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AEGIS: Advanced, efficient and green intermodal systems

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Abstract. The European maritime transport policy recognizes the importance of the waterborne transport systems as key elements for sustainable growth in Europe. A major goal is to transfer more than 50% of road transport to rail or waterways within 2050. However, waterways are at a disadvantage as they normally depend on transhipment and land transport to and from final destination. To meet this challenge we need a completely new approach to short sea and inland waterways shipping in Europe. This needs to include ships as well as ports and the digital information exchanges between them. A key element in this is automation of ships, ports and administrative tasks. The AEGIS project has been funded by the EU Commission to develop new knowledge and technology to address this challenge.

1. Introduction

The European maritime transport policy [1] recognizes the importance of the waterborne transport systems as key elements for sustainable growth in Europe: In EU, 30% of road freight over 300 km should shift to rail or waterborne transport by 2030, and more than 50 % by 2050. So far, this ambition has failed [2]: In the period 1995 to 2016, the share of road transport in intra-EU ton-km increased from 45% to 49%, whereas the share of short sea shipping (SSS) dropped from 33% to 32%. Inland had a decrease from 4.3% to 4.0%. Rail was reduced from 13.6% to 11.2%. Total freight, on the other hand, increased with 29% (ton-km).

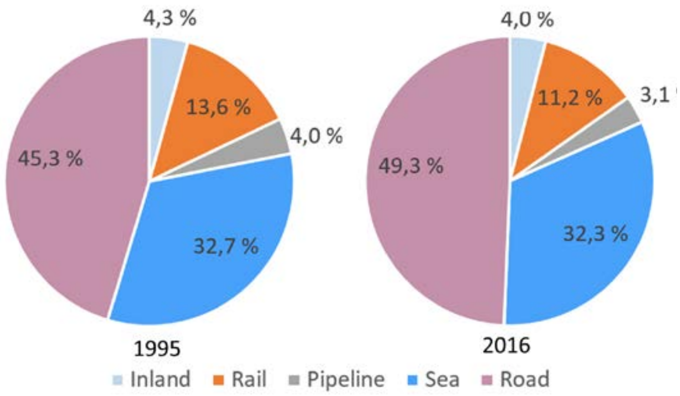

Figure 1: Share of transport (ton-km) in EU in 1995 and 2016 [3].

Waterborne transport has a great potential to reduce road congestion as well as pollution from the transport sector. When used correctly, it is very energy efficient, and new ship types can now operate with a combination of electric batteries, fuel cells and, when necessary, highly efficient combustion engines, e.g. powered by biogas or LNG. This can make them virtually emission, dust and noise free. However, ships have for a long time grown larger to reduce energy and operations cost. This restricts the terminals they can call on, increases costs and sizes of these terminals and reduces service flexibility by reducing frequency and fixing one speed for all cargo on one ship. Figure 2 summarizes the conclusions on why short sea waterborne transport today cannot compete efficiently with trucks, from the Auditor General in Norway [3]. Ship transport is generally cheaper and friendlier to the environment, but it loses on offered service quality. Fewer and larger ships are one part of this problem.

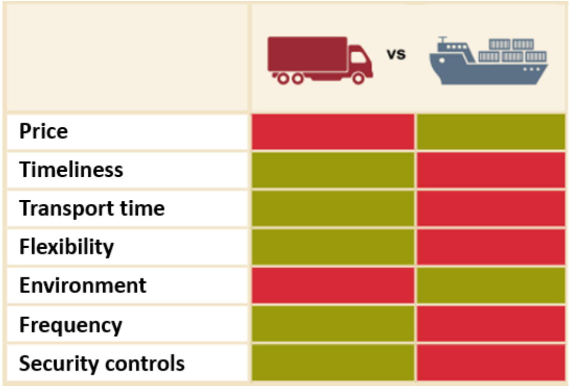

Figure 2: Why Norwegian short sea transport fails to compete with trucks [3].

AEGIS proposes a concept with more and smaller ships that can be used to increase frequency, differentiate speeds, reduce terminal costs and reduce time in port for the larger ships as they will not need to call smaller ports. Several smaller ships also increase reliability and resilience in the transport systems. Breakdown of one vessel has little impact on transport capacities. Automated cargo handling and standardized cargo units will further reduce problems and transhipment costs in ports and on ships. In addition, ships are most efficient when the cargo holds are full, so AEGIS also addresses how to attract new cargo, inbound as outbound, to waterborne transport. This requires new types of services, new business models, better logistics and more streamlined digital solutions.

This paper will first explain why autonomy and automation are critical factors in tomorrow's waterborne transport systems (section 2). It will then give an overview of the AEGIS use cases and explain how autonomy and automation is used in these (section 3). We will then briefly describe the main technologies and operations developed in the project (section 4), how we plan to measure economic and societal benefits (section 5), before we summarize and conclude in section 6.

2. Autonomy and automation are critical factors

2.1. Autonomy can defeat economy of scale

Autonomy can defeat economy of scale simply by reducing personal costs, increasing efficiency, resilience, speed and frequency and thus the competitiveness compared to other modes of transport. Small automated shuttles can operate more flexible and are much more economic because the crew costs will be much lower. By reducing the crew, the personnel and related auxiliary costs can be decreased significantly. That is very important due to the fact that crew-related expenses are approximately between 10 to 44 % of a ship owner’s operating expenditure. In addition to the described cost savings, autonomous ships offer additional benefits due to changes in ship design and possibilities for more efficient use of fuel. Data from the MUNIN projects predict savings of USD 7 Million over a 25-year period for an autonomous merchant ship, due to improved fuel consumption and reduced crew supplies and salaries [4].

It is expected that autonomy and automation in ships can improve safety, increase efficiency and relieve humans from unsafe and repetitive tasks. A study by the insurance company Allianz shows that between 75% and 96% of maritime accidents are caused by human errors. Autonomous ships also offer a possibility to solve the growing problem of lack of qualified personnel onboard. In addition new types of jobs will be created on land by automation such as high-skilled route operators, new kinds of pilots and technical maintenance. Some claim that autonomous hips are more likely to alter jobs rather than eliminate jobs. Combined with the creation of new types of jobs, a greater prosperity is expected [5].

2.2. Automated cargo handling and more standardized cargo units
Cargo handling is a considerable cost driver in transport. In waterborne logistics, transhipments are often needed, which dramatically increases the costs. Terminal handling charges (THC) are typically on the order of around EUR 100 per container [6]. Ship to ship transhipment is even more expensive and THC does not include storage beyond a few days and not transport to and from the terminal gate. For shorter distances transport, this is a significant addition to the basic freight rate. As an example, a typical short sea route on the Norwegian costs is estimated to cost about EUR 284 for 236 km by road while a small autonomous feeder ship can do it at a cost as low as EUR 133 (194 km by sea) [7]. However, adding two THC to the by sea cost will obviously create problems for the short sea alternative. In addition to that, one has to add the various port fees the ship may have to pay.

To be able to develop competitive waterborne door-to-door logistics systems, more automation in cargo handling is required. Ideally, all discharge and loading operations should be automated. This can be used to minimize labour costs which are one important factor. Operation around the clock will also reduce costs and increase service quality for the users but will also require full automation to avoid problems with working hours and additional shift costs.

In addition to personnel costs, capital costs will also be a significant factor in THC. Thus, it is necessary to find more reasonably priced equipment for automated cargo handling. One possibility for cost reduction is improved standardization of cargo units. This applies to physical sizes as well as to maximum weights. One element in this may be to provide automated handling only for lower weight, e.g. max 25 ton 20 feet containers and charge a higher price for manually handling larger containers with more powerful cranes. This could also provide positive feedback by defining a more competitive business model for using the standard container sizes wherever possible. This issue is a part of the investigations in the AEGIS project.

2.3. Automation of administrative processes
Physical automation is an important part of AEGIS, but cargo information management must also be automated. The World Bank [8] has analysed 190 countries and shows that in certain cases, the administrative paperwork related to export through seaports can incur direct costs of more than USD 2000 and delays of more than 14 days per container. In addition to import and export, come all logistic related information exchanges. This is particularly important for seamless integration with automated cargo handling and efficient transport to and from storage in the terminal.

Another central issue in this work is to enable the seamless transhipment between the larger international cargo ports with their ISPS (International Ship and Port Security code) compliant and customs guarded terminals, and smaller rural or urban terminals without such facilities. This means that customs clearance and ISPS security checks must be done in a way that do not hinder efficient movement of goods (see case A in section 3.1), but that it neither interferes with the correct tariff payment nor the assurance of the security and safety of the ship and port.

AEGIS will investigate these issues and develop new concepts for port community systems (PCS) in small ports. These systems will be based on full digitalization of all relevant information messages and an improved logistics management system. It will make use of new emerging message standards based on the new IMO Reference Data Model [9] and extensions to that, developed through the AEGIS project. Inherent in this concept is also use of electronic signatures to ensure sufficient trust in the information received to enable automated processing of it [10]. The public key infrastructure will not be developed in AEGIS but will be reused from related and ongoing projects.

3. Three AEGIS use cases

3.1. Case A: Short sea, urban and rural terminals in Norway
This case is led by North Sea Container Line in cooperation with the inter-municipal port of Trondheim. It covers transport from large ports in Europe (Rotterdam) to smaller destinations along a less populated coast of Europe (Norway). This line is a load-on, load-off (LOLO), and mainly container-based transport system. The idea in this use case is to use fewer terminals closer to the main fairway in Norway to

increase liner service speeds and then shuttle cargo to its final destination with small unmanned and preferably autonomous and electric vessels. Figure 3 shows the relevant coastal liner route.

Figure 3: Short sea connection to Norway

Figure 4 shows the regional distribution system. The new fairway terminal is indicated as the large grey circle at Sandstad. By loading and discharging at this terminal instead of going to the commonly used ports inside the fjord (red circles), the liner ship will save between 5 and 10 hours. The rest of the system consists of small international urban ports (red), non-international rural terminals (yellow) and one suggested new terminal with possibilities for transhipment to rail and air (green). The main route northward is indicated with a dashed line as it is not part of the use case today, but will be considered if the coastal route should be extended in that direction. The case will also look at local shuttling to the south-west of the new terminal. It is possible to operate in sheltered waters all the way down to the next major city, Kristiansund (orange terminals).

The use-case will also investigate the complete container transport pattern along the Norwegian coast to find possibilities for better cooperation between transporters to provide more user-centric services. At the time of writing, there are eight operators that provide different types of scheduled services (LOLO, RORO, Heavy lift) on the coast, but with different routes and schedules. A better coordination, possibly also with transhipments between main lines, could drastically improve the user's service quality on seaborne transport in this area.

The project will also investigate a future small and non-storage terminal in cities where cargo can be transferred directly to and from the shuttle without intermediate storage.

The key element in this case is the small container shuttles, perhaps as small as 10 to 20 TEU that provide low cost and flexible transport to rural as well as urban terminals. If roll-on/roll-off (RORO) solutions are used, one may significantly reduce the noise related to the cargo handling process. In rural areas load-on/load-off (LOLO) may be considered, but RORO may also here be a preferred solution as one may be able to manage with a relatively simple ramp into the water for the shuttle to dock to.

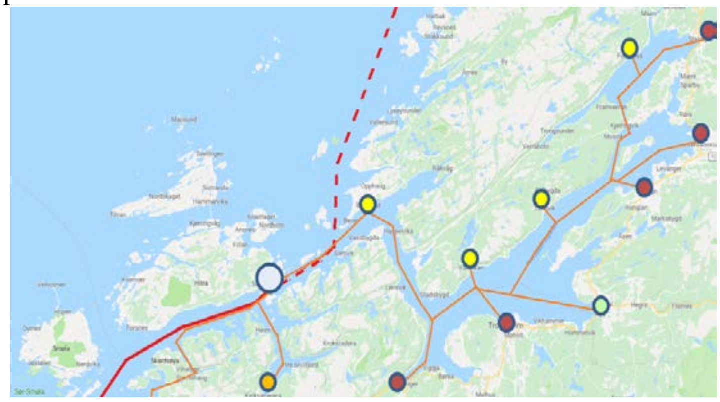

Figure 4: Local distribution in Trondheimsfjorden

3.2. Case B: Short sea and inland shipping interface in Belgium and Netherlands

This use-case is led by DFDS and covers the interface between DFDS' RORO transport from several North European ports to Rotterdam (Vlaardingen – with an existing link to Antwerp), Ghent and Zeebrugge and further on to smaller inland destinations in Flanders with waterway connections. The Rotterdam, Ghent and Zeebrugge roads are heavily congested, but it is currently difficult to get efficient handling of RORO type cargo on barges in the area. The idea is to bring cargo as close to the end destination as possible with small vessels with zero emission propulsion (battery, fuel cells, etc.) and in the future autonomous vessels. The main inland waterway connections between the case ports are shown in Figure 5.

Figure 5: The inland interface case

The use case will consider the use of existing RORO inland vessels, but these are few and difficult to get hold of. Thus, the use case will also need to look at alternative vessel designs to simplify transhipments and cargo handling in general. It may also be relevant to look at AGV use, but this will depend on the characteristics of the different ports. It is also interesting to look at delivery closer to final destination with RORO vessels.

The main emphasis will be on the logistics perspective. A detailed analysis of transport needs between different areas and cities will be carried out followed by an analysis of time lost in transhipment and administrative tasks and other obstacles (mapping according to economic and environmental criteria). AEGIS will develop solutions to minimize such obstacles and will involve vessel size and design, intelligent routing (emissions, time, cost, etc.), cargo handling (ramps for trailers/vehicles) and study potential impact on congestion and other relevant KPIs. The project will take into consideration vessel sizes in relation to the inland network with CEMT (Conference of European Ministers of Transport) categories, specifically to find optimal size to reach most destinations. An ICT solution will also be included, with a proof of concept being developed, in the form of a digital portal, to suggest to the customer and logistics companies the best way to transport the cargo to destination (time, environmental impact, cost, etc.).

3.3. Case C: Revitalizing regional ports and city centre terminals in Denmark

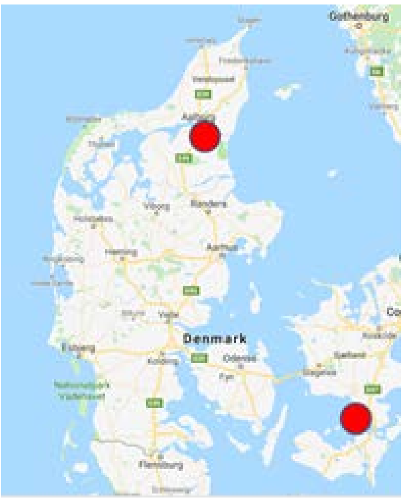

Figure 6: The regional port case

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. It will be using the two Danish ports Aalborg and Vordingborg as pilot sites. The case will estimate the potential gross volume that can be shifted from road transport to short-sea-shipping in Denmark and analyses of the price structure for transportation of different types of goods by both road transport and short-sea shipping and hereby unfold the potential for a shift towards short-sea-shipping in Denmark. Based on analyses the project will identify potentials and constraints for enhanced short sea transport through the two ports.

In order to examine the challenges and opportunities for increased short-sea shipments in the above mentioned and between neighbouring ports separate and confidential SWOT analyses in the respective ports, including an evaluation on how implementation of AEGIS concepts being may affect the shift towards waterborne transport solutions, and to what degree autonomous solutions may be implemented, including considering if the concept of satellite and autonomy ports within a group of ports can be used to promote fast ship handling and frequent calls. Explore the potential for integrating RORO calls to the existing route schedules giving priority to, but not limited to project partners.

Based on the concepts developed in AEGIS, a new terminal layout will be proposed for the Port of Vordingborg comprising: A multipurpose port area for multiple users on short lease and/or slot booking basis; A multipurpose storage and parking areas with multiple users on short lease and/or slot booking basis; A set-up for autonomous ship handling and self-services packages for both conventional and future autonomous ships. Whereas, for the Port of Aalborg it will be demonstrate how an Intermodal Automatic Green Terminal in medium ports like Aalborg can be designed and technologically equipped based on AEGIS concepts and solutions: A proposal will be made for a new fully automated terminal in the Port of Aalborg, with interface to handle intermodal transport - green rail and short-sea shipping covering RORO, containers and bulk operations.

4. Critical Technologies and Operations

The technical activities in AEGIS are concentrated around seven "Critical Technologies and Operations" (CTO) that are described in the following.

4.1. Logistics system redesign

Automated cargo handling, new terminal types and use of lightweight shuttle vessels to complement and increase overall speed of the main liner ships will enable significant changes in the logistics systems that can address several weak spots. It also makes it possible to stretch waterborne supply chains further into the coastal areas and inland waterways, further increasing flexibility and attract new customers to sea transport. Use of roll-on/roll-off (RORO) solutions combined with automated guided vehicles for the small shuttles can also reduce use and cost of transhipments, for certain cargos, both in cities and in urban areas. Improved standardization of unit cargo will be an important factor in efficient realization of several of these improvements. Also simplification of the digital systems handling safety and security as well as import and exports regulations is important. Finally, we will also need to ensure that the new system is as least as robust and resilient as the old. AEGIS will develop user-centric logistics systems with new components, better service quality and much lower impact on environment and society.

The logistic system redesign will be based on the three use-cases in AEGIS, all representing existing logistics chains operated by ship owners, terminal operators and ports in the consortium, and break them down into the various elements of the complete logistics chain. This will be the basis for further studies to identify bottlenecks and cost drivers by means of qualitative and quantitative methods (optimization and simulation). The outputs of this analysis will show where and how implementation of new business models, technology and systems can further improve the waterborne logistics systems to be a better alternative for a shift from road to sea.

4.2. New terminal concepts

Large terminals already have very high degrees of automation, as e.g. in Singapore and Rotterdam. There are also many publications on various optimization in such ports, e.g. on container storage, intra-port movements, ship arrival optimization etc. [11]. The target of AEGIS is smaller ports with a yearly capacity of typically in the range 20 000 to 100 000 TEU and its links to even smaller terminals with yearly capacities in the 100's of TEU. This means that similar concepts as is used in the large ports have to be scaled down and made applicable to smaller and more cost-sensitive environments.

The concept proposed by AEGIS in case A has similarities to "dry ports" [12], which is an inland intermodal terminal that acts as a centre for transfer of cargo to inland destinations. Here, the emphasis is on efficient truck or rail last mile transport, but AEGIS will extend this idea to the use of more remote seaport terminals, linked to automated water shuttles with a corresponding change in automated cargo handling systems, on the liner ships, in the new remote terminal, and on the shuttles. The concept will in a certain sense look like a large transhipment port like Singapore, where most of the cargo never leaves the port area, but on a much smaller scale. The urban and rural terminals will in most cases rely on self-loading and unloading shuttles, either using RORO or LOLO technology. Capacity for these terminals is on the order of some hundred to a few thousand TEU per year, and large investments in infrastructure cannot be made. The complete system must be digitally integrated to allow paperless transfer of cargo between the terminals.

Case B looks at better utilization of inland waterways (IWW) and in particular the possibility to scale down barge sizes to reach longer into the hinterland and provide more flexible services, similarly to what is proposed in case A. However, case B will mainly interface with an international RORO shipping line, which typically has a large part of their cargo on trailers. These are not normally shipped on IWW vessels and one of the challenges here is to find a good solution to how this type of cargo can be handled in the terminal and on the old and new IWW vessels.

Case C represents an upgrade of medium sized terminals in terms of increased physical and digital automation. The goal is to give better service to the immediate hinterland and to waterborne transport in general, as well as investigating how more of the current truck transport can be encouraged to use the sea. It is necessary to investigate how layout and design have an impact on the efficiency of terminal operations and thus also the efficiency of waterborne logistics systems. Qualitative and quantitative analyses based on simulation will be carried out. Automation in cargo handling is decisive for competitiveness. Concepts will be developed and validated by means of numeric simulation.

4.3. Automatic cargo handling
Cargo handling by state of the art handling systems is a considerable cost driver in waterborne transport. In waterborne logistics, transhipments are often needed, which dramatically increases the costs. THC is around EUR 100 per direction (section 2.2). To be able to develop competitive waterborne door-to-door logistics systems, more automation in cargo handling is required. This may also affect the need for novel and more standardized cargo units.

The new logistics system relies on more flexible exchanges between larger liner ships with LOLO or RORO capabilities, various forms of inland or short sea shuttles and last mile transport on land. This requires cargo transfers and AEGIS needs to automate all or most of these forms for cargo handling. This may require more standardized cargo units to reduce complexity of the equipment, both in terms of unit sizes and maximum weights. The trade-off between automated cargo handling equipment on ships and in terminals will also be investigated. This trade-off will obviously be different for RORO versus LOLO and in small versus large terminals.

New equipment may also include use of automated trucks for certain types of short distance transport from terminals to end users close to the terminals, e.g. if shuttles use RORO solutions. This is most relevant for the rural terminals, but could also be considered in urban areas.

In order to enable an automatic cargo handling of standardized cargo units in terminals and on-board innovative concepts will be developed and validated in simulators, and the impact of novel solutions will be benchmarked concerning profitability and externalities in cost benefit analysis and environment assessments. Therefore the necessary cargo handling requirements and terminal designs will be developed with AEGIS.

4.4. Autonomous shuttle
Small, lightweight and fully automatic cargo shuttles will be used to link waterborne transport from the large ports and terminals to rural or inner-city areas. As stated in Global Marine technology trends 2030 report [13], we need to extend the reach of waterborne further into the logistics chain, including new solutions for last mile transport.

Small autonomous shuttles can significantly reduce transit and port time for the larger ships on their main lines while providing efficient transport to and from end users located further from the main ports and terminals. This can also reduce infrastructure costs in smaller ports and terminals and allow new terminal concepts with less negative impacts on society.

To realize this ambition, the shuttles must also facilitate automatic berthing and cargo operations as well as shore support in the form of electricity or other necessary services. The logistics capabilities of the ship in the selected use cases are the main focus in AEGIS, e.g. related to door-to-door logistics represented by a set of use-cases; - smaller autonomous shuttle vessels from bigger ports along the main fairway to e.g. destinations inside fjords; - how autonomous vessels can be used for last mile deliveries into city centres to reduce road transport and also to reduce the need for storage capacities inside city centres; - how autonomous inland shuttles can be linked to bigger RORO-operations calling the Benelux area to be a competitive alternative to road transport in this region; - and finally how short distance last mile transport on land by means of AGVs can be used to “close the loop” towards the consignee.

The advances beyond state of art in AEGIS is to look at autonomous shuttle as an integral part of the transport system and optimize cargo handling on board with facilities in non-city terminals and at private and public quays. The main case is expected to be LOLO, but in Norway it is, e.g. possible to use car ferry ramps during night time for such vessels, if they carry RORO cargo. Also, the RORO liner case will have to consider the use of RORO solutions, also on the small shuttles.

4.5. Digital connectivity
An addition to physical hindrances, international ship traffic and local port logistics are also hindered by digital barriers. A lack of digitalization and automation of the clearance and planning processes between ship, port, logistics operators and authorities adds significant to the cost of transhipment. In the digital connectivity field, some improvements have been made, but these must be leveraged by supporting new digital cargo and ship documents as well as automation of work processes in shipping

and within authorities. Digital connectivity to ships is still much inferior to what land-based transport has. This applies to communication systems, protocols and to integrated management tools.

An important part of this research is communication efficiency and cyber security. The project will make an inventory of the most relevant ship to shore communication systems and their characteristics [14], [15]. The characteristics is mainly the quality of service (e.g. bandwidth, reliability), but special emphasis will be put on properties related to cyber security, e.g. how easy is it to jam or spoof messages when using the communication system. The latter will be used in a criticality analysis of the communication between the different ship types, particularly the autonomous small shuttles, and relevant shore or waterborne assets.

Another important area for research is digital interoperability. Based on work already done in the IMO's Facilitation committee (FAL) [9] and in ISO 28005 [16], the project will extend the scope of IMO reference data model and the implementation of it in the ISO 28005 standard. This is partly a traditional data modelling exercise, but a challenge is that the developments need to be aligned with international work undertaken in various organizations, such as IMO, ISO and IALA [17].

The third activity is an improved port community system (PCS) for small ports. PCS is common in large ports and is used to automate interactions between all commercial parties in the port as well as with authorities' systems [18]. The challenge is to develop a new type of PCS that fits smaller ports, and which can be operated by the port itself. This PCS should also make more extensive use of AIS signals from approaching ships to automate logistics and planning processes.

4.6. Policy measures
The concept designed by AEGIS will require high initial investments and new business models. Deploying this concept without considering the pre-existing socioeconomic scenario may result in less efficiency being brought to the logistics chain rather than more, or to the concept being altogether disregarded by market actors. Policy support will provide an important level of legal certainty and predictability for the necessary investments and business model readjustments to be made.

The transition to short-sea shipping automation bears an impact at various levels of the logistics chain. Automated vessels will at first coexist with unmanned and manned vessels, as well as with non-automated terminals. An overall efficiency gain in that chain produces externalities, namely those associated with the substitution of seafarers with programmers and remote pilots. This transition requires that actors indirectly involved in waterway and coastal navigation are aware of and educated on shipping automation. A preliminary research task involves assessing who was involved in the process so far and what other actors may have a role to play in the governance arrangement renegotiation.

The political ambition to ensure a transition towards short-sea shipping will possibly require public authorities to intervene at the national level and at the international level (EU/IMO). This intervention translates into two types of approaches: the removal of existing obstacles and the creation of new incentives. The need to exempt, either temporarily or permanently, automated vessel operators and terminal handlers from fiscal and administrative burdens applicable to their competitors requires sound evidence. Such evidence can for example be determined by reference to qualitative KPI (section 5) and quantitative assessments of use cases specific issues. The policy design may also consist of new incentives designed specifically for the AEGIS concept. A positive discrimination between alternative but equally lawful transportation solutions may however be considered an anticompetitive behaviour. Fine-tuning the possible nudges to ensure the AEGIS concept remains attractive all the while not impairing fair competition is a key activity in this regard. For that purpose, it is necessary to establish a dialogue between all the parties present in the AEGIS consortium, together with external stakeholders and policymakers, on perceived hurdles and alternative policy solutions.

The successful delivery of policy support to the implementation of the AEGIS concept depends on the willingness of all the actors consulted to participate and contribute to producing the knowledge associated with the governance of AEGIS concept, and to reflect on it. The outcome will expectedly be a revision of existing norms governing short-sea shipping in a way that accommodates the new AEGIS concept and steers all actors participating in the logistics chain towards shifting freight from land to sea.

4.7. Safety, security and resilience

The whole idea of AEGIS is to develop more integrated transport systems, both physically and digitally. On one hand, this creates new threats as the system may become more integrated and reliant on individual components, but it also creates new possibilities in that the system is more diverse, has smaller units and may be easier reconfigured in case of major problems or attacks. AEGIS aims both to reduce threats to individual components and increase resilience by offering more diversity and easier reconfiguration. Thus, a focus both on the possibilities for increased resilience as well as the more complex threat picture is an important part of AEGIS.

Safety, security and resilience are not in a separate work item in AEGIS. It is an embedded component of most activities. This reflects the ubiquitous nature of these factors. Research in AEGIS on safety, security and resilience will mostly follow the lines of previous research, but more focused on the cargo handling, smaller last mile vessels and how these are integrated in the whole transport system. A particularly important issue is establishment of digital trust in digitalized and automated work processes. This requires electronic signatures, integrity checks and non-repudiation of electronic exchanges. This is an issue similar to cyber security, but with implications much beyond that. AEGIS will also support the development of a related work item in the IMO Facilitation Committee where ISO have provided some suggestions for how this can be implemented [19].

Resilience is a special theme in the logistics systems redesign where it is linked to the implementation of the more distributed and automated transport system. In general, one may expect that more complex technology and higher reliance on wireless communication reduces resilience, but a system with several smaller shuttle vessels may also turn out to be more robust against disruptions. We will follow traditional research approaches but will need new metrics on the robustness of the automated features of the transport system. Also, the risk of cyber security attacks needs to be included in the analysis.

Safety of autonomous ships is a relatively well published area although one cannot say that any of the theories have been verified or tried. However, much research has been done and AEGIS will make use of already published results. One area of special interest is the danger of "stowaways" on small cargo shuttles. When operating close to land without crew on board, it can be an interesting target for youths that are out in small boats in the area the shuttles operates. We will also need to consider similar "attacks" where the vessel is forced off-course by deliberately running small boats on collision course at its intended route.

5. Measuring the economic and societal effects

Whatever solutions are contemplated in AEGIS, it is imperative to assess them in a holistic fashion, so as to capture the effects of all conceivable cross-linkages and interdependencies and hopefully obtain what we call "win-win" solutions. The objective here is to perform a comprehensive Cost Benefit Analysis and environmental assessment including also social aspects, as is indicatively depicted in the figure in the context of sustainable maritime transport. One can see from Figure 7 that a great number of factors can be at play. In the context of the AEGIS project, the distinct perspective is the interaction among the *environmental,* the *economic* and the *social* dimensions [20]. Achieving a balance among these is important as it would make no sense for the vessels, the shipping operations or the maritime supply chain systems under study in AEGIS to be performing well economically but be non-viable from an environmental or social perspective. So, it is imperative that all trade-offs be evaluated and achieving what we call "win-win" solutions is an indispensable prerequisite. The study on these impacts will link to the case studies examined in AEGIS and also to several other activities of the project.

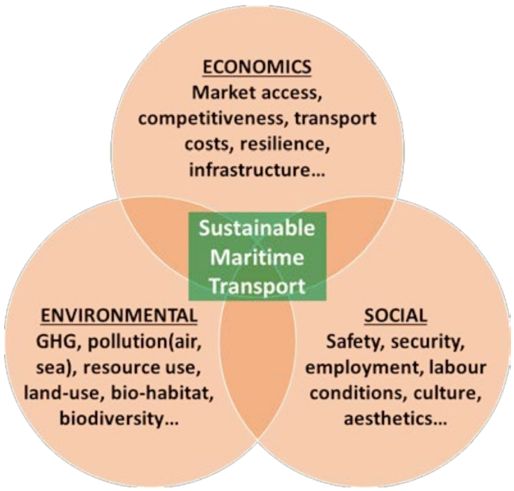

Figure 7: Sustainable Maritime Transport, based on [20].

To perform this analysis, our work will consist of the following tasks:

Identification of KPIs*:* This task will develop a comprehensive set of Key Performance Indicators (KPIs). KPIs represent the criteria under which the set of solutions developed under AEGIS will be evaluated. They include criteria grouped under the following classes (refer also to figure above):

- Economic KPIs including cost, profit, logistical efficiency and others
- Environmental KPIs including GHG and other emissions
- Social KPIs including safety, security, externalities and others.

Economic analysis: This task will evaluate the solutions developed under AEGIS in terms of the economic KPIs developed as per above. The full range of AEGIS case studies will be investigated. Economic data will be collected for all these case studies including their variants.

Environmental analysis: Similar to the economic analysis task, this task will evaluate the solutions developed under AEGIS in terms of the environmental KPIs identified in the first task.

Social analysis: Also running in parallel to the previous two tasks, this task will evaluate the solutions developed under AEGIS in terms of the social KPIs,

Identification of win-win solutions. For each of the user case studies studied in the AEGIS project, and the analyses performed as per above, this task will identify "win-win" solutions, as well as the conditions for these solutions to be realized. A "win-win" solution is defined in terms of being acceptable in terms of most of the KPIs that have been identified as important. These solutions will also be compared to the solutions in common use today.

6. Conclusions

The central objective of AEGIS is to develop a new waterborne transport system for Europe that leverages the benefits of ships and barges while overcoming the conventional problems like dependence on large terminals, high transhipment costs, low speed and frequency and low automation in information processing.

To achieve this objective, AEGIS will leverage a multidisciplinary team to integrate new innovations from the area of Connected and Automated Transport (CAT), including more diverse sizes of ships and more flexible ship systems, automated cargo handling, ports and short sea shuttles, standardized cargo units and new digital technologies to design the next generation sustainable and highly competitive waterborne transport system in Europe.

AEGIS will also integrate technological advances on ship and cargo systems, development of improved digital connectivity and automation, and specific logistics use cases with studies on how this can be realized in terms of necessary policy measures and how the effects can be measured by economical, environmental and societal key performance indicators.

Many of the activities in AEGIS will be of a pre-competitive nature and the project plan includes provisions for extensive publication both of project reports and public papers. These will be made available on the project web site [21] as well as in other channels.

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