top) and Vordingborg (bottom). They are typical representatives for the obstacles SME ports are facing to increase goods to be moved by green transport compared to road transport. The port of Vordingborg is a small port facing not only challenges from cheap and flexible road transport but has also previously been pressed out from the city boundaries due to real estate development at the waterfront in the city centre. Because of this, only a limited space was left for terminals and further port development. Despite these challenges, the port has turned this negative experience into a well driven and growing port in the vicinity of residential areas. The port of Aalborg is a medium sized inland port serving the production area of Northern region of Jutland and supporting an industrial park in the hinterland. The port has moved out of the city centre and is well located, but to be competitive with road transport it needs to increase efficiency at its terminals to reduce costs and secure higher frequency by feeders, be competitive at the RORO segment and provide multimodal green logistics solutions combining short-sea shipping with rail transport.

In order to strengthen competitiveness of SME ports and increase short-sea shipping there is a tremendous need to redesign logistic systems in SME ports, develop new terminal concepts, introduce automatic cargo handling equipment and improve digital connectivity.

The Aalborg use-case is focusing on the development of an intermodal, automatic, green terminal area, centred around the existing container terminal located at the port. The port has an established container feeder connection transhipping cargo to/from Northern Germany. However, AEGIS data and analysis shows, that a vast majority of cargo going to and from Northern Germany and Aalborg is being transported on roads. A more sustainable and time- and cost-efficient automated terminal would provide a competitive logistical solution, when transhipping cargo from the two regions and could thereby attract more feeder cargo to Aalborg. Further the Aalborg case focuses on the potential for being included in existing Ro-Ro networks. Both for transnational shipments to connect Northern Jutland to the capital area and for international shipments to regions in the other Nordic countries.

The Vordingborg Port use-case will look at how transhipments in larger ports can be avoided by use of smaller vessels directly calling smaller ports and city centre terminals. Congestion in larger ports will be reduced and cargo will go faster to the ultimate destination. This will alleviate the need to develop, expand and equip additional port facilities in larger ports, as traffic would be diverted directly to smaller ports and terminals. Pressure on big cities will be reduced. The concept can be used in conjunction with simple RORO vessels and electric trucks for last mile delivery that reduces environmental impact. The concept will provide areas further away from highways and infrastructure with links to the greater EU network, will maintain workplaces and industry in these areas and will limit the negative impact of urbanization in rural areas. AEGIS will investigate how port areas inside city centres can be developed for multipurpose utilisation.

3.2 Characteristics of the two Danish ports

3.2.1 Port of Aalborg

The Port of Aalborg Group is a public limited company owned by the Municipality of Aalborg, with seven independent subsidiaries and appr. 100 employees. The board members of the Port of Aalborg Group include, politicians, business representatives and Port of Aalborg employees.

Port of Aalborg is a modern inland port with a 360-degree view, multimodal logistics solutions, and a focus on supporting the realization of Aalborg Municipality's business and sustainability strategy. It is located outside the city centre on the open plains - with room for long-term development.

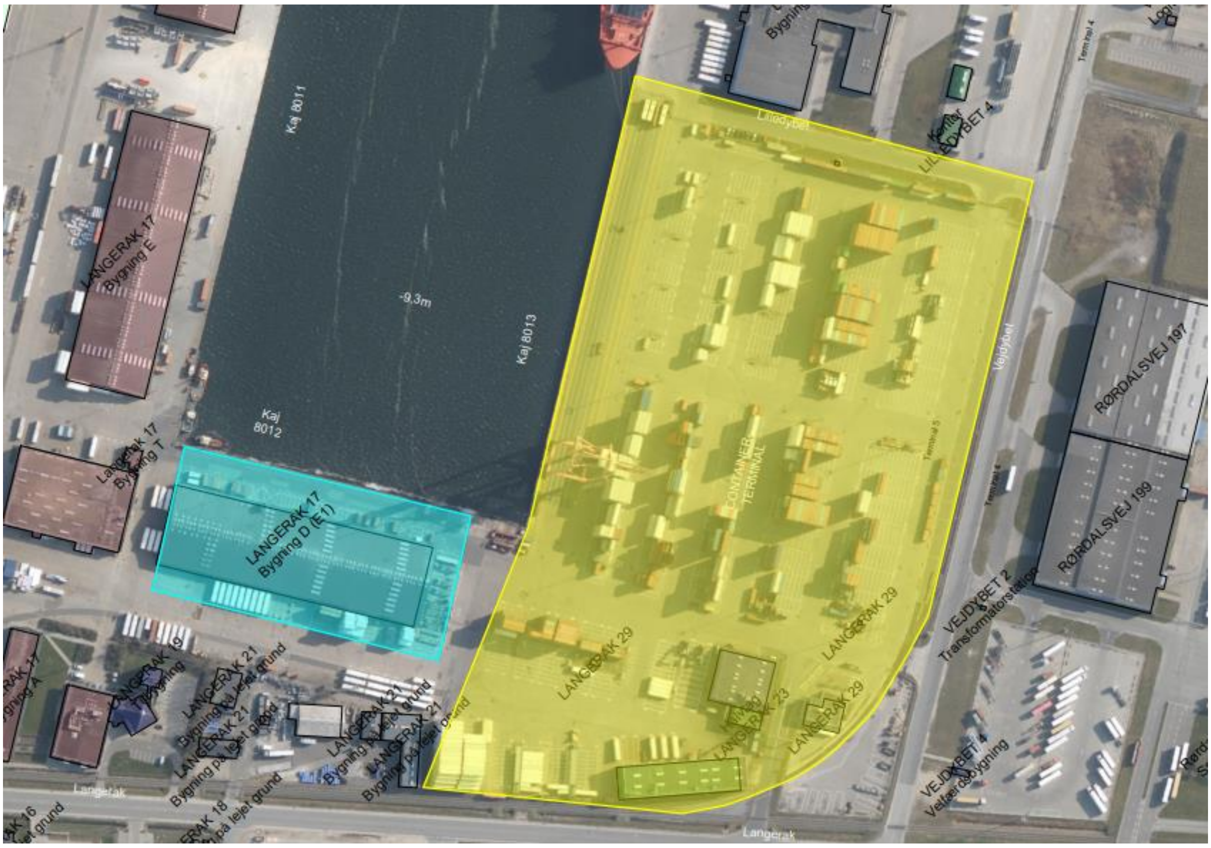

Figure 1 – The area for an intermodal, automatic, green terminal area. Marked with blue is the area for a RORO terminal and parking (currently a warehouse). Marked with yellow the aera for container handling including a fenced automated area. Included in the yellow area is a rail network (right/east)

In addition to the quaint facilities, the Port of Aalborg owns DKK 4.2 million m^2 of commercial land in the hinterland, where the infrastructure is closely linked to the E45 motorway. Almost 100 companies have already established themselves in the attractive area, about half of which are in the quay areas. The Port of Aalborg is an active and rational part of the individual port customer's logistics chain; a hub for all types of goods and all types of transport by ship, truck and rail - with the *Nordic Transport Centre*, integrated into the total service offering, which also includes terminals, warehouse hotels and production facilities in the hinterland.

Figure 2 - The current design and layout for the automated container terminal, including interface towards the rail network (bottom/east)

Port of Aalborg wants to further develop its position as a central logistical multimodal hub for the Region of Northern Jutland. This includes to expand the connections and routes going to and from the port (focusing on rail and feeder connections) and the port is currently working on determining the feasibility of more RORO routes. In AEGIS Port of Aalborg is focusing on the design and equipment of a multimodal terminal aera (Figure 1), that can contribute to this ambition and a fenced automated container terminal (Figure 2). So far, the key feature is the concept for the new automated container terminal with direct interface to the rail-network at the port. The automated terminal consists of 44.500 sqm fenced area fit with a capacity of 75.000 TEU. The conceptual study is currently being developed with the AEGIS partners.

3.2.2 Port of Vordingborg

Vordingborg Port (Vordingborg Havn) is a Danish small - medium-sized entrepreneurial port (SME port) port situated on the island of Masnedoe, south of Zealand. This is a self-governed port under a Municipality, meaning it is managed by a Municipal Council. The ownership is represented by the mayor, the executive board, and the Municipal Council. The port reports to the municipal council of Vordingborg and has board with five members. The port administration is carried out by a CEO, Financial Controller, project manager, communication manager and 3 harbour assistants.

The port has been growing rapidly and has undergone a substantial expansion. The harbour area has since 2015 quadrupled in size. Today, the port is amongst one of Zealand’s biggest ports. The huge expansion project has, as mentioned, taken place since 2015 and has included an enlargement of the harbour area and a dredging of the fairway down to a depth of 10.4 meters with a width of 70 meters.

The area of the harbour has gone from 45.000 m^2 in 2015 to 188.000 m^2 by 2019. The port is undergoing a further expansion with about 225.000 m^2 which will bring the total port area to about 413.000 m^2 in 2026.

The growth of Vordingborg port has meant that more cargo has moved from road to sea. The port wishes to continue this development. The expansion of the port was performed with a unique focus on sustainability together with the clients of the port. Using recycled products such as contaminated soil and slag to build a new quay is unique in building port facilities. This method has meant a reduced cost of the project by 10 % to 100 %.

An important part of realizing the port expansion project has been the participation in the EU Interreg Project DUAL Ports, where Vordingborg Port has been one of the key pilots. The carbon emission footprint has shown a reduction for the port of Vordingborg and the municipality of Vordingborg by at least 20 %. Thus, the aim for reducing the carbon emission footprint is vital for the whole municipality of Vordingborg. Vordingborg Port has been one of the key pilots (soil treatment and LED lighting) in the EU Interreg DUAL Ports project. The main objective of the SOIL pilot was to expand and develop the port with a quick and high return of investment and with a minimum economic risk by using recycled products, such as contaminated soil, concrete and excessive soil from building projects in the municipality. The objective of the LED pilot was to optimize the use of port area lighting. For safety reasons a good lighting is critical in port areas. The aim of the LED pilot was to reduce carbon emissions, by installing, managing and monitoring a new intelligent and innovative lighting-system.

4 Technology gaps in Danish case-studies

The Danish case-studies face technological gaps of three different orders. One is the gaps in digitalisation associated with the autonomous shipping operations, which includes issues of communication and of standardization. The second type of technology gap relates to port operations and autonomous cargo handling. A third gap is presented in this section as it indirectly affects the ports: the fact that ports will be servicing of new vessel types, which have a different design and are equipped with alternative propulsion systems that require a different type of energy supply, and how this affects the port's own infrastructure.

A further gap that is transversal to these three types of gaps is the financing of autonomous port infrastructure. Already now financing port infrastructure is challenging due to the high building costs and the rather short loans a port can get, typically 25 years, whereas depreciation is up to 75 years or more. When a port, with or without a commercial / private partner, has to look at a business for new port infrastructure the future expected (guaranteed) cargo turnover is of great and significant importance. Though a port might want to prioritize and promote autonomous shipping and cargo handling, the port, especially the smaller commercial ports, might be willing to compromise on priorities and choose the more economical beneficial solution and therefore not have the needs space and/or infrastructure to handle autonomous ships. This can eventually be resolved by new public policy and regulation, and lack thereof represents a challenge (see further in 5.).

In terms of applying new technology in an operational context, the primary challenge is rarely the technology in itself, but the implementation of the technology and understanding the limitation of the technology. It requires a lot of specific knowledge to identify the correct use case, and the correct usage and integration of the technology, and that knowledge is difficult to build in a smaller port, as there are few available resources for these kinds of projects. Further, the consultancy industry also does not have the needed domain knowledge to be an efficient change agent, because there is not yet a critical mass of demand for automated solutions in small to medium sized ports. Therefore, the primary technology gap in small to medium sized ports, is not the technology itself, but the knowledge to find the solutions and implementing them in the correct context. There are of course some technological limitations that affects which solutions can be implemented, these are however more general technological limitations and not specific to a port. This can e.g., be automation solutions in a mixed environment, where both manual operated and automated equipment operate. Here a large auto manufacturers automation system would be a good example of technological limitations, and this can in part be solved by applicating the technology to closed system, where only automated equipment operates, thereby mitigating the biggest challenge of autonomy software.

4.1 Gaps in digitalisation (automation)

Fully autonomous sailing (and mooring, cargo handling etc.) seems to be far in future mostly due to regulatory hinders. However, lower levels of autonomy (up to remotely controlled or even just observed) are likely to be introduced in near future (are already in test phase) Although this report does not discuss the social consequences of automation, it is important to flag from the outset that workers unions may eventually oppose partly or totally this transition to automation and robotics, namely on the grounds that it will turn certain existing positions redundant.

However, the primary issue regarding full automation is actors from outside systems, the autonomy system cannot track and understand, or at least adhere to strict rules and distance requirements in the context of navigable waterways (such as the Limfjord). Therefore, all automated areas need to be fenced in, so all objects inside this area is controlled and operated by the autonomy system. This is the current major gap in autonomy software, so it is possible with current technology to create autonomous operated areas.

One key aspect of the interlink between port and ship is the existence of a RCC. These need to be built up, and it is not a given that they would be located at the terminal. Communication between port and RCC is important. These RCC need to be built up, which includes a discussion on where to place them (probably close to or inside the port area), which communication standard to be used. This latter element requires high speed internet and/or 5G network and also secure communication. RCC could include RC for autonomous yard operations as well, and not only the vessel RC.

The physical infrastructure of the port, and the surrounding area, will also need to be configured to support autonomous sailing and mooring; this includes installation of positioning systems along inland waterways and application of suitable sensors.

Furthermore, the waterways will need to be virtually fenced. A fenced port area for autonomous cargo handling can limit the use of the port area by other users. This will have an effect on the revenue. **Port of Vordingborg** would like to work with the Pop-Up solutions where an autonomous port area is temporarily fenced and/or closed. In the context of the Limfjord, where **Port of Aalborg** is located, this represents a huge issue: if autonomous mooring systems are unavailable, then autonomous vessels become unpracticable.

There are three dimensions to analysing gaps in digitalisation in these use-cases: ships, terminals, and hinterland transports. For ships with autonomous functions, the main gap is the lack of achieving situational awareness based on information collected from the ship. This includes information related to cargo operation (exchange of cargo information), maintenance (status information about the ship), and other information that is needed by the control centre operator that is otherwise available to the officers on the ship bridge. For terminals, there is a gap in the information handled by the TOS and what is available for the ship. For hinterland transport, there is a gap in the information of the cargo operations performed at the terminal and the truck services.

For **Port of Aalborg**, the major technological gaps in relations to application of autonomous vessels, are handling of objects outside the autonomous system, as there is no real solution for this problem, see automobile self-driving etc. Regarding semi-automated or remote-controlled vessels, the major issue is connectivity and input latency for the ships, ad high latency can lead to accidents. Another issue is the required infrastructure as this is not clearly defined, as well as cost of investment etc.

4.1.1 Gaps in communication

Communication between linked and dependant processes is a necessity for facilitating optimal planning of each consecutive process. And as logistic processes happen between partners, often with different IT systems, the ability to provide information to other partners can be difficult and is often hampered by intercompany policies. For cargo operations in port and terminal, there is a lack of standardized communication between onshore and onboard equipment.

- General agreement about datatypes
    - What data is needed
    - What data is available for who
- Electronic signing and encrypting of messages in the maritime domain:

- Not yet agreed on the method for electronic signing and encrypting data
- No maritime authority has been assigned to publish public and private keys

For autonomous operation in ports and terminals, it is important to note that the specification of 5G base stations has not been finalized. The specification of VDES has not been completed/approved yet. Protocols used for implementation of the ship-shore reporting are also not decided.

For **Port of Aalborg**, the major issue in communication between actors in a port environment is the lack of a system that facilitates communication of activities directly and in real time to all relevant parties. This is not so much a direct technological gap, but more a lack in applicating the correct functionality in a standardized manner. Another issue is the ability to get all actors in the value/supply chain to use such a system, and using it optimally is huge challenge, as these actors have very different backgrounds and capabilities. Further, politics between possible competitors is also a potential issue, in relation to information sharing. Therefore, the biggest issue for the port of Aalborg is the lack of unified standards, securing interoperability between partners and systems.

For **Port of Vordingborg**, another gap in digitalisation is the communication between the different stakeholders. The ship has a shipowner, and the shipowner has a chartering department, operations department (in-house or external partner); once the ship is loaded there is a shipper and receiver of the cargo, and maybe there is a cargo owner. Ports have typically appointed an agent and/or stevedoring company. When the cargo is loaded and discharged there will be a representative of the shipper and/or receiver to check quantity and quality of the cargo. In the context of the port of Vordingborg, there is already a foreseeable challenge, both practically and legally, in the handling and communication with the different stakeholders. Furthermore, with respect to the communication to authorities and ports. And the communication from the port or local agent in regard to planning purposes or for example to warn congestion at a certain quay.

4.1.2 Gaps in standardization

Data exchange and communication between different stakeholders involved in port calls, cargo operations in terminals, and the provision of maritime services suffer from lack of standardization when it comes to communication means and information exchange. Ships sailing between several ports on different continents face different ICT systems, procedures, and authority requirements for different port calls. Automatization of cargo operations and the information exchange between the ship, equipment onboard and on shore, and the various ICT systems, are defined by each vendor.

EDIFACT is widely used for container transport, as this contains several well-defined messages for data exchange with terminals and customs, but the communication protocol is not well defined when it comes to how feedback and acknowledgement are given to ensure that the messages are complete and well understood by all parties.

There are different needs of standardization for different domains. Figure 3 lists some processes and data sets relevant for the administrative domain, nautical domain and operational domain.

Administrative Domain
Mandatory reporting to port state, flag state, and other authorities before, during, and after port call and for specific reporting areas.
Data:
Data used by authorities for instance for clearance of ship, cargo, crew and passengers, for ensuring safety and security of shipping.
a) IMO FAL Forms: reporting notifications and declarations
b) IMO Port Facility No.

Nautical Domain
e-Navigation, navigation in port and during the voyage, voyage planning.
Data:
Data used by ships and others for safe and efficient voyage planning and execution, including electronic charts, AIS messages, notices to mariners etc.
a) Port depths and water levels:
b) Port infrastructure:
c) Port information:

Operational Domain
Port and terminal operation planning and execution including Just in time concept and port call planning
Data:
Data used for safe and efficient operations outside basic navigation, for instance just in time operation, and port call planning.
a) Arrival / Departure times:
b) Starting / Completion times for services

Figure 3 – Processes and data sets for the administrative, nautical and operational domains

4.1.2.1 Gap in administrative domain

Guidelines for reporting requirements regarding Maritime Single Window exists, however, there is a lack of detailed guidelines for implementation of Maritime Single Window systems to ensure that ships calling at ports will interface a limited number of different implementations. Each flag state/port state add their own requirements to the mandatory ship reporting obligations in additions to what is decided by IMO and the EU in Europe. There remains, on this issue, a lack of legislation for harmonized/standardized intermodal cargo (units).

4.1.2.2 Gap in the overlap between domains

Better coordination between data relevant for the various domains are needed, even if work on this is ongoing, for instance, through the IMO FAL on development of the IMO Reference model. Examples of data that must be coordinated between domains: Nautical information regarding locations in ports and terminals and operational information regarding the location of maritime services in the port and terminal.

4.1.2.3 Bad uptake of standards

Several standards exist, but their general uptake is too limited to gain substantial benefit for the interoperability between systems. Vendors need to know that a certain standard will gain sufficient uptake in the industry to adapt it, which means introduction of standardized solutions have been slow.

For the **Port of Aalborg,** it is the same issue, it can be very difficult to choose the right standard or system in hopes of wide support of this solution. A set of international standards e.g., from EU, would make this process easier for small actors in a global logistics system.

4.2 Gaps in cargo handling

Certain technological gaps have to do with the handling of cargo, both at the quay and also in the vessel. The combination of both is introduced here, with a focus on the implementation of the AEGIS concept in the case study ports.

Physical infrastructure is necessary for autonomous sailing, mooring and to handle cargo. Locks and bascule bridges need to be autonomy ready (for autonomous IWW vessels passing those). Positioning systems (in the meaning of landmarks) need to be installed along the coastline, at port entries, along IWW (rivers or cannels). Also, suitable sensors (many different types, the more, the better) need to be applied. However autonomous mooring systems are not market ready and need to be applied. Here is a list of technical obstacles and challenges when developing solution for small terminals yard automation.

Table 1 lists issues identified by Kalmar, taking into consideration the issues of both ports:

Table 1 – Identified gaps and contextual solutions

Gap identified by Kalmar	Impact for the Port of Aalborg
Mixed traffic/multiple different machines operating in the same place - How to avoid collisions with other road users? - How to avoid traffic jams or blocking other equipment? - Rerouting if something is blocking the planned route	The Port of Aalborg will fence in the terminal, so only automated equipment will operate in the terminal, and therefore the system will be able to keep track of all objects.
Weather conditions and other external factors when operating 247/365 [1] What sensor setup to use? [2] How to take into account limited visibility, low friction, low light, bright light etc	Choosing correct equipment and creating the most optimal maintenance routines is an issue not unique to automated equipment, but the issue is exasperated when relying on sensors for input, so for the port of Aalborg it is very important that these issues are solved with a high confidence.
Human to machine to human interaction - How to handle safety when manual operated machines and automated machines are interacting?	Since the terminal is fenced, the only interaction between the automated equipment and outside equipment is the loading of container into and from the terminal. The solution to mitigate this in Port of Aalborg is to create fenced booths for trucks, where the truck parks alongside the fenced terminal. Here the driver is forced out of the booth to activate a pick from a kiosk outside the fenced booth. Doing this remove the potential for harming a person.
ECS for small terminals - Standard light weight solution for small terminals - ECS for big, automated terminals to be downscaled for small terminals; how to effectively remove dependencies between existing system modules - Cloud solution for ECS and cyber security for the cloud-based solution	Port of Aalborg have no input currently. However, to solve this issue the Port of Aalborg needs to find and implement an ECS, that support the autonomy system or handle the equipment control tasks with manual orders.
ECS - TOS integration - “General” TOS selection for small terminal(s) does not exist, TOS is each terminal’s own selection and require own integration work to ECS	There must be integration between TOS and ECS, as the ability to facilitate in the terminal is reliant on available equipment etc.

Multiple machines operating together e.g., reach stacker loading terminal tractor - M2M communication - Fine positioning related to each other for the machines	Related to the abovementioned gaps of ECS for small terminals and TOS integration, as an ECS is required to handle and optimize jobs between different autonomous equipment, and jobs received by the automation system originate from the TOS.
Safety in the terminal area - Safety implementations in the terminal: solutions and processes (including infrastructure) - Safety trainings of personnel - Overall understanding and knowledge level regarding safety	The above mitigations together with a training program and clear rules is the foundation for creating a setup that is safe.
Other issues - Twist lock handling still manual, no solution how to automate twist lock handling in terminals (safety for manually operated part of the process needs to be considered)	Twist locks are a manual problem and should be solved around the crane before the container is put into the terminal system.

4.2.1 In context of the Port of Aalborg

Port of Aalborg and Kalmar are working on a proposal for an automated, green and efficient container terminal, based on this work the Port of Aalborg has solutions and thoughts on the issues presented above by Kalmar, see Table 1. The main problem can be solved by fencing the terminal, so only controlled machines and objects exists in the terminal. However, as the solution has yet to be implemented in a context similar to the Port of Aalborg, there are many implementation issues. These are mainly relating to cost and knowledge.

4.2.2 In context of the Port of Vordingborg

As described above (sub section 3.2.2), the Port of Vordingborg is currently expanding its port infrastructure with a view of allowing CEMT autonomous vessels to berth (see Figure 4 below). This section describes those gaps in cargo handling that the port authority has identified as part of this project and that illustrate the impact of AEGIS.

Figure 4 – Port of Vordingborg multiuse pier for autonomous bulk carriers

With respect to the autonomy calls to port, and the issue of congestion and communication, **Port of Vordingborg** understands that a communication procedure / platform should be developed to, for example, give warnings in times of congestion. This will have influence and/or conflict with the terms in the charterparty. Since the ships master legally has to confirm "notice of arrival", how is this aspect dealt with, when the ship arrives autonomous. A legal matter that has to be solved in the terms of the charter party and Bill of Lading.

With respect to the approach to port, the priority is a channel free of traffic. Some navigation channels can be narrow, whole or partly, due to the configuration of the channel. Some channels can be more complex to navigate in due to external conditions, wind, weather, current and so on. This has to be taken in account in the ships design and when navigating through these channels. Including communication to other marine traffic in the area.

With respect to the mooring (ferry dock system) it is probably possible to design low complex automated and autonomous mooring systems for autonomous ships, using experiences from ferry dock systems.

With respect to fuel supply, the availability foreseen on the port of Vordingborg. The ships design for this use case is based on methanol- electric driven ships. But how & when fuelling is to be done is be investigated. Manually / automated and / or autonomy. Also, in regards of safety.

With respect to repair/maintenance on the ship, the how and the when is currently being investigated.

4.3 Gaps in infrastructural support for new vessel types and energy supply

Although this use case is not focused on ship development but rather on port infrastructure development, the creation of new routes from Port of Aalborg to Gothenburg and from Vordingborg Port to the Polish coast will also rely on new types of vessels.

As other deliverables have highlighted in other contexts, it is important to underline that the market is not ready for autonomous on-board craning solutions. The only solution is at prototype status (e.g., being developed by MacGregor).

It is proposed that small and light weight on-board cranes need to be developed, especially for small vessels (such as the shuttles being designed for AEGIS Use-Case A, in Belgium/Netherlands. This prototype would have to be capable of handling at least 20ft containers, but ideally it would be best if it could handle 40ft containers.

Another issue has to do with ballasting systems. It is necessary to develop efficient such systems for small vessels. Quay support and ground-poles are presented as feasible solutions in this regard.

With respect to lifting solutions, the AEGIS concept proposes light-weight and more affordable alternatives, especially for double-deckers in the context of the Danish case-studies. The technical gap here is the inexistence of a transversal loading of trailers on an inland waterway vessel, which would need a lift for each pair of trailers.

When considering autonomous unloading of dry bulk, new systems are also necessary. There is a lack of vacuum/pump solutions that are autonomy ready.

The promise of AEGIS also incorporates a layer of vessel efficiency, namely by relying on alternative energy sources and propulsion methods for ships and for terminal machinery. This is important for the Danish use-cases as they seek to provide on-shore support to new vessels.

There is now not a common decision on which fuel type to follow for ships, as it is the case in car mobility with electric batteries. However, some indicators may be used to speculate on the path forward and associated technological gaps.

For combustion engines, only few solutions are market ready, for example the methanol combustion engines. Hence, bigger new-builds such as SSS vessels are often equipped with methanol-ready engines. However, there is nearly no hydrogen-ready or ammonia-ready combustion engines available in the market. The first prototypes are being developed by MAN and Wärtsilä. And according to DNV Maritime Forecast to 2050 [1], H_2 and NH_3 propulsion will be ready for commercial use by 2030.

As to the potential of fuel cells, there is a greater technological gap since they are even less mature than methanol and the H_2/NH_3 combustion concepts.

Battery electric propulsion are more mature. They are already in maritime use, mainly for car ferry application, or other small vessels. The technical gaps associated with this solution are varied, and greatly affect the feasibility for the Danish use-cases.

First, they require land-based charging infrastructure, which must, for the sake of sustainability, also be powered by renewable sources of energy. This is however only available in few ports due to its high cost, and thus needs to grow.

Second, a decision on whether to service battery swaps or whether to have a fixed rechargeable installation must be made. This has impact on overall efficiency, especially for SME port such as those studied in this case. Both systems have pros and cons [2]. Battery swap will be ideal in places where the electrical infrastructure is not in place to charge a ship in the time frame available due to loading/off loading, as the amount of power required to fast charge a ship is very large. If the electricity infrastructure is in place the issue might be a regulatory/safety issue, whether it is considered safe to work on a ship being charged?

Thirdly, the vessel-design (see above) needs to be adapted to this battery propulsion system. It is for example necessary to find a suitable space to place the battery. It can be installed as a fixed component of the ship, below the deck for stability reasons. Or it can be containerized, mainly on deck for easy exchange. Also, it can be designed as a fuel-dynamic optimized hull shape for low water resistance, and hence delivering savings of fuel (energy density of batteries is lower than for liquid fuels and hence, sailing range is limited or much capacity needs to be installed)

It is proposed in this report and in others of the AEGIS project which touch upon issues proper of port design, that the availability of these “green fuels” (methanol, hydrogen, ammonia) needs to be secured over a wide network of ports. This includes safe and approved bunkering solutions (not discussed here) and regulatory solutions (touched upon below, and in other AEGIS deliverables). It is also proposed that teething troubles of the new propulsion systems need to be overcome: most solutions are on the market for a very short time, if at all, and the weak points of each energy efficiency solutions need to be identified and resolved.

For **Port of Aalborg**, the technology that provide the needed infrastructure for either alternative fuels or electricity, as the need for massive delivery, puts current solutions and technology under pressure. Furthermore, the technology to scale solutions based on fuel cells is still in the very early stages.

5 Regulatory challenges in Danish case-studies

Aside from technological gaps identified in this report, Danish case-studies also evidence regulatory challenges. Regulatory challenges are here defined as potential or existing barriers to the implementation of the proposed logistics system, or the lack of a necessary incentive structure. This section of the report lays out those regulatory challenges that more closely link to the technological gaps described above, meaning that it focuses on challenges proper of small and medium enterprise ports and not so much on the shipping side. Further detail on all regulatory challenges, and potential solutions, is found in AEGIS Deliverable *D6.2 Legal and regulatory challenges for a new European waterborne transport system* [5].

Pursuant to its international obligations on environmental justice under the *UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention)*, in Denmark individual citizens or associations can contact local politicians to influence a decision to license construction projects with an environmental impact.

This means that the development of new marine and coastal infrastructure is, at least in part, of public interest, and thus subject to scrutiny before permits are granted. Ports are thus subject to a licensing process that includes public hearings within an environmental impact assessment setting. This is aimed at ensuring that ports comply with zoning laws, and also that the infrastructure is safe for purpose, e.g. that it can withstand wave overtopping.

Despite being evidence of democratic public participation, this procedure may hinder on the visions the port authority has for terminal expansion. In all major port projects, an environmental impact assessment is part of the licensing process, which incorporates this dimension of public participation and discussion on alternatives. In Denmark, where democratic participation and consensus building is so engrained and valued, the human-factor, more than the technical gaps, is the biggest challenge for the development of port infrastructure, and thus a major element to consider in the implementation of the AEGIS concept.

This notion that ports render a public service is still well reflected in the ownership structure which governs most SME ports in Denmark. Despite recent legal reforms aimed at privatizing bigger ports and making them more competitive at the global scale, many of the SME ports remain at least partly owned by the Municipality, with different levels of managerial independence. According to the Danish Port Act §9: municipal councillors representing the port's owner manage the port and elect a port board. There is thus an overarching political dimension in the port management because the priorities of the municipality, for example with respect to job creation, may interfere with a strictly economic approach from port managers who are not constrained legally by a board with such membership. The decisions that affect the port as a business are thus linked with the role of the port as an employer in the region, as well as a major factor for road, rail, and waterborne traffic. However, municipal planning authorities do not treat the port in a special way despite being linked to the municipal authority, and thus under the same political priorities. The municipal port is, formally at least, a private business who must conform to the same balance of interest as any other private entity, and politicians are advised by planning departments so as to determine whether an expansion is justified and within other urban development plans.

The decision to invest in new infrastructure must be funded to the highest extent by the port itself as a private operator. Modernisation of terminal facilities leased to private operators also follows market rules. With respect to this need to digitalize port handling and communications, as well as adapt docking infrastructure, there must be foreseeability of a return on investment. It is likely that port managers will not be proactive in this respect, but rather respond to the development in the shipping industry, or else depend on external financial support to take the risk in adapting infrastructure. Yet uncertainty for private operators as to what incentive structure is presents a very relevant challenge for SME ports. This situation may deter investors who wish to support the introduction of autonomous ships, and thus delay the digitalisation of port infrastructure that would necessarily follow. The same issue with public incentive uncertainty affects to a lesser extent the adaptations necessary to develop energy infrastructure for new ships. There are ongoing regulatory developments at the EU level to assist in this domain (for example the draft regulation on the deployment of alternative fuels infrastructure), but their implementation remains unknown.

Another challenge for the implementation of the AEGIS concept is the competition with the road sector, namely the rules on road-pricing. Motorways in Denmark are free for drivers of motorcycles, cars and other vehicles up to 12 tonnes. Tolls are paid only on The Great Belt – Storebælt and Øresund bridges between Sweden and Denmark. Charges for individual vehicles are based on the height, length and weight of the vehicle. Vehicles over 12 tonnes pay tolls via the electronic Eurovignette system. The amount of the fee depends on the emission class and the number of axles. The main competitor for waterborne transport is the road sector, which offers more flexibility and less costs. It is important to design new transport regulations that level the playing field for the long-haul between costs for trucks and for ships but that also support last mile road connections from ports, as that is a necessary element of the proposed AEGIS system.

With respect to safety and customs clearance in handling of exports, general points may be referred to from the AEGIS Deliverable *D2.3 Handling export, import and security constraints* [4] that also apply in the context of Denmark. Customs and cargo clearance involves the processes related to validating and approving the state of CCU and cargo passing through a port. Port authorities are required under the ISPS code to have a plan (PFSP) for each of its facilities. The PFSPs should be based upon assessments (PFSA) of each of the authority's facilities. The current lack of regulations may represent a risk of delay in custom clearance if more steps are necessary in the process.

Competition is also an important factor from a regulatory standpoint [3]. In Denmark, successive legal reforms have attempted to make ports more competitive. This was operated by shifting away from centralized coordination to a system in which control lies within local governmental units. This has allowed public ports to be developed commercially, namely by devolving (transferring) managerial responsibilities to private actors or lower tier public sector bodies, and to commercialize port service provision by transforming public to corporate port entities with more autonomy. It is proposed in the literature and validated by the ports who participated in this report, that the regulatory framework for ensuring competitiveness in ports should include mechanisms for monitoring and sanctioning anti-competitive actions.

Aside from these overarching issues of SME ports in Denmark as a use-case, some challenges specific of the case-study ports deserve separate attention.

Port of Aalborg is located in the Limfjord. The port authority perceives itself functionally as an inland port due to its geographical location. However, the official position of the Danish Maritime Authority, who is responsible for determining the legal nature of waters under Danish jurisdiction, is that no internal waters of Denmark fall under the category of "inland waterway". Thus, despite the intentions and ongoing negotiations at the EU level with a view of changing that regime, Port of Aalborg is, at the time of writing, a seaport as if it was on the outer coastline of the country. This legal definition has implications for the port, who must for example incur in all the costs associated with the maintenance of the port access channel. This challenge is likely to exist in other parts of the EU with indented coasts or fjords. Importantly, it is a decision of the coastal State to qualify whether the regime of inland waterways is to apply or not.

Also related with the specifics of the Limfjord, the lack of a clear set of rules on autonomous navigation may complicate the introduction of new vessels, especially when they leave the fjord into the Kattegat. A busy waterway, which includes many sailing vessels as well as a cruise terminal, makes it even more imperative to clarify which navigation rules apply. This is particularly linked to the technological gap of autonomous vessels requiring several configurations to the physical infrastructure of the port area/access (positioning system, sensors etc). Making the port of Aalborg accessible for autonomous vessels will require considerable investment in supporting technologies which, for a SME, may not be immediately available.

Another issue is the port's location in Northern Jutland, but unconnected to the TEN-T network. The creation of a short-sea route to Gothenburg, designed under the AEGIS project, offers an opportunity for **Port of Aalborg** to become part of a transnational logistics corridor, and benefit from the EU funding for infrastructure development. The legal regime of the Limfjord also has impact on private party stakeholders, as insurance rules may differ for navigation in inland waterways and in coastal waters. A predictable legal regime for navigation would also indirectly assist port industry stakeholders with access to public funds to redevelop terminals, namely funding from the EU aimed at supporting trans-European corridors.

At the local level, the port is already relatively far from the city centre, which facilitates the expansion from a planning perspective. However, the creation of energy production and supply infrastructure represents new challenges in the relationship of the port with local populations, which may require local legal developments as well.

Port of Vordingborg is already undergoing a massive expansion, and partly updating its berthing infrastructure with a multiplier for autonomous bulk carriers which, thanks to the support of the AEGIS system, may link to Poland and Germany, relying on inland waterways therein.

The port authority has entered in dialogues with Danish Transport, Construction and Housing authorities and local spatial planning authorities. This setting includes the construction of a new biofuel production plant and a methanol production plant. To handle this new fluid cargo types a multi-use pier is designed where also autonomous ships can be handles autonomously. The construction of quay infrastructure that can receive ships above 1350 nautical metric tons has to be assessed in an EIA process. This is not a regulatory challenge per se, but it bears evidence to the fact that the overarching social challenges mentioned above are at play. Local populations did demonstrate some hesitation to the port expansion project, and some concessions had to be made to accommodate some of the complaints. That notwithstanding, the human factor enriched the potential of the project and gave visibility to the port's plans, reinforcing its role within the local community.

6 Conclusion

This report on technology gaps and regulatory challenges in Danish case studies shows how port terminal infrastructure development plays a key role in the development of a new waterborne transport system for Europe. This report highlighted the impact of the AEGIS concept as experienced by Port of Aalborg and by Port of Vordingborg, as small and medium enterprise ports.

On the side of technological gaps, the report analysed digitalisation in communication and standardisation, cargo handling and infrastructural support for new autonomous vessels.

Communication in a logistic system is also not technologically limited, but limited by no agreed upon standards and systems, and intercompany politics. The ability to solve these issues require very broad consensus in the industry to obtain a wide adoption, so a small to medium sized port only have a limited ability to influence this, even though it would be for the benefit of all partners. Therefore, it will require the support of large national and international organisations, and perhaps governments.

There is a considerable gap between the capabilities of a SME port and the requirements to port infrastructure imposed by semi/fully automated vessels calling a port. Ports will need to be able to support vessels powered by alternate energy sources, either through appropriate bunkering solutions for combustion engines or land-based charging infrastructure for battery electric engines. However, if no common standard is adopted, it will be difficult for SME ports and their stakeholders to support all different types of green propulsion technologies.

The biggest technological gap in automation is the ability for a system to react constructively to unknown and uncontrolled objects i.e., manually controlled equipment vs. automated equipment. The technological gap is the ability of the algorithms that control the system, the ability to collect enough data about the environment and process this in a timely manner. The solution to this is a real scientific problem and is being addressed worldwide. Regarding the application of advanced technology in small to medium sized ports, the major issue is one of financial limitations, lack of knowledge and resources. To solve this, the technology needs to be adapted to a new context and standard solutions needs to be created, this can only happen if ports work together with the logistics industry, technology industry and if governmental institutions are willing to support this with innovation funds.

On the side of regulatory challenges, the main conclusion is that the ownership structure of Danish ports politicizes some of the decisions of the management, which may hinder on efficiency for the sake of social sustainability. The lack of a clear incentive structure to develop port infrastructure is another regulatory challenge, as it introduces lack of foreseeability for terminal operators. The same regulatory instability exists on the seaside, as autonomous ships are yet to be regulated at the national and international level, preventing their introduction in the market, and indirectly giving a signal to port authorities that technological gaps are not yet worth addressing. Finally, SME port authorities highlight the need for public funding to support the transition to alternative fuel production and distribution, as well as to support research and development of digitalisation and automation.

This report generally concludes that there are gaps and challenges that cannot be addressed at the local level alone. There are some recommendations that can however be made on how to develop the right public policy incentives to overcome technological gaps and regulatory challenges. These recommendations are to be made in a separate project deliverable.

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