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Assessing the Role of Mobile Terminals to Reduce Container Barge Inefficiency in Seaports

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Abstract

This study examines how to eliminate the inefficiencies in inland waterborne transport (IWT) by reducing sailing and waiting times at ports without expensive modifications to terminal infrastructures. A new concept known as the Modular Mobile Terminals (MMTs) is examined to achieve this and its potential feasibility in seaports. In doing this, the present paper develops time savings optimization and cost feasibility models that evaluate regions that would be suitable to be linked based on the overall gains by using the MMTs.

Results revealed that regions with low load factors would have a positive business case for using the MMTs. The small call sizes transported from these regions can be consolidated at the MMTs and transferred in high volume to dedicated deepsea terminals. This reduces the port time for the barges involved while ensuring that the barges are handled quicker and better.

Keywords: Modular Mobile Terminal; Container Barges; Deepsea Terminals; Inland Waterway Transport; Time Optimization; Cost Feasibility.

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1. Introduction

With lower emissions per ton-kilometer, Inland Waterway Transportation (IWT) is an excellent alternative to road transport to make container transport more sustainable (European Environment Agency, 2021). However, some inefficiencies remain in the IWT system, thus limiting its attractiveness. The present study focuses on reducing waiting times of inland vessels at seaports to make it a more suitable and competitive option for container transport. To achieve this, the Modular Mobile Terminal (MMT) concept is examined, and its potential impact on the operational efficiency of container barges in seaports is evaluated.

The motivation for this concept stems from the high waiting times experienced by container barges linked to two main issues: containers spread over several terminals and the low priority of barges at the terminals (Van Der Horst & De Langen, 2008; Wiegmans, 2005). Containers are often not bundled but thinly spread over several seaport

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terminals, leading inland vessels to call at several terminals, even between six to eight, to collect a few containers at each call (Ramos, et al., 2020). Each of these calls often takes hours before the barges are handled. This is due to the low priority of container barges at each terminal. Since seagoing vessels are prioritized at terminals, inland vessels must wait for available wharf and crane facilities, with waiting time at and sailing between terminals adding up to 60 percent of the total time spent in port (Port of Rotterdam, 2019).

By providing a consolidation and distribution station, it should be possible to eliminate the need for the container inland barges to call multiple terminals, thereby reducing the waiting time. The consolidation and distribution station could, in principle, be placed on the land. But considering the intensive land use in most ports, developing a mobile terminal concept could bridge this gap. The MMT will be the interface where inland waterway vessels can deliver and collect containers to and from the seaport terminals.

The envisaged operation is that an inland waterway vessel (IWV) collects cargo from several inland terminals with different deep-sea terminal destinations. When the inland vessel reaches the seaport, the MMT can be used instead of calling at the various terminals. The container inland barge will moor at the Export MMT. The crane module will be the center point of the operation, unloading the IWV and distributing the cargo to the shuttle modules. The shuttle modules will then transport the containers to the specified seaport terminal and transport cargoes from the deep-sea terminals to the import MMT. At the import MMT, the crane module will transfer the cargoes from the shuttle modules to an inland vessel to transport them further to the hinterland. These operations and the organization of the modules are shown in Fig. 1, issued from a European Deliverable (Ramne, et al., 2021).

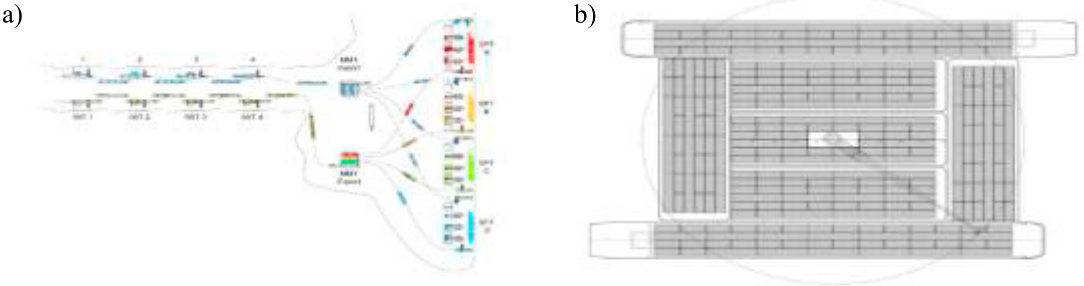

Fig. 1. (a) envisioned operation of the MMT concept; (b) cluster of 4 MMT modules with 2 moored IWVs served by one crane module.

Previous studies have explored similar ideas (Hu, Wiegmans, Corman, & Lodewijks, 2019). Some collection/distribution transport solutions have been explored to reorganize container barge services in deep-sea ports (Konings, 2007). The main idea was to reduce the number of calls for inland barges by collecting cargo at terminals with dedicated feeder vessels and redistributing it to specific locations. The author concluded that the most promising solution was to group the containers of 'small call-size' terminals at a dedicated location for barges and let inland barges with 'large call-size' visit the deepsea terminals themselves.

This hub-and-spoke idea has been developed further for the hinterland of the port of Rotterdam (Konings, Kreutzberger, & Maras, 2013). The results show that the hub-and-spoke is more beneficial for small hinterland vessels and that a greater distance between the hub and the seaport generates more economies of scale. It also underlined that using push barges for shuttling between the hub and the seaport is beneficial because they can serve as floating stacks. The potential of a floating crane is also suggested but not further investigated.

The Port Feeder Barge (Malchow, 2020) is the most similar to the MMT. It consists of a self-propelled container barge equipped with a mounted crane for inter-terminal transfers in deep-sea ports. Besides intra-port operations, the author suggests that the Port Feeder Barge can also be used as a floating terminal for inland vessels. The Feeder would perform a round trip to the deep-sea terminals to collect/deliver containers shipped to/from the hinterland. The inland vessels would then directly visit the Port Feeder Barge instead of deep-sea terminals. Compared to additional land-based facilities, the solution offers advantages regarding the implementation costs, simplicity, and environmental impacts. The author nevertheless points out that the defiance of terminal operators represents a significant obstacle as they are reluctant to delegate container handling operations to external actors.

In that sense, the proposed MMT offers a good compromise as the crane module is situated in a separate location, thus not directly interacting with the deep-sea terminals. Containers are first stacked on modules that are then conveyed to the terminals to keep the crane handling operations from the modules to the yard. In addition to the evident advantages for barge operators, this innovation allows the terminal operators to plan their operations more effectively as incoming cargo will already be consolidated. This would result in a win-win situation, which is essential to get the commitment of all stakeholders (Caris, Macharis, & Janssens, 2011).

The present study adds to the body of knowledge by developing a detailed cost and time analysis of this new concept. Hence, the study examines the feasibility of the mobile terminal concept in the ports of Rotterdam and Antwerp from the cost and time perspective. To achieve this, the study develops two models. Firstly, a time savings optimization model will determine which configuration of the MMTs allows for the system's highest time savings. In particular, it indicates the number of MMTs, the desired frequency of shuttles from MMTs to the sea terminals, and the hinterland flows to be linked to the MMTs: it thus provides some insights into the potential design of this innovation. Secondly, a cost model calculates the overall cost savings of using the mobile terminals for the barge operators, the shippers, and the operators of the MMT: it will allow assessing the economic feasibility of the innovation.

2. Time savings optimization model

We define R as the set of hinterland regions of a seaport S and I as the set of deep-sea terminals in the seaport. We consider that every IWV visits 4 terminals per seaport visit ($|I| = 4$), has a sailing time t_S^{sail} of 1 hour between each terminals, and experiences a waiting time t_i^{wait} of 4 hours at each terminal i. Moreover, the handling time t_i^{hand} is assumed to be 3 minutes per TEU for each terminal i.

The number of IWVs sailing per month between the seaport and a region r is denoted F_r and t_{Sr} represents the sailing time from seaport S to region r (t_{rS} for the other direction). The container flow per month $\tau \in [1,12]$ between a region r and a deep-sea terminal i (expressed in TEUs) is denoted $D_{ir\tau}$ for the import direction and $D_{ri\tau}$ for the export. The monthly flows are obtained by multiplying the annual flows between terminals and regions by seasonality factors ρ_τ.They represent the share of the annual demand that is transported for a given month τ. These seasonality factors are estimated using historical container transport data along the Rhine for each month from 1993 to 2020. For each month of a given year, the share of the annual demand is computed. The seasonality factors ρ_τ used in this study, shown in Table 1, are the mean values of these shares over the 28 reported years.

Table 1. Mean seasonality factors for container transport along the Rhine between 1993 and 2020.

τ	1	2	3	4	5	6	7	8	9	10	11	12
ρ_τ	7.83%	8.06%	8.81%	8.31%	8.63%	8.58%	9.09%	8.56%	8.37%	8.32%	7.78%	7.66%

Source: RhineForest (2021)

We now describe the characteristics of the MMTs. As depicted in Fig. 1b), each MMT is composed of a central crane module surrounded by 4 stacking modules having a capacity K of 138 TEUs (Ramne, et al., 2021). The total surface of a MMT A (including safety margins for maneuvers) is set to 10'000 m^2 and we assume that seaports can dedicate a maximal surface A^{max} of 300'000 m^2 to the MMTs. The handling time of the crane module t_M^{hand} is set to 3 min. per TEU, and the waiting time t_M^{wait} of IWVs before being served by the crane for 1 hour. It is assumed that the modules will have dedicated spots at deep-sea terminals; thus, they experience no waiting time at the seaport. Finally, we assume that the sailing time between MMTs and the deep-sea terminals t_{MS}^{sail} and the sailing time between the import and export MMTs t_{MM}^{sail} are 1 and 0,4 hours respectively.

The proposed time savings optimization model minimizes the total time spent by all vessels during a year in the system (i.e., seaport, hinterland, and MMTs). To do so, some hinterland regions will be linked to the MMTs: the vessels serving the linked regions will not call at deep-sea terminals anymore, but only at the MMTs. Push barges will then carry the stacking modules between MMTs and deep-sea terminals at a certain frequency. The decision variables of the optimization model are then: $\boldsymbol{y_r}$ a binary variable equal to 1 if region r is linked to MMTs, $\boldsymbol{z_i}$ the number of shuttles needed per month between MMTs and deep-sea terminal i, and $\boldsymbol{x^{in}}$ and $\boldsymbol{x^{ex}}$ the number of imports, respectively export, MMTs needed to handle the containers from the linked regions.

The objective function is expressed in (1) as a sum of T^R the time spent by IWV sailing between the hinterland and the seaport area (see (2)), T^S the time spent in the seaport, and T^M the time spent with MMTs. T^S is made of 3 terms, as shown in (3): the service time at terminals, the time spent waiting to be served at deep-sea terminals for IWVs, and the time spent by IWVs sailing between deep-sea terminals. Regarding MMTs, T^M has 4 components, expressed in (4): the handling time for inland vessels being served by MMT, the waiting time at import and export MMT for inland vessels, the sailing time of shuttles between MMT and seaport area and the sailing time between import and export MMT. The time savings model is then expressed as:

$$min\,\Phi = \sum_{\tau\in[1,12]} T^R + T^S + T^M \tag{1}$$

Where:

$$T^R = \sum_{r\in R} F_r(t_{rS} + t_{Sr}) \tag{2}$$

$$T^S = \sum_{r\in R}\sum_{i\in I} t_i^{hand}(D_{ri\tau} + D_{ir\tau}) + \sum_{i\in I} t_i^{wait}\sum_{r\in R}(1-y_r)F_r + \sum_{r\in R} F_r\, t_S^{sail}(1-y_r)|I| \tag{3}$$

$$T^M = t_M^{hand}\sum_{r\in R}\sum_{i\in I} y_r(D_{ri\tau} + D_{ir\tau}) + 2t_M^{wait}\sum_{r\in R} y_rF_r + 2t_{MS}^{sail}\sum_{i\in I} z_i + t_{MM}^{sail}\left[\sum_{r\in R} y_rF_r + \sum_{i\in I} z_i\right] \tag{4}$$

Subject to:

$$\sum_{i\in I}\sum_{r\in R} y_r\, D_{ir\tau}\, t_M^{hand} \le 480x^{in} \qquad \forall\tau\in[1,12] \tag{5}$$

$$\sum_{i\in I}\sum_{r\in R} y_r\, D_{ri\tau}\, t_M^{hand} \le 480x^{ex} \qquad \forall\tau\in[1,12] \tag{6}$$

$$\sum_{r\in R} y_r\, D_{ir\tau} \le z_iK \qquad \forall i\in I, \forall\tau\in[1,12] \tag{7}$$

$$\sum_{r\in R} y_r\, D_{ri\tau} \le z_iK \qquad \forall i\in I, \forall\tau\in[1,12] \tag{8}$$

$$z_i \le M\sum_{r\in R} y_r \qquad \forall i\in I \tag{9}$$

$$\frac{\sum_{i\in I} z_i}{30}/2 \le x^\delta \qquad \forall\delta\in\{in, ex\} \tag{10}$$

$$\frac{\sum_{i\in I} z_i}{30}/2 + 1 \ge x^\delta \qquad \forall\delta\in\{in, ex\} \tag{11}$$

$$A(x^{in} + x^{ex}) \le A^{max} \tag{12}$$

$$x^{in}\in\mathbb{N},\quad x^{ex}\in\mathbb{N},\quad z_i\in\mathbb{N}\ \forall i\in I,\quad y_r\in\{0,1\}\ \forall r\in R \tag{13}$$

Constraints (5) and (6) limit the number of hours that each import, respectively, exports MMT can operate to 480 hours per month (i.e., 120 hours per week). Constraints (7) and (8) set the minimum required frequency of shuttle barges to a terminal i given import and export demand, respectively, and the capacity of a module. The shuttles' frequency will then be set in the direction with the most demand. Constraints (9) ensure that the number of shuttles to terminal i is null if there is no region linked to the MMTs (note that M is a large enough positive number). Constraints (10) and (11) define the number of import and export MMTs based on the total number of shuttles traveling to the deep-sea terminals. It is assumed that each month has 30 days and that, within one day, 2 modules per MMT can be shuttled to the seaport, whereas the other two modules remain at the MMT to hold the cargoes coming from (or going to) the hinterland. Finally, constraint (12) prevents the total surface occupied by all MMTs exceeds the maximum available surface in the seaport, and constraints (13) define the decision variables.

The solution obtained with this time savings model is then compared to the base case, where no MMTs are installed: for that, we set T^M to zero in (1) and y_r to zero for all r in (3). We also compute some Key Performance Indicators (KPIs) to compare the efficiency of MMTs further. The total time savings ΔT per IWV linked to the MMTs is computed by dividing the total time difference between the base case and the optimal solution by the number of vessels linked to the MMTs. We also report the average filling ratio ρ for the import and export shuttles over a whole year. This indicator will show if the MMTs are used efficiently.

3. Cost feasibility model

The cost feasibility model estimates the net savings of the actors in the regions linked to the MMTs in Antwerp and Rotterdam. This is achieved by first identifying the optimal terminal handling price per TEU to be charged to yield a positive NPV and IRR for the MMT operator. The cost savings are then estimated for both the barges and the shippers. Based on this, an investment model is first specified for the MMT operator, while cost models are specified for the barges and the shippers.

The investment model of the MMT operator is determined by calculating the Net Present Value (NPV) of the mobile terminal handling and transshipment services. The NPV is used to determine the current value of all the future cash flows, including the capital investment and the terminal value generated by a project. This is specified as:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+r)^t} \tag{14}$$

where:
R_t = Net cash flow (inflow – outflows) in a single period *t* [EUR].
r = Discount rate or WACC [%].
t = Number of periods [years].

The net cash flow is the remaining revenue after all expenses, loan repayments, interest, cost items, and taxes have been deducted. A 6% discount rate is deemed appropriate for the investment type, while the project is estimated to have a lifespan of 30 years.

The goal for the MMT operator is to generate positive NPV and IRR values which would cover the cost of investments and yield a positive return. To do this, an optimization model that iterates through the capital and operating costs, rate of return, and the potential net cash flow is developed. This then returns the optimal price, which yields a positive NPV and IRR after taking in the different cost and rate parameters. In doing this, some constraints specify the minimum and maximum handling rate that can be charged and at what point the iteration stops to select the optimal handling rate. These constraints are defined as:

$$\begin{aligned} &x = \max f(x) \\ &s.t \\ &\sum_{t=0}^{n} \frac{R_t}{(1+i)^t} > 0 \\ &x \leq O(x) \\ &x \geq \Omega(x) \end{aligned} \tag{15}$$

where:
max $f(x)$ = The optimum handling rate that can be charged.
$x \leq O(x)$ = The rate cannot exceed the rate (upper bound) charged at the deepsea terminal. This is specified as EUR 41.01 per TEU from the model of van Dorsser (2015).
$x \geq \Omega(x)$ = The rate cannot be less than the minimum transshipment rate (lower bound) charged based on the capital and operating cost. This is estimated at EUR12.17 per TEU from the model.

This cost model for the barge operators and shippers focuses on the cost of sailing to the port and using the shuttle transport from the MMT to the deepsea terminal. By doing this, the net benefit of the actors can be derived. Based on this, the cost models and net benefits are expressed as:

$$C_{tot/teu} = \frac{(C_{fix} + C_{var}) * T_t}{cap * r_{occ}} \tag{16}$$

$$C_{total,mto} = C_{mt} + C_{sdt} \tag{17}$$

$$S_{barge} = C_{tot/teu,dt} - C_{tot/teu,mt} - \max f(x) \tag{18}$$

$$S_{shipper} = C_{tot/teu,dt} - C_{\frac{tot}{teu},mt} - \big(O(x) + C_{total,mto}\big) \tag{19}$$

Equation(16) specifies the cost of sailing from the linked regions to the deepsea/MMT. Equation(17) determines the cost of sailing to the MMT and using the shuttle barges to transport the containers to the deepsea terminals. In this case, C_{mt} is the cost of sailing and handling at the MMT, while C_{sdt} is the cost of shuttle barge transport from the MMT to the specific deepsea terminal. Equation(18) estimates the cost savings of the barges by using the MMT, where $C_{tot/teu,dt}$ is the cost of sailing to the deepsea terminal without the use of the MMT, while $C_{tot/teu,mt}$ is the cost of sailing to the MMT. Equation(19) estimates the cost savings of the shippers with the use of MMTs, where $O(x)$ is the upper bound terminal handling rate, which is the handling rate charged at the deepsea terminal.

4. Results

The time savings optimization problem is solved in Python GUROBI for both the ports of Rotterdam and Antwerp. Table 2 presents the optimal value of the objective function, its components, and the respective values for the base case.

Table 2. Values of the objective function and its components for the base case and the optimal solution with MMTs for both seaports.

	ROTTERDAM				ANTWERP			
	Φ [hr]	T^R [hr]	T^S [hr]	T^M [hr]	Φ [hr]	T^R [hr]	T^S [hr]	T^M [hr]
BASE CASE	888,424	541,656	346,768	-	612,959	367,176	245,783	-
WITH MTTs	817,098	541,656	199,648	75,794	581,919	367,176	151,703	63,040

These results show that the MMTs generate substantial time savings in the seaports. Indeed, T^S is reduced by 42% and 38% for the ports of Rotterdam and Antwerp, respectively. Even if it considers the whole journey of vessels to and from the hinterland, the total time Φ is decreased by 8% for Rotterdam and 5% for Antwerp. This means that the proposed Modular Mobile Terminals have the potential to significantly reduce the waiting time of inland vessels in the seaports. Table 3 reports the number of MMTs and shuttles per month needed to achieve these savings to get additional insights into this solution. It also contains the predefined KPIs and the regions that should be linked to the MMTs. The region codes correspond to the NUTS classification (European Commission & Eurostat, 2020), the official division of the EU and UK for regional statistics, at level 2.

Table 3. Values of the optimal decision variables, KPIs, and regions linked to the MMTs.

	$x^{in} = x^{ex}$	$z_i(\forall i)$	ΔT [hr]	ρ^{in}	ρ^{ex}	Linked regions
ROTTERDAM	6	81	9.7	90.6%	91.3%	BE22,DE12,DE13,DEA2,FRF1,NL22,NL31,NL32,NL34,NL41,NL42
ANTWERP	6	90	6.6	47.5%	91.3%	BE22,BE23,BE24,BE33,CH03,DE11,DE13,DE71,DEA1,DEA2,DEB2,DEB3,NL22,NL31,NL42

Although the number of linked regions is higher for Antwerp, the same number of MMTs are needed for both seaports (6 import and 6 export). This is because the volumes going through the port of Antwerp are generally lower than for Rotterdam. Regarding shuttles frequency, 90 shuttles per month are needed for each deep-sea terminal i: for each MMT, a shuttle should depart to a given deep-sea terminal once every 2 days. Since we assume that 4 deep-sea terminals are visited at the seaport, a two-day cycle per MMT could be envisioned. On the first day, one shuttle could depart to terminal 1 in the morning and another to terminal 2 in the afternoon (of course, empty modules are brought back when a full one leaves). The two remaining deep-sea terminals can be visited by shuttles on the second day.

We also notice that almost 10 hours can be saved per vessel linked to the MMTs for Rotterdam and around 6.5 hours for Antwerp. This difference happens because the total savings are higher for Rotterdam, spreading among fewer vessels (since fewer regions are linked to the MMTs for Rotterdam). We also notice that the modules are used much more effectively in the case of Rotterdam (filling ratios of both import and export shuttles are higher than 90%). For Antwerp, we notice that the occupancy of import shuttles is less than 50%. This asymmetry is because the sum of export flows is almost 2 times higher than the import flows of the linked regions. This is not the case for the port of Rotterdam, as the sum of import and export flows of the linked regions are almost equal.

The cost feasibility model is also developed and analyzed in Python for Antwerp and Rotterdam. The solution analyses the benefits for the three actors. Starting with the MMT operator, the model result reveals that the optimum terminal handling rate to be charged to have a positive NPV and a high IRR is EUR 24 per TEU. This rate would lead to an NPV of EUR 2,036,954 and an IRR of 8%, leading to a profitable investment for the MMT owner/operator.

Concerning the benefits of the barges and shippers for the two ports, the linked regions from the time optimization model are further analyzed in Fig 2 to determine their cost feasibility. The figure shows that the regions with positive net benefits (potential net savings) for the barges in the port of Antwerp(a) include BE22, BE23, BE24, DE11, DE13, DE71, DEB2, and NL22, with NL22 providing the biggest net benefits. Meanwhile, the positive regions for the shippers in the same port include: BE24, DE11, DE71, DEB2, and NL22, with NL22, also providing the biggest net benefits.

It can further be seen from the figure that not all feasible regions from the barges analysis are represented in the shippers' analysis, with regions: BE22, BE23, and DE13 not feasible for shippers using the mobile terminal from the cost perspective. This is due to the additional transport cost from the mobile terminal to the deepsea terminal. Hence, for the regions that are not feasible for the shippers but feasible for the barges, additional analysis needs to be conducted to determine the time benefits that the shippers can derive from using the mobile terminal for the regions. This could be done by incorporating the value of time and how this can shape the shipper’s decision to opt for this system.

On the other hand, the port of Rotterdam(b) shows that the feasible linked regions are less than Antwerp, with only DE12, DE13, NL41, and NL42 being viable for the barges linked to Rotterdam from the cost perspective. At the same time, only DE13 is feasible for the shippers in this case. This is so because many regions with small volumes/call sizes are linked to Antwerp than to Rotterdam. Hence, it because more suitable for the barges and shippers transporting from the linked regions to Antwerp.

With this, it can be deduced that the mobile terminal system may be more attractive in the port of Antwerp than in the port of Rotterdam from a cost perspective. More regions can be linked to the MMT in Antwerp than in Rotterdam, thereby providing a positive business case for using the concept in Antwerp.

Fig. 2. (a) cost analysis of regions linked to Antwerp. (b) cost analysis of regions linked to Rotterdam.

5. Conclusion

The time optimization analysis reveals the potential time that could be saved by using the MMTs in the seaports. Although this could benefit different regions connecting the ports, the cost feasibility analysis ensures that these are narrowed down to regions with a positive business case and could provide net cost savings to the barge operators and the shippers.

Two observations can be established from the cost feasible regions connected to the ports. The first is that these regions have extremely low annual cargo volumes of IWT transport, with less than 50,000 TEUs transported annually via IWT between each region linked to the ports, except for NL33-NL41 and NL33-NL42, which have 259,597 TEUs and 82,342 TEUs transported respectively.

The second observation is that although these regions have extremely low cargo volumes, the service frequency between the regions and the ports is relatively high, leading to a low occupation rate for the vessels. The implication is that the vessels in the identified regions visit the deepsea terminals with small call sizes, which is inefficient.

Therefore, the MMT could be a viable solution by creating a niche market for vessels with small call sizes. By doing this, it provides collection, consolidation, and transportation services. It collects cargoes from container barges with small call sizes, consolidates these containers until they reach a significant volume, and transports the high volumes to a dedicated deepsea terminal.

This arrangement has several advantages; first, it reduces the port time of the barges in that they do not have to interact with different deepsea terminals. Furthermore, it ensures that the containers are handled quicker and better; thirdly, it makes the deepsea terminal more efficient and effective in barge planning and handling. Finally, it reduces the overall transport cost for both the barge operators and the shippers, especially for the regions where the shippers' net benefits are positive. All these findings can generate a new business model and operations in the port area.

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References

Caris, A., Macharis, C., & Janssens, G. K. (2011). Network analysis of container barge transport in the port of Antwerp by means of simulation. *Journal of Transport Geography, 19*(1), 125-133.

De Jong, S. D. (2017). *The impact of a B-to-B container transferium on the sojourn time of inland container vessels.* Delft University of Technology. Retrieved from http://resolver.tudelft.nl/uuid:ce7480a8-554f-4f9e-a72b-89a1c5de8be5

European Commission, & Eurostat. (2020). *Statistical regions in the European Union and partner countries : NUTS and statistical regions 2021 : 2020 edition.* Publications Office. doi:10.2785/72829

European Environment Agency. (2021). *Rail and waterborne — best for low-carbon motorised transport.* doi:10.2800/817894

Gort, R. (2009). *Design of an autonomous loading & unloading inland barge.* Delft University of Technology. Retrieved from https://hdl.handle.net/10067/823210151162165141

Hu, Q., Wiegmans, B., Corman, F., & Lodewijks, G. (2019). Critical literature review into planning of inter-terminal transport: in port areas and the Hinterland. *Journal of Advanced Transportation*.

Konings, R. (2007). Opportunities to improve container barge handling in the port of Rotterdam from a transport network perspective. *Journal of Transport Geography, 15*(6), 443-454.

Konings, R., Kreutzberger, E., & Maras, V. (2013). Major considerations in developing a hub-and-spoke network to improve the cost performance of container barge transport in the hinterland: the case of the port of Rotterdam. *Journal of Transport Geography, 29*, 63-73.

Malchow, U. (2020). Port Feeder Barges as a Means to Improve Intra-Port Container Logistics in Multi-Terminal Ports. In J. W. Böse, *Handbook of Terminal Planning* (pp. 465-480). Springer.

Ottjes, J., Hengst, S., & Tutuarima, W. (1994). A simulation model of a sailing container terminal service in the port of Rotterdam. *Proceedings of the 1994 Conference on Modelling and Simulation* (pp. 876-880). Citeseer.

Pielage, B.-J., Konings, R., & Schuylenburg, M. v. (2007). Barge hub terminals: a perspective for more efficient hinterland container transport for the Port Rotterdam. *Transp. Res. Forum*, (pp. 1-19).

Port of Rotterdam. (2019). Barge Performance Monitor. Retrieved from https://www.portofrotterdam.com/de/geschaeftsmoeglichkeiten/logistik/verbindungen/barge-performance-monitor

Ramne, B., Martens, S., Pot, H., Friedhoff, B., Ley, J., & Thill, C. (2021). *D.4.2: Concepts and selection of innovative NOVIMOVE concepts.*

Ramos, C., Burgees, A., van der Geest, W., Hendriks, I., van Hassel, E., Sh

obayo, P., . . . Alias, C. (2020). *D.2.1: Detailed requirements of the NOVIMOVE transport model.* NOVIMOVE Technical Report.

Rhineforecast.com & WSV. (2021). *Real Time Rhine Water Level Forecasts.* https://www.rhineforecast.com/form/

Van Der Horst, M. R., & De Langen, P. W. (2008). Coordination in hinterland transport chains: a major challenge for the seaport community. *Maritime Economics & Logistics, 10*(1), 108-129.

van Dorsser, C. (2015). *Very Long Term Development of the Dutch Inland Waterway Transport System.* 2600 GA Delft, The Netherlands: TRAIL Research School.

Wiegmans, B. (2005). Evaluation of potentially successful barge innovations. *Transport Reviews, 25*(5), 573-589.