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Cyril Alias, Helmut Broß, Jonas zum Felde, and Dieter Gründer

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Enabling Decentralized Transshipment in Waterborne Container Transportation

Cyril Alias[1], Helmut Broß[1], Jonas zum Felde[1] and Dieter Gründer[1]

1 – DST – Development Centre for Ship Technology and Transport Systems

Purpose: *This research aims at developing a comprehensive transshipment solution leading to additional opportunities of transshipment from small inland vessels throughout the West German canal network and, thereby, extending the existing capacities consisting of container bridges and reach stackers.*

Methodology: *The cargo flows between the major western seaports in Belgium and the Netherlands and relevant hinterland destinations in the West German canal network were analyzed and complemented by spatial analyses of potential transshipment points and their respective facilities. Based on this, the design process of a mobile transshipment facility has been initiated in order to realize its integration into the decentralized waterborne container transportation network.*

Findings: *On the basis of the framework conditions, an effective transshipment solution in the form of a mobile onboard crane has been developed. Performance data of both the small inland vessels and the newly developed cranes have been generated so that a comparison of the existing alternatives and a performance evaluation have been made possible.*

Originality: *Equipped with the mobile onboard crane, the small inland vessels operating in the designated area are no longer dependent on the transshipment facilities ashore. Comparable projects have either focused on the transport network or the onboard crane exclusively.*

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1 Introduction

Throughout Europe, including Germany at its heart, traffic has been growing over the past decades so strongly and steadily that capacity limitation hinders further growth at many points now. With the prospect of further economic growth, further aggravation of the problem is expected. Parallelly, the existing infrastructure has begun to show undeniable signs of wear and tear and partly even decay. This is particularly true for road transport but applies to rail transport as well. Less availability of the transport infrastructure and its ever increasing use are conflicting trends leading to a deadlock in the foreseeable future.

Furthermore, the transport sector has seen the freight structure change effect, a deep transformation of the composition of the transport volume in the development process of the national economies. As part of that development process, the production structure is converted from bulk goods into high-quality piece goods. Thereby, different types of shipments are required which again reflects in gradual modal shift from some transport to certain other ones. Along with the freight structure change effect come more demanding service level agreements between consignors and logistics service providers and the need of integration of all participating actors and stakeholders across company or even national boundaries using all opportunities from modern information and communication technologies.

In addition, the macrosocial trend of increased environmental awareness and vivid climate protection affects the transport and logistics domain by a clear and ambitious agenda of adequate measures, including the reduction of greenhouse gas emissions in each transport mode by 2035 and 2050, respectively, the adequate and consistent pricing of CO2 as a means to take external effects into consideration, the promotion of alternative (emission-free or at least low-emission) fuels, and a modal shift towards the more sustainable transport modes. On a political level, the sector pursues the vision of zero-emission transport by 2050.

Inland waterway transportation appears as a possible solution as it offers significant untapped potential in various regions in Europe and around the globe while featuring high reliability, cost efficiency, and energy efficiency (Frémont, Franc and Slack, 2009;

Janjevic and Ndiaye, 2014; van Duin, Kortmann and van den Boogaard, 2014; van Hassel, 2015; Stein, et al., 2016). Today, the share of IWT amounted to mere 6.1 percent of the total inland freight transport in 2019 while road freight transport accounted for 76.3 percent and rail transport for 17.6 percent (Eurostat, 2021). Traditionally, inland waterway transportation predominantly serves bulk and liquid bulk transportation whereas only ten percent of all cargo goods transported by inland barges was containerized in 2019 with 69 percent loaded and 31 percent empty containers (Eurostat, 2020). In combination with the above-mentioned freight structure effect, the barge owners and fleet managers need to watch out for new business segments to serve and, thereby, to secure an income. Hence, expanding efforts in the container transportation business appears obvious.

The huge potential of waterborne transportation offers a remedy to the above-mentioned threat of a traffic deadlock and, thus, deserves particular attention. Due to the low density of inland waterway transport network, various combinations with other transport modes like road and rail in the long-haul routes and cargo-bikes and electric vans in urban distribution concepts appear promising but may require one (or even more) additional transshipment operation. A series of prototypical implementations and use cases of multimodal transport concepts including inland vessels throughout Europe and elsewhere illustrate the technical feasibility of such solution concepts and their economic viability, at least under specific conditions.

This work presents the case of a decentralized waterborne hinterland container transportation service in the West German canal network and its transshipment concept. The precise task was the enhancement of transshipment capacity in the network. Coming from the starting condition in the considered geographic area, several approaches to detect and select appropriate and promising transshipment points on a concept level and integrate them into the overarching logistics concept in a technical perspective are presented. While some transshipment points in the network are already equipped with container handling infrastructure, such as container bridges and reach stackers, others require minor investment into such classical handling equipment or innovative solutions, such a mobile onboard crane.

2 A Decentralized Waterborne Hinterland Container Transportation Service

The goal of the underlying research initiative is to foster modal shift towards IWT by designing and developing a container transportation service in the German federal state of North Rhine-Westphalia (NRW). This service is to operate in the West German canal network, call at numerous inland ports and transshipment points in the considered area, and make use of dedicated small inland vessels. Slightly deviating from the official definition of an inland port, a simple transshipment location deems sufficient for the concept (Rodrigue, 2020, pp. 434–435). Furthermore, it is to exploit various transshipment solutions and feature a full integration into existing transport service concepts and familiar transport planning and monitoring systems. From the perspective of economic geography, the major focus of the service lies in moving import and export containers between the Western North Sea ports of Zeebrugge, Antwerp (both Belgium), Rotterdam, and Amsterdam (both Netherlands) and some of the economic hubs of NRW.

When looking at a typical transport chain in an import case, the first leg between the consignor's premises and the nearest seaport takes place overseas and is mostly likely carried out via truck. Followingly, the cargo is transshipped onto an ocean carrier and hauled to a seaport in Europe from where the shipment is either directly hauled to the consignee via truck or sent to an inland port via inland waterway transportation. In the latter case, the transshipment ashore marks the begin of the final leg between the inland port in the vicinity of the consignee and his factory, warehouse, or distribution center. Analogously, the export case works vice versa. In the German federal state of NRW, this results in a clear focus on the river Rhine and the adjacent inland ports like Duisburg, Düsseldorf-Neuss, Cologne, and Wesel, some of them the largest of the state, the Federal Republic of Germany, and even entire Europe (Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen, 2016). Typically, these inland ports are served by large CEMT class VI inland vessels, a waterway classification specified by the European Conference of Ministers of Transport, with a carrying capacity of up to 500 Twenty-foot Equivalent Units (TEU) and 5,500 tons, respectively (Lucke, et al., 2012, p. 353). With respect to container transportation, a significant increase is expected on the route between NRW and the Western North Sea ports in the coming decade whereas bulk cargo haulage on the Rhine is expected to decline significantly. The volume of container shipments between the considered geographic region and the Western seaports accounted for approximately 400,000 TEU in 2010 and is expected to increase by approximately 300,000 TEU by 2030, of which the half is expected to be transported on inland waterways in the main leg (Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen, 2014). As a contrast to that, the West German canal network has remained underutilized so far with a less optimistic outlook until 2030 (Information und Technik Nordrhein-Westfalen, Statistisches Landesamt, 2020).

A decentralized waterborne container service could be an economically sound and environmentally friendly alternative to existing transport services for the task of container shipping between NRW and the Western seaports. The entire concept of the decentralized waterborne hinterland container transportation service consists of four sub-concepts, i.e., a logistics concept, an integration concept, a vehicle concept with a series of dedicated small inland vessels, and a transshipment concept. All four sub-concepts are presented briefly. Conceptual details of the designed decentralized waterborne hinterland container transportation service can be found in a dedicated research article from which some major content elements are used for illustration hereafter (Alias, et al., 2021).

2.1 Logistics Concept

The logistics concept consists of a supply and a demand side. The supply side represents the service offer to be designed in terms of shipping locations, transport capacities, service frequency, and attainable service level whereas the demand side refers to the eligible cargo volumes.

The logistics concept of the decentralized waterborne hinterland container transportation service includes the waterways of the West German canal network and a multitude of transshipment points in the geographic area form its backbone (see Figure 1). The frequented waterways include the Datteln-Hamm Canal, the Dortmund-Ems Canal, the Mittelland Canal, the Rhine-Herne Canal, the Wesel-Datteln Canal, the navigable part of the river Ruhr, and a small portion of the river Weser – and feature a total length of approximately 400 kilometers on the waterway. The covered geographic area extends from Duisburg and Wesel on the Rhine in the west, the Mittelland Canal with its direct vicinity in the north, the river Weser in the east, and – loosely – the river Ruhr in the south. Large cities like Dortmund, Essen, Duisburg, Bochum, Bielefeld, Münster and Osnabrück belong to the covered area as well as the Ruhr area, Münster region, Eastern Westphalia, and the adjoining Lower Saxony (Osnabrück region). Larger inland ports, such as Dortmund, Osnabrück, Hamm, Lünen, and Minden, are situated in the covered area. Further appropriate transshipment points have been sought when appearing promising (Alias, et al., 2020a). Details and results of this work are presented in a subsequent chapter of this article.

An optimal logistics system is characterized by high service level, low cost, high efficiency, low stock levels, best availability, and high transparency. Opening up all potential ports may lead to maximal service levels – but deteriorate the pertaining costs possibly and ultimately result in unprofitability. Thus, a thorough selection of the ports and transshipment locations from the pool of possible locations is a goal of the scientific examination. In the later stages of the research work, the number of transshipment points will be modified in both directions - in reaction to the results of each configuration.

As to the demand side, the existing cargo generated in each municipality of the considered area has been examined and checked for eligibility for westbound haulage. The eligible cargo volumes need to be assigned to the potential inland ports and transshipment locations in order to design the resulting transport chains. Details of the assignment of the cargo volumes to each of the municipalities can be found in a separate research article (Alias, et al., 2020b). In the end, precise values for the cargo volumes at each considered inland port and transshipment location are ready for further processing.

With respect to the related transportation costs, three design variants of the transport chain need to be compared with each other (Alias, et al., 2021). The cost analysis encompasses the direct truck haulage between the seaport and the consignee (and the consignor and the seaport, respectively), the intermodal transport with an IWT leg from the seaport to the inland port followed by a truck transport to the consignee, and the new variant which replaces large parts of the truck leg with a combination of a new IWT leg between the large inland port and the small transshipment location in the vicinity of the consignee and a much shorter truck leg from that transshipment location to the final destination at the consignee's premises. So, the new variant exhibits an additional transshipment with related costs and an elevated journey time due to its higher share of waterway transport with a speed ranging between nine and fifteen kilometers per hour.

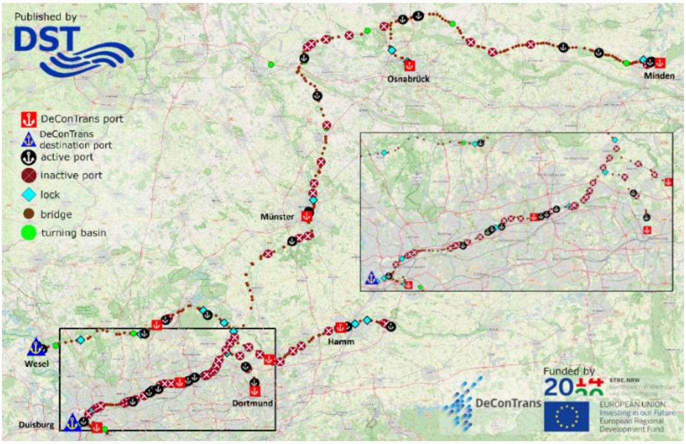

Figure 1: Map of the hinterland container transportation service network

2.2 Integration Concept

The integration concept refers to the integration of the new service concept into existing transport service concepts and the exploitation of the opportunities offered by today's information and communication (ICT) landscape in transportation management.

As to the integration into existing transport chains, the new service around the small inland vessels may cover different legs. In an import use case example of goods being hauled from Rotterdam, the Netherlands, to Bielefeld, Germany, the base case of a IWT leg to Duisburg, Germany, and a truck leg to Bielefeld, three different integration scenarios have been defined: in the first scenario, a small inland vessel as part of the new decentralized waterborne hinterland container transportation service would take over the containers in Duisburg and haul them through the waterways of the West German canal network to Minden, Germany. From there, a much shorter on-carriage is carried out by truck or rail. In the second scenario, several small inland vessels from the new service receive their respective cargo in the western North Sea ports. Subsequently, the vessels are coupled as a pushed convoy, and pushed to Duisburg by a push boat. There, the convoy is decomposed, and each vessel starts the journey to its respective regional destination port, i.e., Minden. From there, the containers are then transported to Bielefeld. The third scenario omits the intermediate stops and allows a direct trip from Rotterdam to Minden with the small inland vessel before the final leg is taken over by rail or truck. All three scenarios will be examined in detail with respect to service level, cost level, profitability, and ecological effects at a later stage of the research.

For the integration into the existing ICT system landscape, an exemplary use case based on the first integration scenario, i.e., with a new IWT leg between Duisburg and a port in the West German canal network, has been translated into a diagram of the planning and execution processes with multiple parties involved (Alias, et al., 2021). The interactions between the different parties have then been showcased by means of classic booking and planning tools and routines in a typical use case example.

During the planning and booking processes, the usual sequence of request for information (RFI), request for proposal (RFP), and request for quotation (RFQ) is pursued for each transport leg. After completion of the booking, the related transport details including the conditions and requirements to take into account during execution of the respective transport leg are passed on to the logistics service provider. On arriving at the destination address, both the shipment and documents are handed over to the subsequent party, possibly with the help of intermediaries. After finishing each leg, the party responsible for the transport planning and execution, especially vis-à-vis the consignor, is informed and kept up to date. By this, the ease and comfort of using the new service can be proved. In the execution process, the various steps, especially during cargo transfer, can be monitored with solutions already existing and available on the market. In essence, there is hardly any additional ICT system needed to make the decentralized waterborne hinterland container transportation service work and go live (Blic, et al., 2018). Thereby, IWT can be perceived as a ‘normal’ transport mode without any elevated background or specialist knowledge required. It can be expected that the ease of operation promotes the acceptance and prevalence of IWT in large transport chains of global value-creation networks.

2.3 Vessel Concept

The vessel concept mainly focuses on small inland vessels appropriate for the predominant use in the West German canal network, i.e., several vessels of CEMT class II to IV with a length of 50 to 80 meters and a width of 6.8 to 9.5 meters as well as one larger vessel of CEMT class V with 95 meters length and 9.5 meters width (Alias, et al., 2021). In order to take the expected variances in freight volumes into account, a series of different vessel sizes have been determined before conceptualizing, designing, and examining the respective inland vessels computationally - and testing them in a towing tank from a hydrodynamic perspective. In total, seven different types of vessels have been determined with a load capacity between eight and 30 TEU, and 36 TEU, respectively. Due to restrictions related to the clearance gauge, the dimensions of the vessel are limited: the width and the length of the vessel are supposed to be suitable for the lock chambers of the considered geographic area, the height is confined to the clearance height of the bridges, and the draft of the vessel is limited by the depth of the waterways (Lucke, et al., 2012, p. 338). Consequently, the vessels are designed as one-layer container transportation services – with two exceptions for the analysis of a potential future scenario of bridges lifted by several decimeters and, thereby, allowing two-layer container transportation in the long run.

As to the model tests in the towing tank in Duisburg, Germany, the different small inland vessel models have been tested for an operation on the Rhine (with a rectangular profile of the waterway) as well as on the canal network (with rectangular trapezoid profile). Precisely, drag and propulsion tests with model ships belonged to the portfolio as much as propulsion tests in the canal and the collection of rope forces and ramp forces measured during the scenario of conventional inland vessels passing. The tested models of inland vessels have changed in size and draft, respectively. The shaft power required to operate the inland vessels on the Rhine accounts for 72 to 189 kW with an average speed of 13 kilometers per hour. In the canal network, the shaft power for inland vessels operating at an average speed of 12 kilometers per hour amount to 43 to 196 kW.

Regarding the operation modes, typical modes applicable to the Rhine and to the West German canal network are to be applied. On the Rhine, the modes A1 (max. 14 hours with two persons), A2 (max. 16 hours with three persons), and B (max. 24 hours with four persons) are allowed (CESNI, 2017). On the contrary, the operation modes on the canal network include A (max. 16 hours with two persons), B (max. 18 hours with three persons), C (max. 20 hours with three to four persons), and D (max. 24 hours with four to five persons) (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, 2018). However, the operation modes applicable to the Rhine can also be applied on the canal network – not vice versa. When looking into the future, several potential operation modes like reduced crew with only one person being operative 24 hours and the cases of remotely operated inland vessels as well as fully unmanned autonomous inland vessels are of interest for the remaining research as well.

3 Transshipment Concept

The transshipment concept foots on two threads: on the one hand, the eligible inland ports and transshipment locations need to be detected in order to select the most promising ones among them. On the other hand, additional solutions are sought as existing container handling infrastructure is assumed to be a precondition for the well-functioning of the entire decentralized waterborne hinterland container transportation service . That means in effect that each transshipment location with container bridges, slewing cranes, and mobile reach stackers is eligible to become part of the network and, thus, be served by the new service. The pertinent literature gives a good overview of existing options of transshipment equipment at different ports (Studiengesellschaft für den kombinierten Verkehr e.V., 2002; 2017; POM Oost-Vlaanderen, 2019).

However, such investment in port superstructure, i.e., mobile equipment such as cranes and reach stackers, fixed equipment, and surface arrangements located in a port in order to provide transport-related port services, can be huge and lead to a too long amortization time (ATF savjetovanje d.o.o., 2017). This again may result in a reluctance among many smaller ports and municipalities to participate in the new service. Since the new service is designed to be decentralized in nature and to avoid large influx to an inland hub on the congested road, smaller transshipment locations with lower container volumes are to be included. The (possibly only initially) low container volumes at such locations, however, will impede a quick amortization of huge capital expenditures which can amount to up to several million euros (POM Oost-Vlaanderen, 2019). Consequently, innovative solutions with lower capital intensity with respect to capital expenditures and operating expenditures are called upon to step forward. Such a solution needs to connect smaller, more remote inland ports to the new service and be cost-efficient in order to remain attractive for them.

The following sub-chapters describe the process of gradually extending the operation area of the decentralized waterborne container transport service by adding further inland ports and transshipment locations to the network and, thus, carefully expanding the solution space. In addition, the new transshipment concept, a mobile onboard crane resting on the sideboards of the new small inland vessel and being used after the berthing of the vessel at the respective port, is presented. Such a stand-alone solution helps to connect remote locations with little freight volumes to the new service without significant initial investment costs.

3.1 Starting Condition: Major Container Terminals

The starting point of our investigation was the map of existing inland ports in the state, esp. those of larger size and offering container handling services. Such larger container terminals feature the advantage of sufficient provision of transport connections, existing infrastructure and superstructure, and a solid customer base. When looking at the considered geographic area, the major inland ports with container terminals are situated in the cities of Dortmund and Minden (see Figure2). When lifting the prerequisite of existing container handling business, a few additional locations like Hamm, Lünen, Gelsenkirchen, and Osnabrück come into play.

In the initial stage, the two container terminals in Minden and Dortmund have been used as transshipment locations in the hinterland. When defining the catchment area of both locations, a sufficiently large share of the total route from the respective origin port to either destination port should be covered by IWT. As an example, the so-called relevant periphery of each transshipment location can be defined on the basis of half of its waterway distance to the nearest destination port at the Rhine, i.e., Duisburg and Wesel. Thereby, lengthy detours can be avoided, and the attractiveness of the new service safeguarded. On applying the rule, only two regions scattered across the federal state and not even connected to each other represent the catchment area of the two selected transshipment locations and, thus, the operation area of the decentralized waterborne container transportation network.

Adding the major inland ports and transshipment locations of the considered geographic area helps to expand the operation area of the new service. In total, nine transshipment locations for the decentralized waterborne hinterland container transportation service have been selected based on their size, their existing container handling business and devices, and their regional balance (Alias, et al., 2020a). The latter encompasses the inclusion of all waterways served by the new service, a balance between the various regions in the designated operation area, and a connection to the economic hubs in the considered area. However, white spots on the map remain a challenge leading to partly isolated operation areas as an interim result.

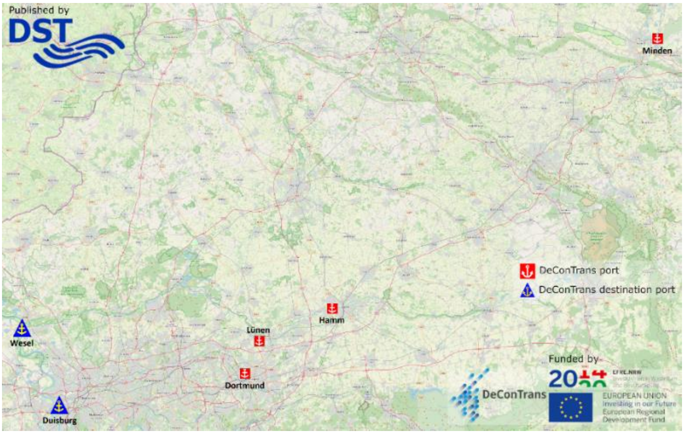

Figure 2: Map of the major inland ports and transshipment areas

As part of the search for further eligible transshipment locations, the geographic area of interest needs to be scanned for potential locations. Apart from using existing literature, reference projects, maps, and databases, external experts with profound knowledge have been consulted as part of this task in order to conduct semi-structured expert interviews. The experts have selected from shipping lines, third-party logistics service providers, consignors and port authorities but also state ministries, chambers of industry and commerce, and local municipalities. Derived from the expert interviews as well as the analysis of other publicly available information is a list of initial criteria to be considered when looking for additional transshipment locations. After a careful check whether any of the collected locations can be omitted with good reason, the residual set of criteria is the used as the final set and applied on the considered geographic area in the West German canal network with its three rivers and five canals (Alias, et al., 2021).

3.2 Enhancement: Active Ports

The first enhancement level was the consideration of all active ports in the considered geographic area, regardless of their current business focus. The reason behind this decision was the comparatively easy transformation of inland ports from dry bulk to containerized cargo. The required spaces and infrastructure need to be repurposed and processed accordingly, and the required superstructure needs to be acquired and prepared for operation. Parallelly, the ongoing transition from the fossil fuels and nuclear energy age to the solar and efficient energy age strongly affects inland waterway transportation and inland ports as the transportation and transshipment of dry bulk cargo is expected to shrink significantly over the next two decades, leaving the players in desperate search for new activity areas. Engaging more in container transportation and handling appears logical in this respect.

In total, the considered area features 44 active inland ports have been marked as eligible transshipment locations of the new service (Alias, et al., 2020a). Thereby, the effort of developing and setting up new locations is omitted. Among those 44 active inland ports, the largest part neither offers any container handling service nor features any related superstructure. So, adding these ports as transshipment locations requires additional effort of providing them with container handling equipment.

Despite the considerable increase in eligible transshipment locations, their geographical clustering still leaves some white spots on the map.

3.3 Reactivation: Inactive but Reactivatable Ports

The second enhancement level is the identification of additional transshipment locations. As the considered geographic area, the Rhine-Ruhr area, has a long heritage of coal mining, ore smelting, and iron and steel production with many former production sites. These host currently inactive transshipment locations that can potentially be reactivated in case of need and have also been taken into consideration. As 61 of such inactive loading bays are deemed eligible, a total of 105 potential transshipment locations of the decentralized waterborne transportation service have been identified (Alias, et al., 2020a). Figure3 shows the network of all potential transshipment locations.

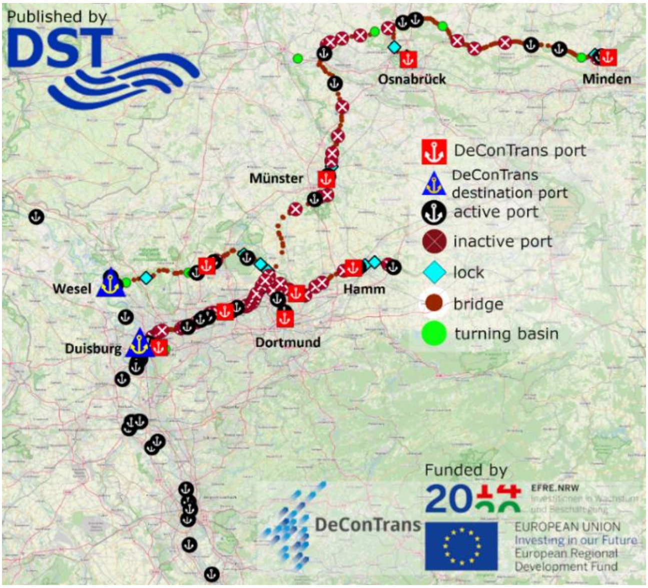

Figure 3: Map of the transshipment locations (Alias, et al., 2021)

From a technical point of view, preparatory aspects like enquiries about the permissible floor load and the surface stabilization are already completed and require minimal care, if at all. As these locations have been used for the very same purpose in the past, the prerequisites for a resumption of the operation appear advantageous.

From a political point of view, this approach finds support as the concept provides a new role for the formerly active transshipment locations that nowadays find themselves under pressure to become transformed into residential or recreational areas. Once completed, a re-purpose to commercial activities, let alone transshipment and port operations, appears highly improbable. In order to keep as many locations reserved for current and future use, this approach has an essential part in this political endeavor.

After identifying the eligible transshipment locations and selecting the ones to serve with the decentralized waterborne hinterland container transportation service , those transshipment locations that do not exhibit any existing container handling infrastructure need to be equipped with appropriate devices.

3.4 Upgrade: Equipment with Handling Infrastructure

The options range from gantry cranes (container bridges), hydraulic slewing cranes for material handling, mobile harbor cranes, mobile reach stackers, and crane ships (POM Oost-Vlaanderen, 2019). While gantry cranes promise throughput levels between 25 and 45 container moves in an hour, their acquisition costs account for seven to twelve million euros. Transshipment locations without a bright and shining future in container handling business ahead might be deterred from investing in such costly equipment without the clear prospect of adequate container volumes to handle.

Hydraulic slewing cranes can be acquired for 600,000 euros in smaller size and between two and three million euros in larger size. With 40 to 60 container moves per hour, their performance level is even higher than the one of gantry cranes. Their quick interchangeability with other tools allows a swift and flexible use of such cranes as multi-purpose devices. However, the cost level might still be too high for transshipment locations that still need to develop a steady consistent handling volume.

Mobile harbor cranes cost approximately 2.5 million euros and feature a performance level of 30 moves per hour. Clearly, the cost-to-benefit is significantly less favorable for these devices than for others.

Whereas new reach stackers may cost between half a million euros and 650,000 euros, used reach stackers promise equal service at considerably lower costs, i.e., between 50,000 and 250,000 euros. With twenty container moves per hour, the performance level is sufficient for a low-volume port. Moreover, it can reach inside the inland vessel and take up containers even in the fourth row. Likewise, it is able to stack container up to five container levels high on the quay and allows a negative lift of up to 2.5 meters below quay. The only major prerequisite regarding the infrastructure is the existence of a heavy duty quay wall.

As to container handling in inland terminals, the use of reach stackers amounts to costs between twenty and fifty euros per container move. The costs of the alternative devices are assumed to be higher despite a lack of publicly available information.

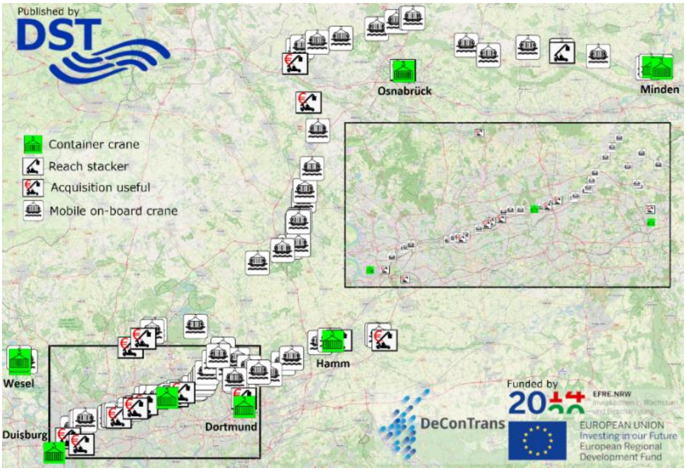

Figure 4: Container handling equipment at each location (Alias, et al., 2021)

For the decentralized waterborne hinterland container transportation service , mobile reach stackers are thus recommended as the container handling device to be acquired for those transshipment locations whose container handling volumes at a threshold value. Generally, the reach stacker serves the goal at low investment cost and decent performance level for low volumes. In the case of substantial growth of volumes, the option of upgrading the container handling superstructure still remains open.

Figure4 illustrates the respective situation at each inland port and transshipment location. While some locations feature container cranes and mobile reach stacker, respectively, others do not exhibit any operational equipment for container handling. While some of them are recommended an acquisition of a reach stacker due a sufficient container volume expected, others are eligible for a stand-alone solution with no investment effort ashore. A mobile onboard crane on the small inland vessels operating in the considered geographic area represents such a stand-alone solution.

4 Mobile Onboard Crane

A stand-alone solution like the mobile onboard crane on the inland vessels exempts the operators of the transshipment location of their duty to provide superstructural equipment on their respective premises. Thereby, the transshipment task, along with the transportation task, is to be taken over by the vessel operator. Parallelly, the investment cost for the handling device remains with the vessel operator, not with the port or terminal operator. The mobile onboard crane complements the decentralized nature of the waterborne container transportation service as potential new locations can participate easily and without too challenging and costly preconditions. Even network expansions limited in time or for selective times are conceivable. In this way, the entire concept becomes easily scalable as the entry barriers are remarkably low. The only preconditions are a sufficient soil bearing capacity and enough maneuvering space for the mobile onboard crane ashore. For the operators of the individual locations, the risk attained to a large investment is avoided in this way. On the contrary, when the business gains momentum, they are able to upgrade their handling equipment by acquiring a reach stacker or even a container bridge.

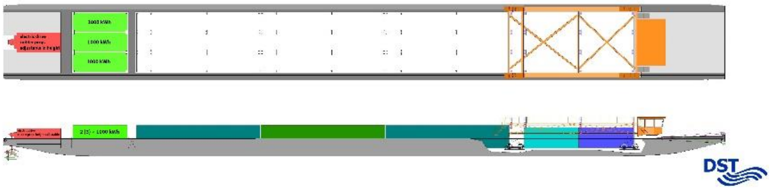

Figure 5: Plan of the mobile onboard crane (own illustration)

The mobile onboard crane is designed to work on nearly all small inland vessels of the current program except for the smallest one with only 50 meters length, 6.8 meters width, and a capacity of eight TEU. All other small inland vessels can be equipped with the mobile onboard crane. For instance, the vessel type 4 (80 meters length, 9.5 meters width, and a capacity of 24 TEU) exhibits an air draft of 4.50 meters with a draft of 0.45 meters in the unladen case and a maximum draught of one meter with 3.95 meters of air draught, respectively. Similar values apply to all eligible types of small inland vessels of the current program. Figure5 shows a plan of the mobile onboard crane.

With respect to its operation mode, the mobile onboard crane sits on the side passage of the inland vessel and is able to run along its length on wheels with rubber tires. The home position of the crane is next to the ship's bow. The crane operator's cabin is co-located with the control stand of the vessel so that no valuable space is wasted aboard.

On arriving at the transshipment location, the vessel docks to the quay wall semi-automatedly, and the control stand along with the container lift truck is hydraulically lifted to deck's level (see Figure6). After safely berthing in the port, the skipper switches the operation mode to crane operation and uses the mobile onboard crane henceforth. In order to retrieve the respective container, the skipper moves the crane to the desired position. Once the container is lifted, the crane starts moving to the bow and leaves the vessel in order to place the container at the right position in the container storage area ashore. The right position can be a storage position on the ground, container supports resembling stilts, or even a truck trailer available at the destination (see Figure6). Apart from the cargo containers, the battery boxes can be exchanged with the same technique.

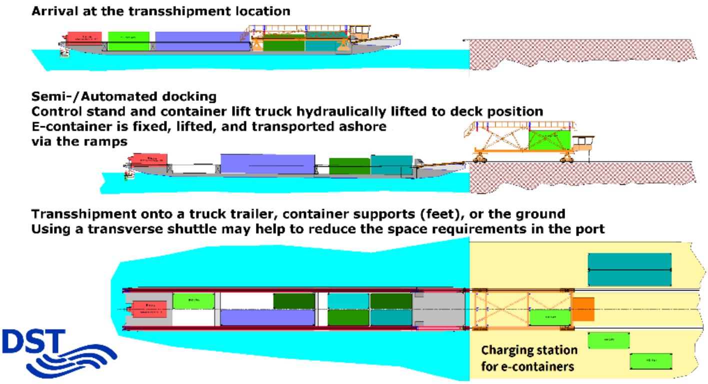

Figure 6: Transshipment with the mobile onboard crane (own illustration)

Then, the mobile onboard crane returns back to the inland vessel and retrieves the subsequent containers according to the loading and unloading list. Ultimately, after finishing all unloading and loading tasks, the crane returns to its home position so that the skipper can take over the control stand again and resume the journey on the waterways. Table1 shows the cycle times and energy consumption for several exemplary use cases. While low volumes of containers to loaded or unloaded appear realistically feasible, larger transshipment demand causes severe delay. This complements the starting argumentation that the mobile onboard crane is supposed to act as a first entry ticket to the decentralized waterborne hinterland container transportation service which can be upgraded when the volumes grow.

Figure7 shows the system components of the vessel, , that is composed of a steel body and features an adjustable hydraulic or mechanic rudder propeller with a shaft power of 70 to 200 kW, with the mobile onboard crane. The energy supply comes from up to three battery boxes with 1,000 kW each. In addition, the vessels have a bow thruster of approx. 100 kW and a Ro-Ro ramp with a coupling point safeguarding a holding force of approx. 200 kN. The container lift truck, which is co-located with the control stand, has a lifting capacity of nearly 42 tons and, thus, is able to deal with overload containers. Four scissor lifts are active for the container lift truck, exhibiting a lifting capacity of nine tons each.

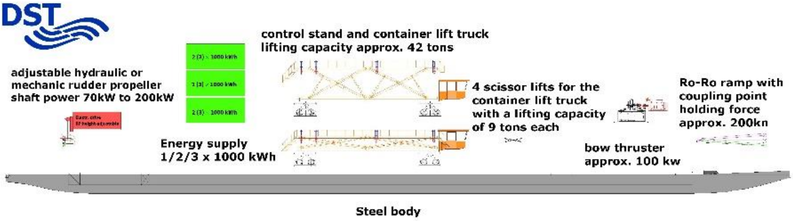

Figure 7: Components of the vessel with the onboard crane (own illustration)

The container lift truck is capable of adjusting the respective space requirements in different situations and can be raised and lowered according to the specific need. Figure8 shows the various positions of the container lift truck. During the vessel journey, the lift remains retracted and on deck’s level. During the loading processes, the crane needs to run above the empty or filled loading bay of the inland vessel and, thus, is elevated. The truck is even able to adjust to different container heights and raise itself appropriately. When the container lift truck runs above deck to store or retrieve a container, it needs to run with sufficient room with the transported container and the residual ones onboard. Therefore, the scissor lifts are extended, and the required height achieved.

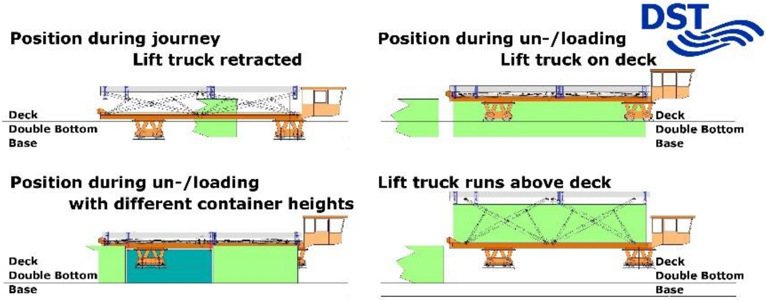

Figure 8: Positions of the container lift truck (own illustration)

The mobile onboard crane allows the participation of many potential transshipment locations in the decentralized waterborne hinterland container transportation service at low investment risk and reasonable performance level. Further examination and development tasks cover the feasibility check and impact assessment of rail guides on the terminal ground, the increase in flexibility by adding steerability to the container lift truck, and the energy supply and signal transmission of the container lift truck while ashore.

5 Related Work

Related work can be found in manifold areas. On the one hand, several waterborne transportation service including such of containers can be found in scientific and grey literature. On the other one, dedicated transshipment solutions are occasionally researched, and pertaining results presented.

The probably most relevant article in terms of an overview of use cases of urban freight transportation on the water is the work of Janjevic and Ndiaye (2014). The authors looked into various prototypical and commercial application examples and reviewed them with scientific criteria. However, the transshipment process did not play a central role in the review.

With respect to waterborne transportation services, van Hassel (2015) has looked into opportunities of reviving the small Flemish inland waterways. His approach included introducing new vessel types for this purpose and designing an intelligent logistics network (van Hassel, 2011). Transshipment facilities and capacities has not been an integral part of the work but has been assumed as given at the respective locations.

The potential of a network of hubs for waterborne distribution of goods in the city of Amsterdam, The Netherlands, has been at the center of a work of van Duin, Kortmann and van den Boogaard (2014). The authors examined the performance of the system and determined the number of required urban hubs and the required size of the optimized vessel fleet by means of discrete-event simulation (van Duin, Kortmann and van de Kamp, 2018).

In the research project RUHRCARGO, a transportation service between the inland ports of Duisburg and Dortmund based on nonmotorized barges has been developed and examined (DST - Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V., 2013). Whereas the number of barges, push boats and staff members has been examined thoroughly, the transshipment points were fixed from the beginning.

In the German-Dutch research project tRHEINco, the goal was to promote intermodal transportation chains by better utilizing existing waterway and terminal infrastructure in the Rhine-Waal Euregio on both sides of the border (DST - Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V., 2015). With the new push convoy service, (containerized) continental cargo between Germany and The Netherlands was supposed to be hauled via IWT. As the availability of a sufficient number of efficient terminals was the prerequisite for the development and implementation of such transportation services, a longlist of potential destinations has been worked out. However, the transshipment facilities themselves were not in the focus of the research work.

In the research project MEGAHUB, a potential new inland port on the Rhine with hub function was to be examined (DST - Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V., 2014). With the opening of the new hub and re-assigning the incoming containers according to the final destinations, existing seaports and inland ports should be relieved, and transports on the waterways optimized.

Good overviews of existing transshipment technologies in the ports can be found in different sources, dating back to early 2000s and more recent ones (Studiengesellschaft für den kombinierten Verkehr e.V., 2002; 2017). Even crane ships are mentioned in some of them, indicating handling costs of 50 to 60 euros per container move and the requirement of well-functioning bollards and a quay with asphalt or granting access to trucks in some other way (POM Oost-Vlaanderen, 2019).

Concerning mobile transshipment solutions, various crane barges can be used as reference. Malchow (2019) presented the so-called Port Feeder Barge which was designed for the use in seaports like Hamburg, Germany. With a storage capacity of 168 TEU, it was designed as a mobile floating terminal that could serve inland barges for mooring, loading, and unloading.

In the German project Watertruck, an innovative lightweight container barge with an onboard gantry crane has been designed and developed (ISE – Institut für

Strukturleichtbau und Energieeffizienz gGmbH; Kaufmann, et al., 2018). With the container crane aboard, various commercial zones adjacent to the waterways can be served. By using modern lightweight materials, the onboard crane can be applied without increasing the maximum draught of the inland vessel. The gantry crane uses telescopic arms along the vessel length and an internal stabilization system based on a ballast water tank and pumps allowing the movement of the water according to the specific need. Thereby, static and dynamic loads on the ship's hull can be controlled, and the hydro-stability guaranteed.

Further examples of mobile onboard cranes as part of the inland vessel and the entire logistics concept are the beer boat project in Utrecht, the Netherlands, and the AMSbarge in Amsterdam, the Netherlands (Journée; Jong, 2013; Post, 2015). In general, crane barges mainly encompass slewing cranes with an extended reach towards onshore storage areas whereas gantry cranes are a minority.

6 Conclusion and Outlook

Setting up a decentralized waterborne container transportation network requires the detection of sufficient demand and the set-up of an attractive service offer that should encompass adequate inland vessels and sufficiently dense network of transshipment locations.

Creating such a dense network of ports participating in the new service is not an easy task – particularly when considering the lack of adequate cargo handling equipment like for containers in this case.

The present article has shown the cascade of steps to enhance the transshipment capacity in the new network – from adding more transshipment locations to the network over reactivating old disused ports and loading bays to developing a stand-alone solution and, thereby, disburdening the new locations from any major investment. In addition, design parameters and performance indicators of the mobile onboard crane have been presented and explained.

Detailed analyses of the configuration of the transportation network are to follow. The selection of the routes and ports to be served, the composition of the fleet, and the service concept to be pursued need to be determined. With the help of discrete-event simulation, various parameters like the operation mode of the vessels, the fleet mix, and the application of different transshipment concepts can be examined and compared with each other. Ultimately, the service levels and utilization indicators, the estimated transportation and transshipment costs, the ecological impact of the decentralized waterborne hinterland container transportation service will be derived from such analyses. From a technical point of view, a solution is still required for seamless container swaps onshore. More precisely, containers placed onshore by the mobile onboard crane must be able to be collected by truck without extra handling equipment, e.g., with the help of four legs on which the container would rest.

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Appendix

Table 1: Cycle times and energy consumption of the mobile onboard crane

	Length (in m):	95		80		66		
	Width (in m):	9.5		9.5		9.5		
		cycle time	*energy consumption*	*cycle time*	*energy consumption*	*cycle time*	*energy consumption*	
#	***Step***	*min*	*kWh*	*min*	*kWh*	*min*	*kWh*	***Comment***
1	Lifting the container lift truck of the mobile onboard crane to deck's level	**0.7**	**0.189**	**0.7**	**0.189**	**0.7**	**0.189**	applicable for each loading/unloading process
2	Lowering the container lift truck of the mobile onboard crane from deck's level	**0.7**	**0.189**	**0.7**	**0.189**	**0.7**	**0.189**	applicable for each loading/unloading process
3	Mobile onboard crane unloads one container from the inland vessel and returns empty back on board	**6.2**	**5.745**	**5.9**	**5.344**	**5.7**	**4.970**	− 1
4	Mobile onboard crane goes empty ashore and loads one container onto the inland vessel	**7.1**	**6.242**	**6.7**	**5.800**	**6.4**	**5.388**	+ 1
5	Mobile onboard crane unloads one container from the inland vessel and loads another container onto it	**11.5**	**10.928**	**10.7**	**9.998**	**10.0**	**9.129**	− 1 and + 1
	EXAMPLES							
A	*unloading 1 TEU (steps: 1+2+1*3)*	**00:07:35**	**6.1**	**00:07:18**	**5.7**	**00:07:02**	**5.3**	
B	*loading 1 TEU (steps: 1+2+1*4)*	**00:08:29**	**6.6**	**00:08:06**	**6.2**	**00:07:44**	**5.8**	
C	*unloading 10 TEU (steps: 1+2+10*3)*	**01:03:43**	**57.8**	**01:00:50**	**53.8**	**00:58:09**	**50.1**	
D	*unloading 12 TEU and loading 7 TEU (steps: 1+2+7*5+5*3)*	**01:53:04**	**105.6**	**01:46:20**	**97.1**	**01:40:03**	**89.1**	
E	*unloading 18 TEU and loading 18 TEU (steps: 1+2+18*5)*	**03:28:26**	**197.1**	**03:14:50**	**180.3**	**03:02:08**	**164.7**	