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Chapter 20

Port Feeder Barges as a Means to Improve Intra-Port Container Logistics in Multi-Terminal Ports

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Abstract The unique *P*ort *F*eeder *B*arge (PFB) can be considered as a "green logistic innovation" for container ports. The self-propelled and self-sustained container pontoon of double-ended configuration (capacity: 168 TEU) can release the terminal gates from queuing trucks and the terminal ship-to-shore gantry cranes from inefficiently serving small inland barges. The PFB can be employed in three business fields: Shifting container haulage within ports from road to waterway, supporting feeder operation, and loading and discharging inland barges. The PFB can be easily integrated in the container logistics within a port. In congested ports or ports with limited water depth and/or insufficient container handling capability even deep-sea vessels can be directly served midstream by the PFB. Hence the PFB can also be used as an emergency response vessel to quickly lighter grounded container vessels. The green potential of the vessel can be further exploited by using LNG as fuel.

20.1 Introduction

Within multi-terminal ports, such as Hamburg, Antwerp, Rotterdam, New York, or even Santos (Brazil), a lot of intra-port container haulage has to be organized. It is not only between the various deep-sea terminals but also between terminals and other container-related facilities like depots, packing stations (stuffing/stripping), and repair shops. For example, in Hamburg, it is estimated that 540,000 TEU are moved just within the port during the year 2015 (see Malchow 2016), which is done almost completely by truck causing congestion on the roads within the port, at the terminal gates and unwanted emissions. Especially the Köhlbrand Bridge (one of Hamburg's landmarks) which connects the eastern and western part of the port has

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to be crossed by 50% of the intra-port container trucking and serves as a major bottleneck (see Bönning 2009).

Beside the deep-sea terminals of container ports, also on-site located intermodal terminals (see, e.g., PoRA 2017c) and minor container-related facilities[1] are partly equipped with their own quay and can be accessed by water, i.e., at least by inland barges. Hence, it seems to be quite useful to look for a water-based alternative to container trucking within and around multi-terminal ports.

However, deploying conventional inland barges (or pontoons) for intra-port haulage would mean that the big *S*hip-*T*o-*S*hore (STS) gantry cranes of the deep-sea terminals had to be used for loading and discharging the small barges. Unfortunately, one single move by such crane is already as costly as approx. the entire trucking within the port.[2] That is why container haulage by conventional inland barges is at least twice as expensive as trucking. Additionally barges enjoy only the last priority at the deep-sea terminals causing significant delays in their port turn-around. Hence haulage by truck is much faster. Minor container handling facilities sometimes even do not have their own crane equipment.

Both aspects led to the conclusion that a self-propelled harbor vessel of sufficient container capacity which is equipped with its own full-size container crane would be a useful tool if waterborne intra-port container haulage had to be realized. However, such type of vessel does not exist yet.

20.2 The Port Feeder Barge Concept

The internationally patented *P*ort *F*eeder *B*arge (PFB) is a self-propelled container pontoon with a capacity of 168 TEU (completely stowed on the weather deck), equipped with its own state-of-the-art container crane mounted on a high column (see Fig. 20.1). The crane is equipped with an automatic spreader, extendable from 20 ft to 45 ft, and a turning device. A telescopic over-height frame is also carried on board. The PFB is of double-ended configuration, intended to make it extremely flexible in connection with the sideward mounted crane. Due to the big width of the vessel no operational restrictions (stability) for the crane shall occur (see Table 20.1).

The PFB crane has a capacity of 40 t under the spreader, at an outreach of 27 m (maximum outreach: 29 m). The vessel is equipped with 2 electrically driven rudder propellers at each end in order to achieve excellent maneuvrability and the same speed in both directions. Hence the vessel can easily turn on the spot. While half

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[1] For example, empty container depots (see, e.g., PoHM 2017a and PoRA 2017a) or container packing stations (see, e.g., CPA 2017).

[2] Depending on the liner shipping company, the terminal handling charges for 20 ft and 40 ft standard containers amount to about 225 EUR at the port of Hamburg and about 205 EUR at the port Rotterdam (winter 2016/17).

Fig. 20.1 Port Feeder Barge (artist impression)

Table 20.1 Port Feeder Barge – main data

Type	Self-propelled, self-sustained, double-ended container barge
Length (overall)	63.90 m
Width (overall)	21.20 m
Height to main deck	4.80 m
Max. draft (as harbor vessel)	3.10 m
Deadweight (as harbor vessel)	2500 t
Gross tonnage	Approx. 2000 BRZ
Power generation	Diesel/gas electric
Propulsion	2 × 2 electrical rudder propeller of 4 × 280 kW
Speed	7 knots at 3.1 m draft
Class	GL ✠ 100 A5 K20 Barge, equipped for the carriage of containers, Solas II-2, Rule 19 ✠ MC Aut
Capacity	168 TEU (thereof 50% in cellguides), 14 reefer plugs
Crane	LIEBHERR CBW 49(39)/27(29) Litronic (49 t at 27 m outreach)
Spreader	Automatic, telescopic, six flippers, turning device, over-height frame
Accommodation	Six persons (in single cabins)

of the containers are secured by cell guides, the other half is not, enabling the vessel to carry also containers in excess of 40 ft length as well as over-dimensional boxes or break bulk cargo. Fourteen reefer plugs allow for the overnight stowage of electrically driven temperature controlled containers.

The PFB shall fulfill the highest environmental standards. A diesel- or even gas-electric engine plant with very low emissions has been chosen to supply the power

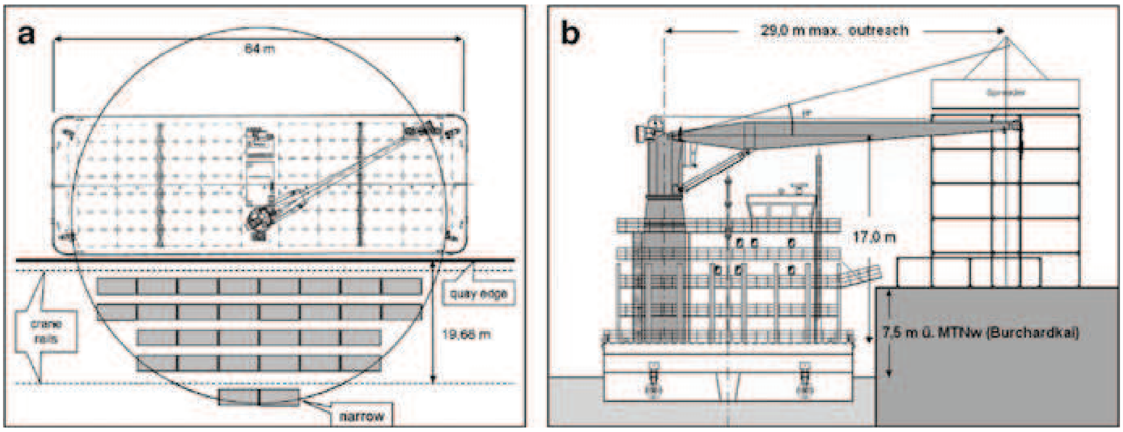

Fig. 20.2 (**a**) Turning cycle of crane, (**b**) Outreach of crane

either for propulsion or crane operation. The vessel can be operated by a minimum crew of 3 whereas in total 6 persons can be accommodated in single cabins.

The key element of the worldwide unique PFB concept is its own full-scale heavy duty container crane. All its mechanical components have been especially designed for continuous operation – unlike standard shipboard cranes, which are designed for operation only every few weeks when the vessel is in port. Due to its nature the load cycle requirements of the PFB are even higher than for many quayside cranes, which has a significant impact on the design of the mechanical components of the crane. When berthed the PFB is able, without being shifted along the quay, to load or discharge 84 TEU in three layers between the rails of typical quayside gantry cranes (see Fig. 20.2a). This is more than sufficient, with a total loading capacity of 168 TEU.

That is why the full outreach of the crane is not always needed. Berthing the barge with the crane on the opposite side of the quay (see Figs. 20.2b and 20.3) would speed up crane operation as the turning time of the outrigger is minimized. Depending on the specific conditions and the driver's ability the crane productivity is estimated to at least 18 moves/h.

The height of the crane column is sufficient to serve even high quays in open tidewater ports at low tide while stacking the containers still in several layers on the quay (or to serve even deep-sea vessels directly, see Fig. 20.6). Due to its short length of 64 m the PFB needs only a small quayside gap between two deep-sea vessels for self-sustained operation (see Fig. 20.3).

The operation of the PFB is not limited to inside a seaport or its neighborhood. As the hull is classified according to DNV-GL's class notification for seagoing vessels, the operation in (sheltered) open waters off the coast is also possible which opens some interesting opportunities for additional employment (see, e.g., Sect. 20.4.1). Considering intra-port container haulage the PFB shall ply between all the major and minor waterfront container handling facilities, including a dedicated berth to meet with the inland waterway vessels which can even be located somewhere at the dolphins.

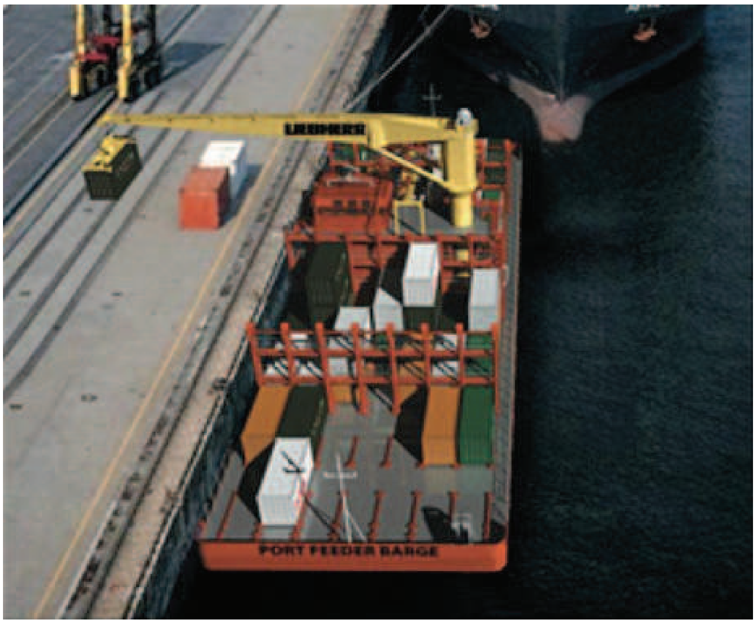

Fig. 20.3 The PFB is working independently from quayside equipment at a deep-sea terminal requiring only a small gap between two deep-sea vessels (artist impression)

20.3 Business Fields

20.3.1 Intra-Port Haulage on the Example of the Port of Hamburg

The PFB shall serve as a “floating truck” in the course of its daily round voyage throughout the port, i.e., shuttling containers between the various container facilities. Hence container trucking within the port can be substantially reduced.

It is estimated that in 2015 within the port of Hamburg approx. 290,000 containers, i.e., approx. 88% of the total volume, have been carried by truck (which is corresponding to approx. 475,000 TEU, Malchow 2016).[3] The remaining 12% have been already carried on the water by ordinary inland barges. The reason for the poor share of conventional barging is very simple: In most cases intra-port barging of standard containers is not competitive unless the liftings by the quayside gantries were subsidized by the terminals which cannot be expected.

According to industry sources one-third of the road haulage within the port of Hamburg is between two (out of four) deep-sea terminals while more than half is between the deep-sea terminals and off-dock facilities (like depots, packing stations, repair shops, etc.) of which some have their own water access (see Malchow 2016). Taking into account all aspects, e.g., no complete water access of all minor facilities and required cut-off time for the booking procedure, the present cargo potential

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[3] According to the Port of Hamburg Marketing Board the average TEU ratio at the port of Hamburg was approx. 1.6 TEU/box in 2015.

Fig. 20.4 Typical view on Hamburg's Köhlbrand bridge linking the port's eastern and western part (German Press Agency)

for the PFB out of the intra-port haulage in Hamburg is estimated to roughly 95,000 containers p.a. (corresponding to approx. 150,000 TEU). At present approx. 50% (!) of all intra-port container trucking has to pass the frequently congested Köhlbrand Bridge (see Bönning 2009 as well as Fig. 20.4).

Considering the advantages discussed in Sect. 20.2, the PFB offers a more competitive service than the trucks can do. Beside lots consisting out of many standard containers, this especially applies to over-sized boxes like flats with over-width/-height and also boxes containing dangerous goods whose trucking requires special-licensed but very rare drivers. Hence the PFB operation can contribute to less congestion at vital bottlenecks on the roads within port areas and is a viable and much more environment-friendly alternative compared to trucking.

20.3.2 Feeder Operation

In multi-terminal ports common feeder services have to receive and deliver containers from/to all facilities of the port where deep-sea vessels are berthing. For this reason the feeder vessels have to call at all such terminals within the port – sometimes even if only a few boxes have to be handled.

For example, in the port of Hamburg the daily business of feeder operators shows that each of their vessels has to call in average at four different facilities (incl. waiting berths, see Behrend 2016 and Malchow 2015). In order to save some berth shiftings the companies make already intensive use of road haulage services. Otherwise the number of shiftings within the port would have been even higher. From the experience of deep-sea terminal operators, vessels with less than approx. 100 boxes to handle are critical with respect to profitability (see Meyer and Wörnlein 2008). However, at the port of Hamburg a big portion of all terminal calls of feeder vessels are below that figure. Smooth and efficient feeder operation is essential for the port's economic well-being as its entire container throughput relies to more than one-third on transhipment (about 36% in 2015, PoHM 2017b).

As the feeder operators are usually an important customer of the trucking companies for intra-port haulage the PFB can replace trucking for collecting and distributing containers in multi-terminal ports. With its cost advantage it is expected that the PFB will be used by feeder operators more intensively than truck services at present enabling the concentration of feeder calls on fewer terminals. This reduces the number of berth shiftings as well as the port time of the feeder vessels and related costs. Furthermore, it leads to increasing terminal and berth efficiency and is associated with significant improvements in safety (danger of ship collisions).

20.3.3 Inland Navigation

In general, inland navigation is facing a dilemma as far as the hinterland transport of containers to and from seaports is concerned. On the one hand, there is a common understanding that its share in hinterland transport has to be substantially increased – for capacity and environmental reasons. On the other hand, inland waterway vessels in sea ports have to berth at the facilities which are tailor-made for the biggest container vessels sailing on the seven seas (with a capacity of 22,000 TEU and possibly even more in the future). Hence the efficiency of the big STS gantry cranes is rather low when serving the small inland barges. It comes as no surprise (but is most disadvantageous) that inland navigation enjoys the last priority when it comes to berth allocation at deep-sea facilities (see Malchow 2007).

Inland barges suffer even more than feeder vessels as they have to call at more facilities. For example, the port of Rotterdam has approx. 30 terminals and depots (see PoRA 2017b, PoRA 2017c and PoRA 2017a) which are frequently served by inland barges (the barge share of hinterland container transport is steadily above 30% during the last decade, see, e.g., Pastori 2015, p. 9).

The average number of terminal calls per barge is about 10 whereas in 50% of all cases less than 6 containers are handled (see Konings 2007 and Konings 2005). This kind of inefficient and hardly coordinated "terminal hopping" is very time-consuming and each delay at a single terminal results in inacceptable accumulated waiting time during the entire port stay. Actually, roughly one-third of the time in port is only spent for productive loading/unloading (see Konings 2007).

In Hamburg – where inland navigation has still a poor share of approx. 2% in hinterland container transport (see PoHM 2017b) – the inefficient operation has been identified as one of the major reasons for such small share. Some Dutch and German studies regarding the problems of transhipment procedures between inland barges and deep-sea vessels have been already published (see Beyer and Pistol 2009; Konings 2005, 2007 as well as Menist 2008). One common recommendation is that container handling for inland navigation and container liner shipping should be separated from each other. In other words: Inland barges should not call at the deep-sea facilities any more.

It has been already proposed to introduce dedicated berths at the deep-sea terminals for processing inland barges. However, most terminals simply do not have any shallow draught waterfront left where such berths could be meaningfully arranged. Transforming existing valuable deep-sea quays to exclusive barge berths with smaller gantry cranes does not pay off for the terminals as such a measure would reduce their core revenue earning capacity. For smooth inland navigation, the introduction of a central (dedicated) terminal within a port, where all inland barges call only once, has also been proposed to spare the barges their inefficient "terminal hopping." However, this would burden the most environment-friendly and economical mode of hinterland transport with the costs of two further quayside crane moves and one additional haulage within the port (either on the water or even by truck). The opposite of more waterborne containers in hinterland transport would be the consequence. Nevertheless, a few facilities for processing non-deep-sea vessels have been put into operation at container ports in recent years. For example, since 2009 the ECT Delta complex at the port of Rotterdam is equipped with a 800 m quay wall and three smaller STS gantry cranes exclusively dedicated for feeder and barge processing (see ECT (2016)).

Hence increasing the share of inland navigation in hinterland transport of containers is frequently facing a dilemma in many major container ports. To overcome such a dilemma the PFB can act as a dedicated "floating terminal" for inland barges. During its envisaged daily round voyage throughout a multi-terminal port the PFB shall collect and distribute the containers also for inland navigation. Once (or several times) a day, the PFB will call at a dedicated berth to meet with the inland barges where the containers shall be exchanged ship-to-ship by the PFB's own gear, independently from any terminal equipment (virtual terminal call). Not even a quay is required but the transhipment operation can take place somewhere midstream at the dolphins (see Fig. 20.5). Such kind of operation would mean that the terminals would delegate their obligation towards their customers to serve also the inland barges partly or completely to the PFB.

A "floating terminal" provided by the PFB will strengthen the competitiveness of inland navigation and contribute to increase the share of the most environment-friendly mode of hinterland transport. Employing one or more PFBs as a "floating terminal" is less costly and much quicker and easier to realize than the erection of any equivalent quay-based facilities (not to mention that less parties have to be involved for approval and that operational flexibility increases appreciably). The entire PFB investment is in the range of the procurement costs of a single STS gantry crane which is designed to serve huge deep-sea vessels.

As ports can avoid heavy land-based investments and with that land consumption as well as changes in townscape, it is apparent that such a terminal concept not only provides economic and environmental advantages but beneficially affects urban issues as well. Considering all this positive impact, a "floating terminal" is much smarter than any land-based facility.

Fig. 20.5 The PFB is serving a conventional inland barge midstream (artist impression)

20.4 Further Applications

20.4.1 Emergency Response

The PFB can also help to keep consequences of maritime averages at a minimum. When container vessels are grounded in coastal zones they mostly have to be lightered very quickly to set them afloat again in order to avoid further damage to the vessel's hull, the environment, and in extreme cases to sustain even the accessibility of a port at all. However, it has to be conceded that most container ports are not really prepared for such a situation and do not have suitable floating cranes (if any) available to quickly lighter big container vessels.

Despite its small size the base version of the PFB (168 TEU) can rapidly lighter grounded container vessels of up to 6000 TEU capacity by working from both sides (Fig. 20.6). For bigger vessels the crane has to be mounted on a higher column and the crane's outrigger has to be lengthened. The average of M/V "CSCL Indian Ocean" in 2016 (see Fig. 20.7) has dramatically demonstrated that adequate salvage equipment is generally missing. If the containers from the ninth deck layer of such a grounded 19,000 TEU vessel had quickly to be lightered a floating crane would have been needed with a hook height of at least 60 m. Such equipment is worldwide very rare and hence was not quickly available in this special case. Unlike some other heavy floating equipment, the PFB can navigate in very shallow waters due to its light ship draught of only 1.2 m (base version).

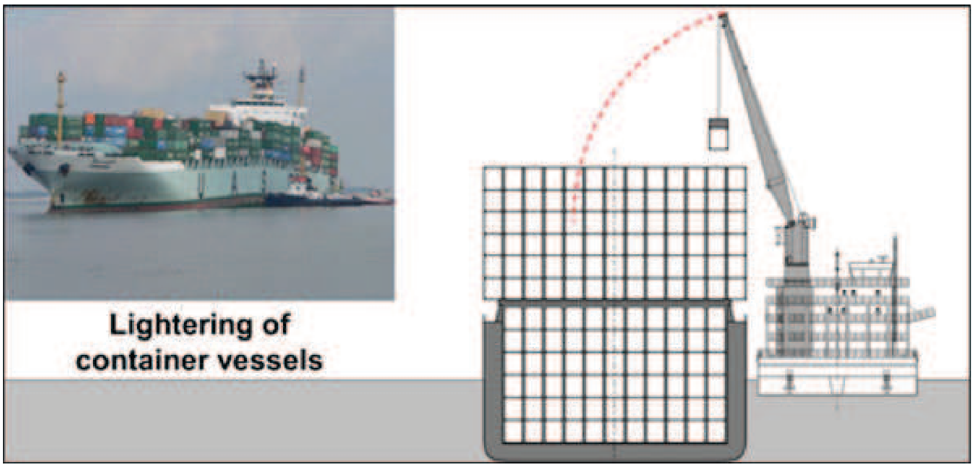

Fig. 20.6 Grounded Panamax container vessel on Schelde river in 2005 and how it could have been quickly lightered by a PFB

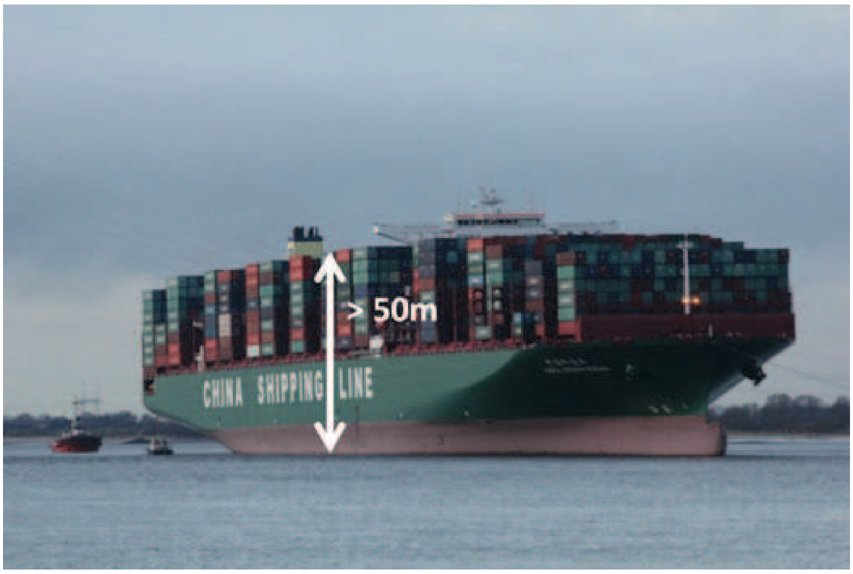

Fig. 20.7 M/V "CSCL Indian Ocean" (19,000 TEU) grounded in Feb. 2016 on Elbe river heading for Hamburg

20.4.2 Hong Kong Style Midstream Operation

In Hong Kong a considerable portion of the huge port's container throughput still relies on floating units directly serving deep-sea vessels while laying at anchor (see Fig. 20.8). These traditional midstream barges are equipped with their own cargo gear, but the handling method is far from being sophisticated. The A-frame derricks have a single beam just controlled by wires and are not even fitted with a spreader. Instead, steel wires are fitted manually to the corner castings of the containers. In fact, this cargo handling technology is from the 1950s and complies hardly with international port labor safety standards. Such midstream barges are only operating in Hong Kong (except a few in Angola and Vietnam). Still in the 1990s, up to

Fig. 20.8 Typical midstream operations in Hong Kong

ten fatal accidents per year were officially reported, whereas the handling method has not been improved since then (see Buddle 1998). Quite apart from the health and safety issues, they are not self-propelled (not even pushed but towed). The midstream share of the total Hong Kong container throughput has continuously decreased to less than 10% at present (see HKMOA 2017, MD Hong Kong 2017 as well as Wan 2009).

PFBs would significantly improve such ship-to-ship operation with regard to safety, efficiency, speed, flexibility, and accessible ship sizes. At other places of the world where terminal facilities are insufficient or congested or water depth is limited such advanced midstream operation provided by PFBs would be a viable alternative to the long lasting construction of costly land-based deep-sea terminal facilities. Beside pure container operation the PFB can also be used as a flexible floating unit with handling, storage, and transport capabilities. With a crane mounted on a column of 17 m and a capacity of 49 t under the hook (40 t under the spreader) complemented by sufficient deck space for any kind of cargo (other than containers), the PFB can also be used as an ordinary floating crane.

20.5 The LNG Option

All costly measures to be taken to keep the exhaust emissions of the diesel-electric engine plant at an envisaged minimum (e.g., exhaust scrubbers, urea injection, filters, etc.) could be saved when choosing LNG as fuel. The PFB can serve as an ideal demonstrator for LNG as ship fuel:

- As a harbor vessel it does not rely on a network of bunker stations. Only one supply facility is sufficient. As the power demand is relatively low the vessel could even be supplied out of a tank truck at the initial stage (a standard 50 m^3 truck load was sufficient for approx. 14 days of operation).
- Due to its pontoon type there is plenty of void space below the weather deck. Hence the accommodation of the voluminous LNG tanks would not be a problem at all which is not the case with most of the other types of harbor vessels. Approx. 500 m^3 of tank capacity could be theoretically installed which is by far more than sufficient as this quantity is good for several months of continuous operation (see Fig. 20.9).

As in the meantime ISO tank container for LNG are available (see Fig. 20.10) such units could also be used for bunkering purposes while making use of an environmental-friendly intermodal supply chain (instead of pure trucking). If the regulations allow, the units could be even loaded on the PFB with its own crane to serve as the vessel's fuel tank.

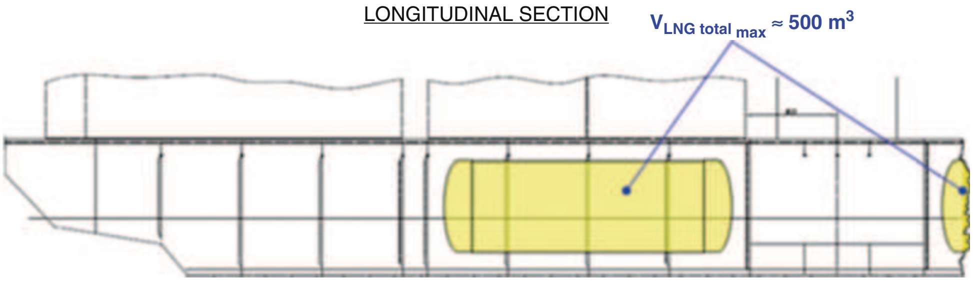

Fig. 20.9 LNG tank arrangement

Fig. 20.10 ISO tank container for LNG

20.6 Interface Between PFB and Terminal

Many discussions with all parties involved have shown that terminal operators' acceptance of self-sustained cargo operation at their facilities is a major hurdle for the PFB operation. Especially the unions of the terminal's labor force might oppose such cargo handling operation "from outside."

When the PFB calls at various container facilities within a port it has to be ensured that the entire operation is following well-established procedures. Such procedures have to be agreed upon in detail between the PFB operator and each individual facility in beforehand. The more sophisticated the terminal operation the more changes in the existing terminal routines have to be implemented. The following aspects have to be agreed upon:

- berthing procedures,
- physical box handling,
- data exchange, and
- commercial issues.

Firstly, it has to be checked whether the envisaged berths are suitable for the entire *berthing procedures* with the PFB. For example, the position of the quay fenders needs to be checked (considering all tide levels) and whether additional bollards for mooring the PFB are to be arranged in the quay wall. Furthermore, the procedure of berth allocation has to be determined at all terminals to be called at (e.g., how much time in advance).

With regard to the *physical box handling*, the relevant safety regulations have to be observed which most probably do not allow for simultaneous straddle carrier operation during any self-sustained cargo operation by the PFB (contrary to STS gantry crane operation serving conventional barges). That means that all boxes which have to be loaded by the PFB have to be put down on the quayside by the terminal before the PFB starts cargo operation with its own crane. Vice versa all boxes which have been discharged by the PFB can only be taken away from the quayside after the cargo operation of the PFB has been accomplished. Although the terminal does not need to use their own STS gantry cranes (incl. their crew) to serve small barges anymore, the relevant quayside might be blocked for a longer time than with "conventional" gantry crane operation. However, many terminals have berths of less occupation where such aspect is actually not relevant. Furthermore, there has to be an agreement on how the boxes have to be put down on the quayside by the terminal and by the PFB. (e.g., regarding the order, distances between the boxes, number of layers, etc.)

As a part of an adequate *data exchange*, there has to be an agreement on the minimum notice time which the PFB has to meet to inform the terminal in advance on the details of the containers to be handled. The necessary data flow, its format, and scope have to be fixed before the PFB operation commences. Depending on the terminal's general standard, such procedures can either be organized manually (in a "jumble of bits of paper style") or rather sophisticated by making use of wireless data exchange between the various facilities of call and the PFB and its operation center, respectively. The containers which are going to be loaded or have been discharged by the PFB need to be checked on their condition and whether they have a seal or not. If such data input is intended to be done by handheld devices, it has to be ensured that they can operate independently from any STS gantry crane where the respective receiving antennas are often located.

Commercial issues mostly refer to the so-called gate charge which the terminals are charging from their customers (container lines) for container receipt and delivery depending on the modes of pre- and on-carriage (truck, train, or barge). Compared to truck and train the gate charge for the pre-/on-carriage by (conventional) barges is much higher as STS gantry cranes (incl. their crews) are involved. In order to achieve the necessary competitiveness compared to intra-port haulage by truck it is essential that the gate charge for the self-sustained PFB is not higher than for trucks. However, this has to be agreed upon between the terminals and their customers, i.e., the container shipping companies. In case the PFB acts also as a “floating terminal” for the inland barges, a further agreement has to be made on the remuneration of such delegation of original terminal duties.

20.7 Conclusion

As there is no doubt that container volumes will certainly continue to increase – however on a smaller rate – ports and their terminals have to prepare to ease already experienced and foreseeable bottleneck situations and to reduce the environmental impact of container transhipment procedures at the quay wall. The PFB concept is a “green logistic innovation” for sea ports whose inherent beneficial effects to the environment can even be further increased by using LNG as fuel. The use of PFBs generally helps

- to shift container trucking within sea ports from road to waterway with all the positive effects on the traffic flow, emissions, and road safety (e.g., less dangerous goods on the roads),
- to ease feeder and transhipment operation within multi-terminal ports,
- to improve the intermodal connectivity of inland navigation within sea ports as well as
- to be prepared for lightering of even very big grounded container vessels.

In particular also the terminals would benefit:

- Their gates would be released from queuing trucks.
- They would gain flexibility in labor organization for checking incoming and outgoing containers.
- Their STS gantry cranes would be released from inefficiently serving small inland barges.

Furthermore, at places with insufficient or congested terminal facilities and/or shallow water restrictions (like in many developing countries) the PFB could facilitate the handling of deep-sea container vessels at anchorage.

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