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FLEXIBILITY IN PORT INFRASTRUCTURES

ABSTRACT

The present volatile environment continues to place new functional requirements on port infrastructure. As a result, the useful life of port infrastructure has been reduced in recent years. Flexibility in infrastructures makes it possible to adapt them for new or changed use. The use of flexible and sustainable-solutions infrastructures needs to be promoted – though initially more costly, these may prove economical over their whole life cycle. The approach taken here was to carry out a real-life case study which entailed an investigation into the technical and financial feasibility of flexible design concepts for an ongoing port project in Rotterdam.

This exercise has led to insights into the suitability of flexible infrastructures for various uses and situations. The benefits of a flexible design concept were monetised and included, so that the resulting business case was viable. The study also served to highlight some barriers to the design, planning, and implementation of flexible infrastructures.

The authors wish to acknowledge that this research was carried out within the framework of Port Research Centre Rotterdam-Delft and Next Generation Infrastructures and sponsored by Water Research Centre Delft and Public Works Department of Rotterdam.

INTRODUCTION

Ports have a design life of several decades that must accommodate today's needs as well as those of tomorrow. They also represent a major infrastructure investment. The present volatility, and the complex and dynamic nature of ports create new challenges for port planning and design. In order to cope with the many uncertainties, the traditional systems of engineering practices try to incorporate fundamental properties such as flexibility, versatility and adaptability into their plans and designs.

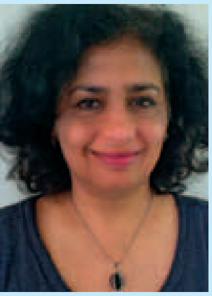
Flexibility in design of civil infrastructures such as quay walls, jetties, basins and approach channels, makes it possible to adapt them for new or changed use. An extended lifetime for infrastructures means not only a greater chance of returns on investments, but it also contributes towards sustainability through efficient use of resources. In the last few years, various flexible concepts for quay walls have been proposed. These concepts however have been seldom applied in practice. The common reasons cited for this are: a lack of long-term vision resulting in implementation of short-term solutions, lack of innovative spirit and institutional barriers.

How to shift focus from short-term profit to long-term vision, how to incorporate life cycle considerations into design of infrastructure, and how to encourage collaboration on innovative projects, which have an uncertain outcome, are some of the key challenges in the port sector.

OBJECTIVES

The objective of this research is to promote use of flexible and sustainable infrastructures – though initially more costly, in view of the uncertainty, they may prove more economical over their entire life cycle. Therefore, a real-life case was examined as a part of an MSc study (Ros 2011). The case entailed an investigation into the technical and financial feasibility of flexible design concepts for an ongoing port project. This was expected to give insights into

Above: The use of flexible and sustainable-solutions for maritime infrastructures though initially more costly, may prove economical over their whole life cycle.Using a case study at the Port of Rotterdam a range of possibilities are explored including, as pictured here, a dolphinarium.



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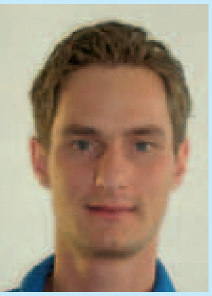

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achieved his MSc degree in Civil Engineering from the Delft University of Technology (specialisation port engineering) in 2012. His MSc thesis is entitled 'Flexible Port Infrastructure on Maasvlakte 2'. Currently, he is looking for a job in a Civil Engineering (related) industry in an international environment. After gaining a comprehensive overview of the industry, he aims for a research career.

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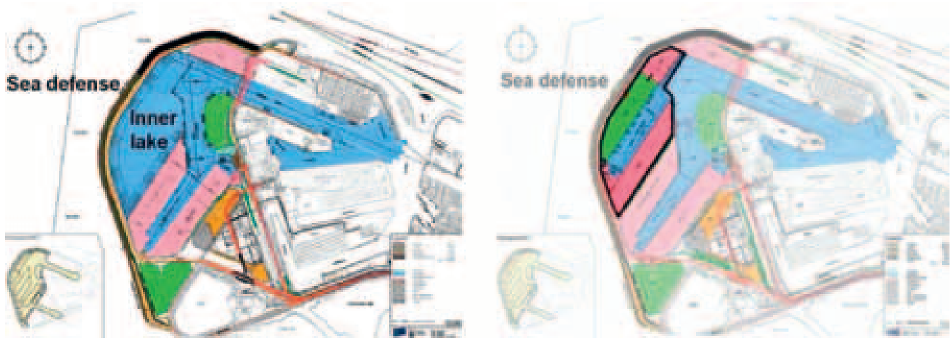


Figure 1. MV2 project in Rotterdam in 2013 (left) and 2033 (right).

the suitability of flexible infrastructures for various uses and situations and also to highlight the challenges encountered during design, planning and implementation of flexible infrastructures. These challenges and issues could be addressed during future research.

CASE STUDY: INNOVATIVE USE OF TEMPORARY INNER LAKE AT MAASVLAKTE 2

Description and research approach

The Maasvlakte 2 (MV2) project, an expansion of the existing Port of Rotterdam (PoR) into the North Sea, is a venture of the Port of Rotterdam Authority (PoRA). The land reclamation began in 2008; 400 ha is already contracted in the first phase, and the first ship will be received in 2013. The construction for the second phase will begin in response to client demand and it is only in 2033 that MV2 will be fully operational. This means that, in between the phases (time uncertain), a large area of water – protected by an expensive sea defense – is not in use (Figure 1).

This situation offers a unique opportunity for the PoRA to generate extra revenues by carrying out commercial activities (of a temporary nature) in this area. This possibility was explored in a study, the details of which can be found in Ros (2011).

The various steps of the study are described briefly in the following sections:

- an inventory of activities suitable for the inner lake (not necessarily related to cargo handling);
- an inventory of infrastructure design concepts (traditional and flexible) and proposals for preliminary designs for each activity based on a cost analysis;
- a life cycle analysis to establish the viability of various activities in various scenarios;
- a detailed analysis to examine the financial viability of the selected alternative;
- drawing of conclusions over all aspects of the case study, with a focus on flexibility.

Site description and boundary conditions

Figure 2 shows the 500 hectare inner lake divided into parcels – the size, water depths and the approximate time that the parcel is expected to become available are also indicated. The container terminals of RWG, APMT, and Euromax, presently under construction in phase 1 of the MV2 project, are also indicated.

A temporary dike divides the area into an open and closed lake. Based on the Master Plan (PMR 2010), which guides the development of MV2, the availability of the inner lake is determined as being about 7 years.

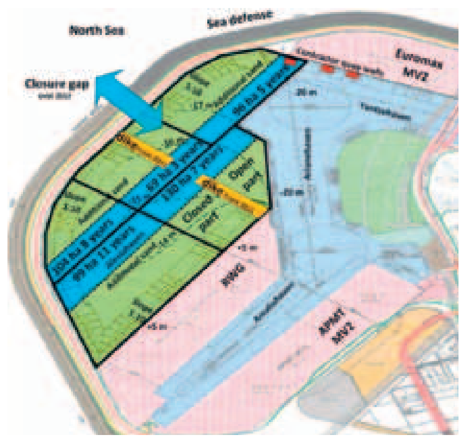


Figure 2. Masterplan of Maasvlakte 2 (MV2).

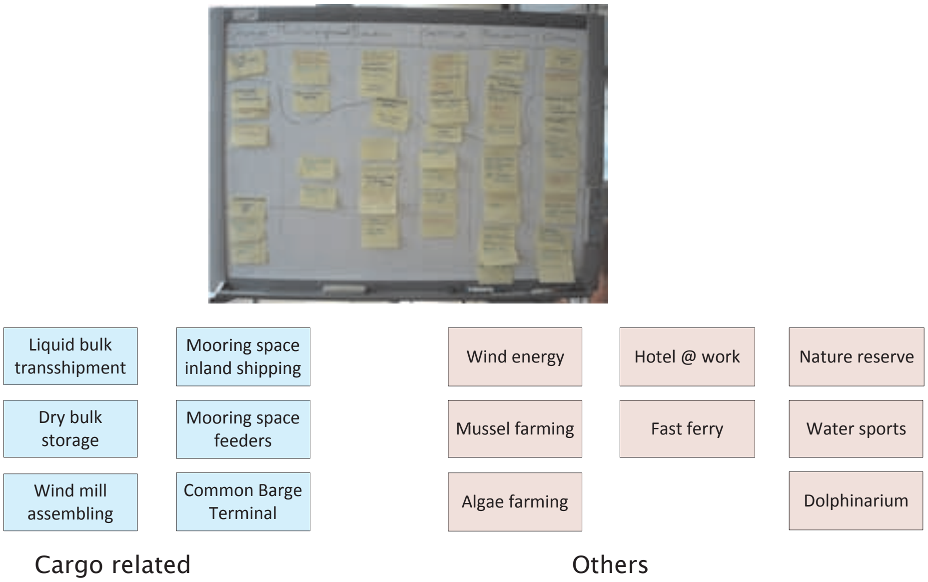


Figure 3. Thinking out of the box to find unusual activities in the inner lake: cargo related (left); others (right).

The inner lake water depth varies from 14 metres in the south-east to 17 metres in the north-west. The planning objective is to select amongst various commercially viable, temporary activities for this area. The selected function or activities for the inner lake, should fit within the policy of site allotment of the PoRA, and not hinder other building or operational activities at MV2. Regulations related to safety and the environment, such as the European Bird and Habitat Directive, the Dutch spatial planning law, and the Dutch water law, limit the activities the activities that can be carried out at the inner lake. The requirements set out in the zoning plan (IGWR 2008) and the Environmental Impact Assessment reports (PMR 2007) are also applicable.

Inventory of potential activities

In order to formulate alternatives, a brainstorming session was organised with participants from PoRA, Delft University of Technology, and Municipality of Rotterdam (PoRA 2011).

Innovative ideas and out-of-the-box thinking were encouraged. The activities were not limited to cargo handling (although these generate the largest revenues in the form of port dues and contract income for PoR). The inner lake also offers a unique location for carrying out pilot projects of innovative character, e.g., realisation of flexible infrastructures or new activities.

Certain activities are beneficial for the existing or future clients of PoR; others can benefit the image of the port, yet others could represent future opportunities for the port.

Figure 3 displays the seemingly most promising activities in the inner lake. Some cargo related activities are:

- ship-to-ship transshipment of liquid bulk using buoys or dolphins saves intermediate storage and requires cheaper facilities than ship-to-shore transshipment; also safer because of its mild wave conditions and patrol vessels nearby;
- storage of construction materials, e.g., granite blocks transported from Norway to the Benelux;
- mooring facilities for inland vessels and feeders which have to wait since seagoing vessels have priority because they generate more revenues and have service time agreements;
- a common terminal as a central trans-shipment hub for inland vessels (barges) which obviates the need for hopping of inland vessels through the port (CBT);
- assembly of structures such as caissons or offshore platforms;
- assembly of offshore wind turbines are transported in components to ports, assembled in ports and transported by sea, big market to meet European Union's renewable energy targets.

Under non-cargo related uses, the inner lake could also be used for:
- the generation of wind energy;

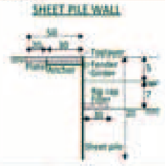
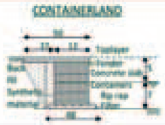
Structure	Port infrastructure	Other
SHEET PILE WALL 	- Quay wall	- Construction pit
L WALL 	- Quay wall - Crane foundation - Superstructure quay wall	- Abutment - Dry bulk storage - Landmark
CAISSON 	- Quay wall - Liquid bulk storage	- In a closure dam - Breakwater - Foundation wind mill
CONTAINERLAND 	- Slabs in crane track - Slabs terminal road	- Slabs in buildings
MAXISTECK 	- Jetty for liquid bulk transshipment - Piles as dolphin - Pile foundation	- Piles as props in a building pit

Figure 4. Reuse possibilities of selected infrastructure.

- mussel farms to cope with increasing demands;
- a pilot project for algae farming (algae can be used as biofuel in the future);
- installing a hotel for the workers at MV2 (as many as 2500 workers are expected between 2010 and 2035);
- a fast ferry for 10,000 commuters to the MV2;
- a temporary nature reserve which can help the flora and fauna, many kinds of water sports;
- a dolphinarium.

Selection of flexible constructions and preliminary designs

Infrastructure facilities are required to facilitate various activities. Some activities require waterside or landside access, others require extensive berthing, mooring, transshipment, or storage facilities, and yet others require no facility.

The inner lake will exist for a limited time and most traditional fixed infrastructure, owing to the long payback periods, is financially non-viable for this situation. Three options were available:

- Traditional fixed designs: a sheet pile wall, buoys or dolphins are relatively inexpensive, and can be reused; a jetty is also relatively inexpensive.
- Design for a shorter technical lifetime (in order to match the short economic lifetime): Containerland with a lifetime of 8-10 years is a possibility.
- Flexible designs that can be adapted for reuse: an L wall, Maxisteck, a barge, or caissons can be employed.

Structure selection is based not only on the immediate functional requirements of an activity, but on long-term considerations that include reuse. These structures can be seen in the first column of Figure 4, which also shows their reuse possibilities (in the port or otherwise). Most quay wall types, except for Containerland (CUR 2006) and Maxisteck (IGWR 2000), are well known (Figure 5). These two innovative concepts were a result of an initiative of PoRA, whereby the market was encouraged to come up with flexible concepts for infrastructures. In spite of pilot studies, these concepts have not been applied.

Each activity has its infrastructural and logistic requirements. Figure 6a and 6b show the alternative activities with the required facilities and the proposed location. The preliminary designs, i.e., dimensioning of the structures is carried out based on reference projects.

The technical lifetime of the structures differs as do the investment, operational, demobilisation, replacement and demolition costs. Reuse at another location is possible in all cases (in the case of Containerland the uncoated containers need to be replaced after 10 years).

The technical lifetime of Containerland is assumed to be 10 years, a sheet pile 25 years, and for the remaining structures 50 years. Investment costs are based on reference projects. Rough assumptions are made over the demobilisation, transport, demolition, storage and assembly costs.

Since the period of use is short, and revenues are not likely to differ irrespective of the structure, life cycle cost is used as a criterion for selecting the type of structure for each activity. This results in the following choices:

- Jetties are suitable for hotel at work and the fast ferry. A short jetty on a protected slope is cheaper than a longer jetty on a natural slope.
- Mooring structures are required for liquid bulk transshipment, as well as for mooring inland shipping and feeders. Piles are slightly more costly than buoys, but preferable.
- CBT requires a quay. Containerland is most cost effective because of the limited. Availability of the inner lake (at most 20 years). The containers, with a lifetime of about 10 years can be replaced, or alternatively they can be protected from corrosion.
- Wind mill assembling and dry bulk storage require a quay. The existing quay wall of the contractor can be used instead of creating costly dedicated facilities.

Life cycle analysis

The financial viability of the activities needs to be examined in a business case. This requires an estimation of all relevant costs and revenue over the anticipated life cycle, the rest value and the possibility of reuse. This is also given the name Life Cycle Analysis. The alternative with the lowest net present value is commercially most attractive.

The revenues of Port of Rotterdam Authority consist of port dues, land rent and mooring dues. The port dues cover the use of the nautical port infrastructure. The dues paid by seagoing vessels are related to the volumes handled. Most inland vessels have annual contracts and pay a relatively small amount irrespective of the number and duration of calls. Figures 7a and 7b show en estimate of the revenues generated per year through each activity using reference projects. The contribution of the port and mooring dues as well as the contract income from land rent can be distinguished for each activity in the figure.

However, not only the future costs and revenues, but the useful lifetime of an alternative is uncertain. Therefore, various scenarios are developed by varying the number and duration of useful service life/lives

Figure 5. Containerland: slabs in terminal load (left), Maxisteck (right): Jetty for liquid bulk, transshipment, piles as foundation piles or dolphins.

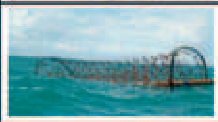
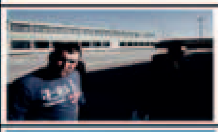
Activity		Requirements	Structure	Allocation
Wind energy		- Power cable - Center to center distance of about 500m - Boat or road access - Obstacle to water sports	- Wind mills (by operator)	- Closed & open part inner lake
Mussel farming		- Tidal range + flow - Fisher boat access - No oil spillage	- Sleeves (by operator)	- Closed & open part inner lake
Algae farming		- No oil spillage - Boat access	- Sleeves (by operator)	- Closed & open part inner lake
Hotel at work		- Floatel: 200x30x7 m - Road connection - Parking area - Not next to activities that cause noise	- Jetty with retaining height of 14m, width 1/10: 140m width 1/40: 50m	- Open part inner lake next to sea defense or temporary dike
Fast ferry		- Ferry: 20x4x2 m - Minimum amount of passengers	- Jetty with retaining height of 6m, width 1/10: 60m width 1/4: 24m	- Open part inner lake next to sea defense or temporary dike
Nature reserve		- Not next to other activities - No oil spillage		- Closed part inner lake
Water sports		- Parking area - Safety distance to vessels	- Parking area	- Closed part inner lake
Dolphinarium		- Basin & accommodation - Sheds, grandstand, facilities basic needs - road access, parking area	- Quaytype structure LxWxRH: 50x50x8m - Fence to separate basin from inner lake	- Closed part inner lake next to beach or temporary dike

Figure 6a. Alternative cargo-related activities with required facilities and locations. (Source: Ros 2011).

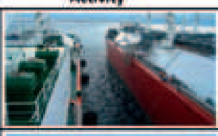
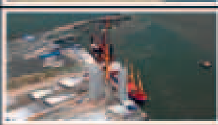
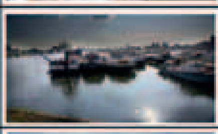
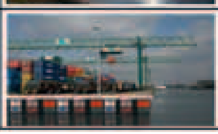
Activity		Requirements	Structure	Allocation
Liquid bulk transshipment		- 150,000 DWT, 400x45x16 - Mooring facilities - Oil spillage measures - Safety distances - Tug assistence	- One dolphin or buoy per 50,000 DWT	- Until Suezmax, draft less than 16m in the open part inner lake next to Yantzehaven
Dry bulk transshipment		- 44,000 DWT, 201x28x6 - Several hectares for storage	- Contractor quay wall	- Open part inner lake at contractor quay wall
Wind mill assembling		- 6-25 ha, 30-60kN/m2 - Quay=200m, draft=6m - 365/24 access for oversize trucks & vessels - warehouse of 1,000m2	- Contractor quay wall - Or, dedicated quay with length of 200m & retaining height 13m	- Open part inner lake next to sea defense or temporary dike
Mooring spaces		- Inland vessels: 3,000 DWT, 135x10x5 - Feeders: 16,000 DWT, 170x30x10	- Dolphin or buoy for one or several vessels	- Open part inner lake next to Yantzehaven
Common barge terminal		- 3,000 DWT, 135x10x5 - Terminal equipment - Quay=300m, draft=5m - Road & vessel access	- Dedicated quay with length of 300 m and retaining height 12m	- Open part inner lake next to sea defense or temporary dike

Figure 6b. Other alternative activities with required facilities and locations. (Source: Ros 2011).

of the infrastructure. The service life of various alternatives depends on development of MV2 – the expected availability is about 7-10 years. The site is expected to remain idle for at least two years and activities with cancellation periods of 1-2 years are favoured. The service life of the quay is assumed to be 10 years. Two sets of alternatives are distinguished here:

a) employing structures with 50 year technical lifetime (revenues come in the case of scenarios 2-5);
b) employing no structures (no revenues in all scenarios).

Figures 8a-8c show the Net Present Value (NVP) of the activities (using the selected structure) on the Y axis plotted against the lifetime of the activity. For each activity, when the break-even point is reached is visible (i.e., NPV=0). For the activities requiring no structure, the cash flow is positive in the first year itself.

The activity with the largest NPV is liquid bulk transshipment followed by dry bulk storage and wind energy generation. Wind mill assembling is also financially viable if the existing quay wall can be used. The common barge terminal, evaluated on the same basis, is non-viable (the next section uses a more rational approach leading to a different result). A dolphinarium, fast ferry, and mooring facilities for inland shipping and feeders are not financial viable.

Water sports do not generate revenues, but create a positive image for PoR. Hotel at work will generate small revenues, could reduce commuter traffic and support other activities at MV2. A floating hotel requires seaside access as well at a certain distance from port activities. The fast ferry generates small revenues and is only useful with activities such as a dolphinarium, hotel at work or an amusement park. A nature reserve has a positive impact on the environment through an increase in biodiversity. Mussel and algae farming, both in the pilot project phase, require little investment and can generate small revenues. Hotel at work has a positive NPV. Liquid bulk transshipment can take place at Maasvlakte 2 with Suezmax vessels (150,000 DWT, 200 m LOA of about 200 m, a draft of 14.5 m). For larger vessels the inner lake has to be deepened locally, and Very

Large Crude Carriers (VLCC) cannot be received in Yantzehaven. Currently, LNG transshipments take place in the North Sea (Figure 9). Ship-to-ship transshipments are more costly at the inner lake but, because of mild wave conditions and patrol vessels nearby, safer than in the North Sea. Still, a larger number of vessels on the inner lake could increase the chance of encounters and minimum safety distances to other activities are required as well. The common barge terminal, a concept that provides flexibility for all the parties (and coincidently, the only activity which employs a non-traditional quay wall), is discussed in detail in the next section.

COMMON BARGE TERMINAL: CONCEPT

A common barge terminal (CBT) is a central point for inland vessels to pick up and drop off cargo instead of hopping among several container terminals. It requires a quay to berth vessels and handle cargo and preferably is located close to the terminals. It has to be accessible via road for the employees, suppliers, emergency services and internal transport of cargo to other terminals. The transport to and from to the terminals is carried out by 25 TEU or 50 TEU vessels. The concept is illustrated in Figure 10 (Malchow 2011).

The market success of the common barge terminal depends on the collaboration between the container terminal operators RWG, APMT and Euromax (CTO), the terminal operator of CBT (CBTO) and PoRA. In the current Master Plan, though a barge feeder terminal is planned at MV2, a part of the quay will be used for handling inland ships.
The container terminals too, will be realised in phases in response to market demand. According to the current forecasts, even in the worst case economic scenario, an increase of 3.5% per year is expected in the container throughput, and on average 6%. When the sea terminals are nearing capacity, a CBT can help in reducing congestion. A SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the CBT concept was carried out to evaluate the strengths, weakness, opportunities and threats of the concept (Table I). Viewing Table I, the left column (Strengths and Opportunities) outweighs the right column and is evidence of the overall benefits of the concept.

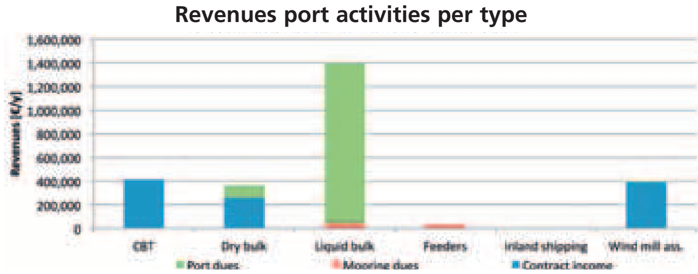


Figure 7a: Revenue from cargo-related activities.

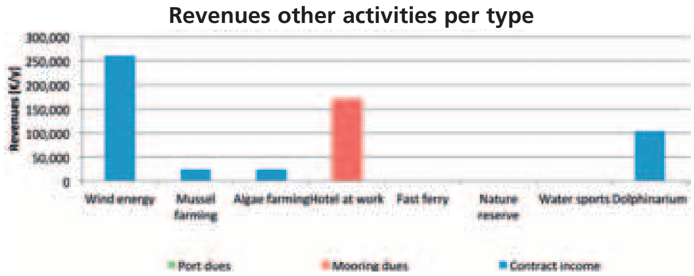


Figure 7b: Revenue from other activities.

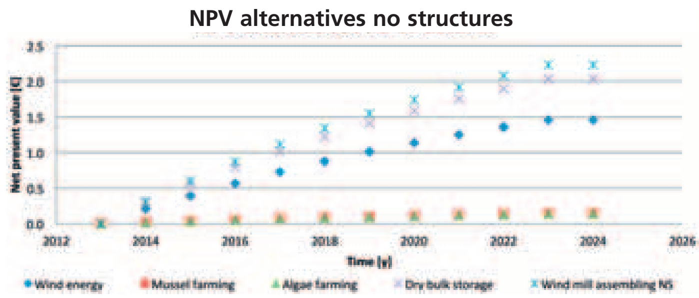


Figure 8a. Net Present Value (NVP) for activities requiring no structures.

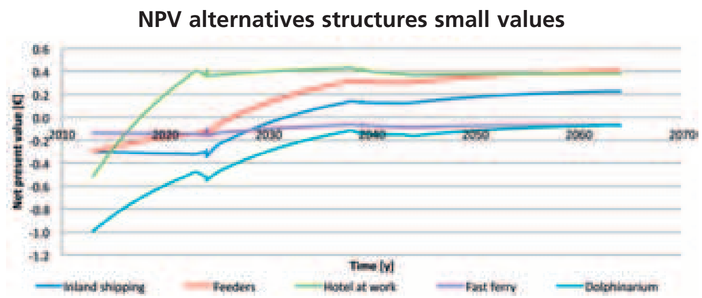


Figure 8b. Net Present Value (NVP) for activities requiring structures (low NPV).

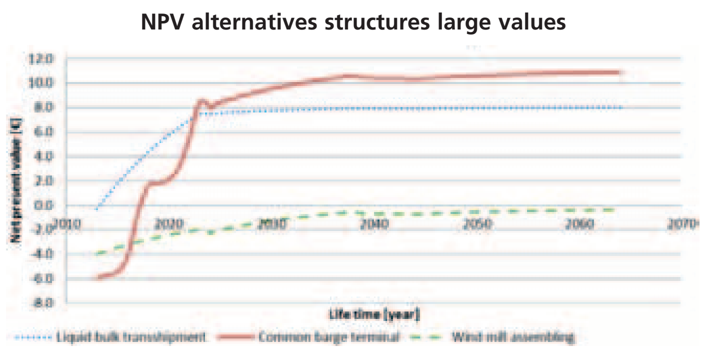


Figure 8c. Net Present Value (NVP) for activities requiring structures (high NPV).

Figure 9. Ship-to-ship transshipment (Source: Excelerate Energy).

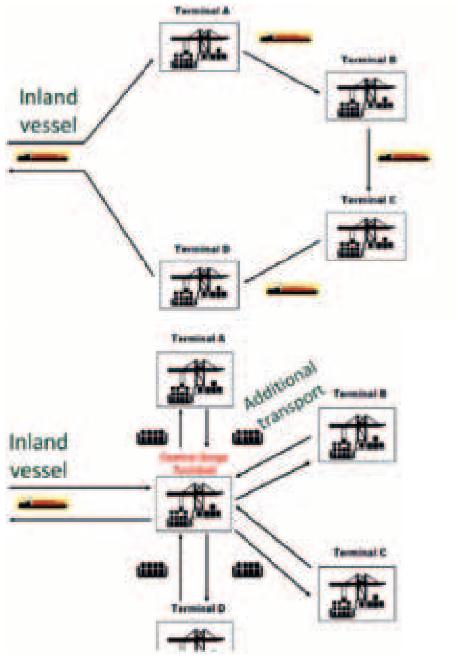


Figure 10. Logistics without CBT (left), with CBT (right) (Source: Malchow 2011).

Result of Financial Analysis of a CBT

PoRA invests in the quay wall and infra plus; CBTO invests in the equipment and additional transport. CTO incurs the cost for transport and container handling of the barges at the CBT in order to relieve congestion at its terminals when they near capacity. The benefit is postponement of investment in infrastructure expansions, without loss of cargo, and its competitive position. Shifting small call sizes to the CBT makes it possible to handle large call sizes as well as a larger number of sea vessels at the container terminals. Handling sea vessels instead of barges increases the productivity, thus in a way a CBT creates extra capacity at the sea terminal (Zuidgeest 2009).

The costs and benefits of this concept need to be monetised in a business case for all individual parties -- the container terminal operators RWG, APMT and Euromax (CTO), the operator of CBT (CBTO) and PoRA. This financial analysis is based on many uncertain factors, e.g., container throughput and terminal productivity which together determine the capacity of the container terminals and when it is exceeded; call sizes of barges at the container terminals and the percentage of small call sizes; the logistic concept selected by the CBTO; the future port tariff structure; handling and internal transport costs and so on. In this analysis assumptions were made in consultation with experts in order to arrive at estimates of these variables in the business case.

The analysis concluded that the CBT was a viable option for the PoR, if the business cases of CBT, the container terminal operators and PoRA are taken into account. Thereby, the eventual savings from postponed investment in container terminal expansions could be treated as income in the individual business cases of PoRA and CTO. The indirect benefits for PoRA in the form of greater efficiency at the sea terminals were, however, not included. CTO benefits most from this concept, and a concrete business case helps in negotiations for mutual sharing of the benefits from this concept.

Table I. SWOT Analysis Common Barge Terminal Concept.

Strengths	Weaknesses
- increased efficiency and productivity at sea terminals (thus creating extra capacity in the terminal) - faster loading/unloading of inland shipping by dedicated barge cranes - cost savings for PoR owing to phased investment in civil infrastructure - cost savings for CTO owing to phased investment in terminal equipment, no additional rent, personnel and operational costs - shorter sailing distances in the port	- initial capital investment by PoR and CBT operator - requires co-operation amongst involved parties (CBTO, CTO, PoR) - logistics of barge transport need optimisation
Opportunities	**Threats**
- delay investment in phase 2 MV2, use resources elsewhere - modal shift to inland transport owing to available infra - reduced congestion at terminals, better relations with CTO, better image for the port, more clients for phase 2 of MV2 - pilot project for flexible structures	- conflicts between parties - each party wants its own barge feeder terminal - inland shipping rates rise making it non-viable - new forms of competitive transport (faster and environmentally friendly) appear

CONCLUSIONS

This case study dealt with utilisation of the inner lake at Maasvlakte 2 in Rotterdam for commercial purposes, using flexible infrastructural facilities. This was seen as a unique opportunity for the PoRA to generate extra revenues. Since the inner lake has a temporary existence in between the two phases of the MV2 project, the infrastructural facilities were meant to be suitable for temporary use. The choices lay between a civil structure with a short lifetime (thus suitable to be demolished), or a flexible infrastructure (easy to dismantle, transport and assemble), that could be to be reused at another location.

The study involved a selection of potentially viable activities in the inner lake, preliminary designs of required infrastructural facilities, as well as a selection of suitable location based on the logistics and safety considerations. The viability of these concepts was examined.

One of the promising concepts, i.e., the Common barge terminal (CBT) was evaluated in a detailed business case. The case study offered many insights related to both engineering and financial aspects of a port project. The following conclusions could be drawn over flexible infrastructures:

- Constraints from the surroundings, such as ongoing construction and operational activities, limit the choice of activities and infrastructure for the inner lake. Similarly, institutional bottlenecks (such as the Master Plan which forms the basis for the Environmental Impact Assessment, and based on which the construction permits have been granted) also restrict the possibilities.
- The selection of the type of structure is determined by the functionality it offers, and the short- or medium-term financial viability. In general, traditional infrastructure associated with minimum costs and risks (since the designs and construction methods have been optimised during multiple projects) is selected and preferred. Long-term viability is seldom examined.
- A capital-intensive concept has a small chance of being selected amongst available alternatives, despite the benefits that it may offer in the long-term future. Flexible solutions, such as a floating terminal, could help PoRA seize many such opportunities in the future, but the huge capital investments and unproven viability means that it will not be realised.
- When a non-traditional design concept does form an option (just as in the present study), the choices are limited to the existing concepts which have been well researched in pilot studies, through experiments or computer simulations. This fact signifies that collaborative research on innovative flexible concepts must continue, so that planners and designers have a variety of infrastructural solutions at their disposal.
- The study concluded that the CBT was a viable option for the PoR, taking into account the business case of CBT, the Container Terminal Operators and PoR. In this manner, the added benefits (such as savings resulting from postponed investment in container terminal expansions and a significant increase in efficiency and productivity at the sea terminals) could be taken into account in individual business cases of PoR and CTO. CBTO benefits most from this concept and a concrete business case helps in negotiation with the CTO for mutual sharing of the resulting benefits.
- Thus, a CBT provides additional flexibility to phase investments in container terminal expansions, both by PoR and CTO; the value of this flexibility has been included in the business case to support decision-making over the commercial use of the inner lake. A valuable lesson from the exercise is that phasing infrastructure expansion offers monetary advantages for all the parties through postponing investment and allows PoRA to keep their options open.

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