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DECOUPLING (UN)LOADING OPERATIONS FROM THE LAND-SEA INTERFACE IN PORT SERVICE: THE MOBILE FLOATING PORT CONCEPT

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ABSTRACT

To address the problem of increasing demand for port service capacity worldwide, subject to the constraint that existing ship structure and load/unload methodologies must be essentially maintained, we pursue the system-level design of port services based on axiomatic design. We show that the traditional approaches to increase capacity (e.g., faster cranes and increased berths) do not address the fundamental coupling between the functional requirements (FRs) to load/unload containers and port the containers across the land-sea interface. We next demonstrate that a mobile floating port (MFP) concept is a design that decouples these FRs. Further, by considering the MFP as an agile service asset with the flexibility to provide port services to multiple port locations, one can decouple the service from dependence upon a specific port.

Keywords: Port services, port design, axiomatic design, mobile floating port, mobile floating harbour.

1 INTRODUCTION

With the rise of nations such as China and India as powerful participants in the global economy, so too has there been a corresponding rise in their demand for and consumption of natural resources (raw materials) and finished goods as well as an increase in their export of products produced. To feed these demands and support the delivery of their industry, much of the materials are imported and/or exported from other nations via the global ocean shipping network. This network employs container ships and bulk goods ships along with an ever growing collection of ports to deliver materials from source to destination, often via the use of intermediate transhipment ports to increase efficiency of distribution.

The shipping industry is thus in a state of relatively rapid growth. Recent worldwide container shipping rates have increased by about 9% annually since 1990 and 10-11% in 2005, 2006 and 2007 [1]. Figure 1 depicts the dramatic growth of global container shipping rates. As a specific example, the Port of Singapore alone served almost 20,000,000 ft^3 of cargo in 2007; an increase of 7.8% from 2006 and 48.5% from 2000. The increase in shipping is expected to continue over the long term (in spite of the recent global economic downturn).

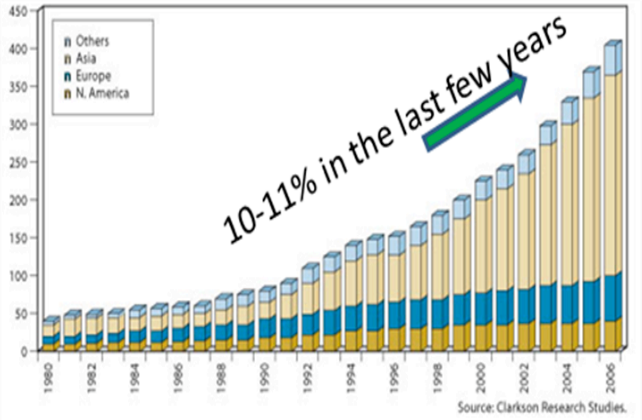


Figure 1. Global container shipping. Y-axis units are million TEU/year. (Source: Clarkson Research Studies)

While current container port service capacity is sufficient to meet the existing demand, according to [2], the projected 2014 demand is expected to exceed the current capacity by 25%. Further, while only about 10% of the current container traffic is handled by mega-ships with capacities greater than 8,000 TEU, this percentage will increase to 25% of the container traffic by about the same time [3]. (TEU stands for twenty-foot equivalent unit and is a measure of the volume of a three dimensional rectangle with dimensions 20'x8'x8.5'.) Current port service facilities will be insufficient to address the projected growth.

To address the trend, the shipbuilding industry has responded by building container ships with increased capacity. The current mega-container ships, such as the COSCO Guangzhou have a 12,000 TEU capacity [4]. Many orders for the construction of such large ships have been placed. In fact, according to [5], in 2007, seventy seven ships with 10,000 TEU or greater capacity were scheduled for completion by 2011.

In response to increased traffic demands and to address the impending arrival of many large ships, hub ports have begun employing the traditional approaches to increase their capacity. To wit, in 2005 Singapore invested S$160 million in tyre-mounted gantry cranes ([6]) and in 2007 it began a S$2 billion construction project to expand its existing 49 berths (with a capacity of 26.1 million TEU per year) to 65 berths (with a projected total capacity of 60 million TEU) ([7], [8]).

Time-honoured and well-tested traditional methods to increase port capacity include the construction of additional berths (which consume waterfront property), purchase of additional cranes (for increased container movement capacity), upgrades to existing cranes or purchase of faster cranes (to increase loading/unloading capacity at the ship), more/faster container movement vehicles (e.g., yard trucks), expansion of yard facilities and the implementation of algorithms to optimize the use and scheduling of existing resources.

Traditional approaches to increasing port capacity, efficiency and service quality (e.g., waiting time) have demonstrated a reliable and steady capability to increase port service performance. However, they are hampered by one key factor – the essential design concept upon which they are based contains more couplings than are necessary. These couplings lead to a limited capability to port containers across the land/sea interface. Further, the existing port service designs limit the applicability of the porting system as a service.

Here, within the Axiomatic Design framework [9], [10], we delve into the system-level design of port services and demonstrate that an agile mobile floating port (aMFP) concept (a mobile harbour was first proposed in [11], [12]) nearly completely removes the couplings present in the current system design. Two consequences are that the aMFP concept has the potential to dramatically increase port throughput and provide an entirely new business model for port operations akin to the operation of a taxicab or bus for containers. It should be mentioned that large floating structures have been proposed as solutions for various maritime and naval problems; none successfully addresses the fundamental couplings. (We discuss other proposed solutions and related work in the sequel.)

The remainder of the paper is organized as follows. In Section 2 we discuss the system-level functional requirements (FRs) of port service. Employing these FRs, Section 3 studies the structure of existing port designs. It is here that we see the fundamental coupling present in current port concepts. Existing non-traditional solutions for port service that have been proposed are briefly overviewed in Section 4. The aMFP concept is explained in Section 5, where we show that the design removes the couplings. Concluding remarks are presented in Section 6.

2 FUNCTIONAL REQUIREMENTS OF A PORT

The abstract purpose of a port in the maritime cargo transport network is to provide a means for cargo on land to be moved from land to sea and loaded upon a sea-going vessel, and vice versa. In addition, for some cargo, the port may not be the final marine destination and the purpose of the port is merely to deliver the cargo to the next ship scheduled to carry the cargo. The cargo and function of the port in this case are termed transhipment. Such transhipment of containers is necessary to optimize the operations of the shipping companies. Typically, large capacity ships with containers that have arrived from numerous sources make the long ocean voyage to a hub port (characterized by a large container handling capacity and a larger percentage of transhipment containers). From this point, smaller vessels, called feeder ships, then deliver the containers to their final destination.

Thus, the container traffic that arrives to a port may be divided into three classes: import, export and transhipment. Import containers arrive to the port on a ship and must be delivered to some point inland. Export containers arrive to the port via a land route and are delivered to their destination via a ship (even if the destination is a transhipment port, the container is an export container from the source port's perspective). Finally, transhipment containers arrive via a ship and the role of the transhipment port is to remove them from the incoming ship and deliver them to another outgoing sea vessel (typically there is a need to store such a container for perhaps one week as the scheduled sea going vessel may not be immediately available). Naturally, the porting operations should be conducted safely, efficiently and with as little negative effect on the environment as possible.

A key point to note is that while all of the three classes of containers must be loaded/unloaded to/from a ship, only import/export container must cross the land-sea interface. This distinction serves to highlight the functional requirement that import/export containers must traverse the land-sea interface.

The subset of high-level functional requirements for port service involving ships is listed in Table 1 below. There are other functional requirements that we neglect to mention dealing with non-maritime operations – they can be designed without couplings to the maritime FRs. Note that we state the FRs in terms of containers (despite that there are other types of cargo) as this is our primary cargo of interest and the port service systems for other types of cargo are distinct from those employed for containers. (There are typically distinct berths and loading/unloading equipment associated with containers and other cargo).

Table 1. Functional requirements of port service.

FR1	Allow ship entry to port system
FR2	Provide location for ship to receive service
FR3	Unload incoming containers from ship
FR4	Transfer import container from sea to land
FR5	Load outgoing containers to ship
FR6	Transfer export container from land to sea
FR7	Allow ship to exit from system
FR8	Store containers between pick-up/delivery times
FR9	Orchestrate operations

There are numerous constraints that such a system must obey such as safety, environmental, cost, efficiency and geographic constraints; we do not mention these further. The key constraint that we impose is listed in Table 2. It is most relevant to the resulting design at the system level.

Table 2. Constraints on a port service system.

C1	The existing structure of ships cannot be changed.

3 TRADITIONAL SOLUTIONS

At the system level, traditional solutions that provide port service are quite similar. Table 3 lists the design parameters DPs (i.e., design concepts) for existing port service solutions. To illustrate a typical port design, the port at Incheon, South

Korea is depicted in Figure 2. One can clearly see the rectangular berths at the land–sea interface.

Table 3. Design parameters of traditional port service solutions.

DP1	Dredged causeway for entry
DP2	Berth at land-sea interface (shoreline berth)
DP3	Crane system for unloading of ship
DP4	
DP5	Crane system for loading of ship
DP6	
DP7	Dredged causeway for exit
DP8	Land based storage facility
DP9	Algorithms and methods for control of system

Proposition 1: Traditional port service solutions are coupled.

Proof: It is immediate from Theorem 1 (Coupling Due to Insufficient Number of DPs), pp. 22 of [10] that the design is coupled since there are 9 FRs and only 7 DPs. □

The coupling arises since the existing design does not consider (nor indeed truly recognize) FR4 and FR6 – transfer containers across the land-sea interface. Though this distinction between loading/unloading and crossing the land-sea interface might at first seem academic, there is a very sound reason for it. Incorporating them into the FRs gives rise to an entirely new concept for port service as we shall see in Section 5.

Figure 2. Aerial view of the port at Incheon, South Korea. (Courtesy of Google Earth, August, 2008.)

The consequence of the coupling of Proposition 1 is that the same solution is used for loading/unloading and to traverse the land-sea interface. These tasks are accomplished simultaneously. Simultaneity need not be a design problem; however, since we are constrained by the existing ship structure, cranes are used for both of these functions. Cranes are not the fastest method for delivering containers. For ships that carry denumerable cargo (such as vehicles) but not containers, it is well known that the fastest that they can currently be (un)loaded is via a roll-on roll-off (RORO) system. The coupling in traditional designs forces both the functions of (un)load and traverse the land-sea interface to be accomplished via the slower crane method. Since, we are constrained to use the existing ship structure, which has been designed for container (un)loading via cranes one cannot avoid their use for FR3 and FR5. However, we ***need not use cranes to traverse the land-sea interface***! A RORO system would be much more efficient at this task. Further, if we used a RORO system or another ***ultra-fast method for traversing the land-sea interface***, we could dramatically increase the productivity of the land-based berths.

The question is then: How can we decouple the (un)loading process from the process for traversing the land-sea interface and enable the use of an ultra-fast system for FR4 and FR6?

4 EXISTING NON-TRADITIONAL SOLUTIONS

There are other non-traditional methods that have been conceived to improve port service capacity. First note that by non-traditional we do not mean concepts such as the tandem twin lift cranes (which enable an increase in crane capacity) or automated guided vehicles for yard operations, though such solutions certainly should be considered for inclusion as a part of any new and enhanced port service design.

In [13] and [14], floating supplementary quays (termed a hybrid quay wall HQW) and replacement ports were considered. The supplementary quay (HQW) is a floating structure that can be moved (or move) to the side of the ship not adjacent to the land-side berth, as shown in Figure 3. The HQW possesses its own cranes and conducts (un)loading operations from the second side of the ship simultaneously with the normal (un)loading from the land-based berth side. Hence the speed at which ships can be served when in their berth is increased. (Note that the speed is not doubled, even though two sides of the ship are served in comparison to the traditional one-sided service, because contention between cranes on opposite sides of the ship must be avoided for safety.) Containers unloaded by the HQW cranes are placed on the HQW structure and RORO transported across a small movable bridge that is placed to connect the HQW with the land-based berth.

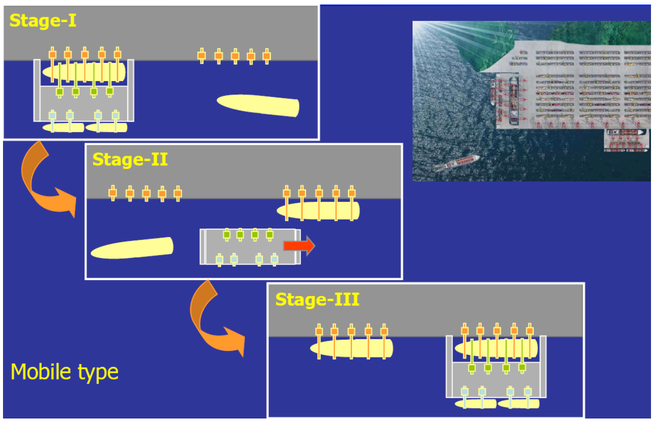


Figure 3. Hybrid Quay Wall concept. (Figure adopted from [14].)

The replacement port concept is to construct a floating or secured port in the ocean. It can then serve as a normal land-based port provided that is has sufficient surface area to store containers and can provide the same services as a land-based port. This concept completely removes port operations from the land. However, as the containers for many ports are in fact import/export containers, this solution requires that containers undertake an additional journey to another land-based port using traditional means. As such, this idea is best suited for use as a hub port with a preponderance of transhipment traffic. A replacement port may be connected to the land via a bridge or it may operate without any connection to the land. Figure 4 shows the two types of the replacement port concept. In fact, the port at Yangshan is essentially this concept as it is constructed around a small island and connected to land via a 32.5km-long bridge.

In [15], a concept for a floating replacement port is described as a challenge for ocean systems engineers. This is similar at the high level to the concept described in [13], [14]. The implementation has several differences including the use of double sided mooring to help stabilize the ship. Naturally, double-sided (un)loading is employed as well.

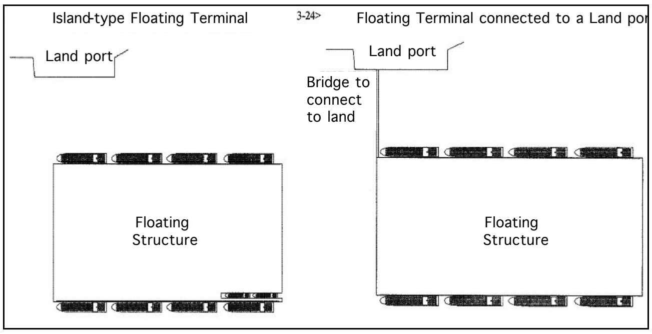


Figure 4. Replacement port concept. (Figure adapted from [13].)

Port service designers were not the first to consider very large floating structures. In [16], a floating modular airfield concept developed by the US Navy is described. Here, connectable modules are proposed that can be concatenated to form an airfield of desired size. One interesting consequence of this design, and it holds true for all existing large floating structure concepts of which we are aware, is that the structure itself may bend as different parts of the supporting ocean rise and fall.

In [17], [18], the LASH (lighter aboard ship vessel) - a true departure from common porting system concepts - is described. There, a design concept for a ship that ports smaller ships filled with cargo is discussed and the implementation described. The idea is as follows. First, small river-going vessels are loaded with cargo at their river port. The river vessels then travel to the river mouth and *board* the larger ocean vessel. The ocean vessel, containing the smaller river ships then travels to another river mouth across the more volatile ocean waters. The ocean vessel then literally sinks itself, allowing the smaller river vessels to disembark and enter the calmer waters of the river system. The benefit is that the cargo need not be removed from the river vessels, loaded to the ocean vessel, unloaded from the ocean vessel and once more loaded to river going vessels for the final leg of the journey to the destination. In fact, the river vessels are loaded and unloaded only one time each. This reduction in transhipment allows improved cycle time (thereby reducing the overall shipment cost) and this is used to justify the expense of designing and constructing a ship that holds ships.

We briefly discuss those designs listed above that are intended to serve a role as (a part of) a port for ocean going container vessels in light of the functional requirements listed in Table 1 for port service. First, note that while the hybrid quay wall HQW supplementary port does allow one to conduct double-sided (un)loading, and this results in an increase in service rate (by less than a factor of 2), the HQW does not serve to decouple the operations of (un)loading and traversing the land-sea interface. The two activities are conducted simultaneously and the opportunity to employ an ultra-fast mechanism for traversing the land-sea interface is lost. Second, for the replacement port concepts (offshore floating ports), the primary goal is to serve transhipment containers. For this subset of the market, the design is a good one (there is no need to cross the land-sea interface, and so the related FRs are not present – the resulting designs need not be coupled). However, if one intends to also serve import/export containers, the solution does not remove the coupling as those containers must also be shipped to a land-based traditional port. In addition, the market size for this transhipment-only port is unclear.

A key point to note is that, for all of the designs intended to serve ocean ports, none recognizes the presence of the FRs to traverse the land-sea interface and designs with too few DPs. The result is a dramatically less productive land-berth than is possible.

5 AGILE MOBILE FLOATING PORT

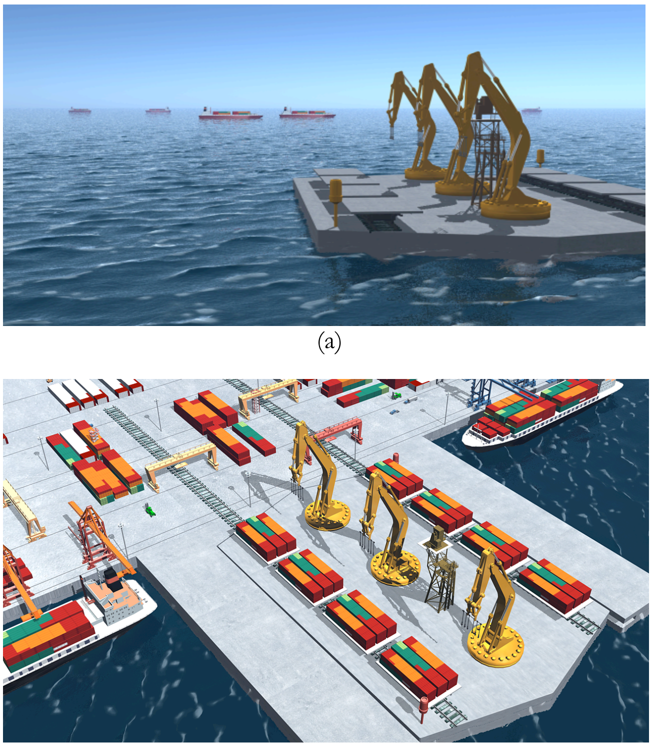
Our design goal is to achieve the functional requirements set forth in Table 1 for port service and satisfy the Independence Axiom of [9], [10]. We do not address the Information Axiom at this level of the design (indeed this is quite difficult to do as the technologies for many of the non-traditional designs discussed as well as the design we will study have not been developed). The key to accomplishing this is to ensure that we decouple the (un)loading function from the function that import/export containers traverse the land-sea interface. By so doing, one will unleash the possibility of a dramatically faster and more efficient land-based berth.

The design solution we will study was first put forth in [11], [12] and consists of a mobile floating platform complete with cranes for (un)loading cargo to and from container ships (according to the constraint that the existing ship structure and loading/unloading method must be honoured). The platform may be propelled by engine driven propellers or perhaps even manoeuvred by tugboat. We call such a platform a mobile floating port (MFP). An essential feature of the MFP is that is possesses an interface for connecting with the land based port that enables the ultra-fast transfer of containers.

In the subsequent subsections, we discuss the MFP design and how it serves to decouple the traditional port service system design. Also, we show that mobility allows for one to consider agile operational schemes that are simply not possible with fixed position ports.

5.1 MFP DESIGN IS DECOUPLED

There are three key features of the MFP concept. First, there is an ultra-fast container transfer interface between the MFP and the land based port which dramatically improves the productivity of the land-berth where the MFP will disgorge or absorb its contents. Second, as the MFP can be positioned in deep water, there is no requirement for dredging (or a relaxed one) to accommodate deep depth ships. Third, to move between deeper water and the land-based port, the MFP should be mobile.


(a)

(b)

Figure 5. (a) MFP heading toward container ships offshore. (b) MFP docked with a designated land-berth. Note that the details in the figures are for illustration purpose only and do not indicate actual technical implementation of the MFP concept. (Illustration courtesy of ICAD laboratory of KAIST.)

As we now show, the MFP design removes the couplings that afflict traditional port service designs. The design parameters to address the functions provided in Table 1 and obey the constraints of Table 2 are given below in Table 4.

Table 4. Design parameters for MFP.

DP1	Floating platform in deep water
DP2	Berth for ship at platform
DP3	Crane system for unloading of ship
DP4	Ultra-fast interface system: Unload containers from platform
DP5	Crane system for loading of ship
DP6	Ultra-fast interface system: Load containers to platform
DP7	Exit method for ships from MFP
DP8	Land based storage facility
DP9	Algorithms and methods for control of system

The design matrix for this design is given in Table 5 below. As is common practice, we use a large "X" to indicate that there is dependence in our ability to satisfy an FR upon the corresponding DP. A zero indicates that there is no relationship. Rationales for each of the off-diagonal non-zero elements are given below the tables, where (i,j) refers to the X at the ith row and jth column.

Table 5. Decoupled design matrix for MFP.

	DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9
FR1	X	O	X	X	X	X	O	O	O
FR2	O	X	O	O	O	O	O	O	O
FR3	O	X	X	O	O	O	O	O	O
FR4	O	X	O	X	O	O	O	O	O
FR5	O	X	O	O	X	O	O	O	O
FR6	O	X	O	O	O	X	O	O	O
FR7	O	X	O	O	O	O	X	O	O
FR8	X	O	O	X	O	X	O	X	O
FR9	O	O	O	O	O	O	O	O	X

(1,3): Properties such as size and weight of crane system affect the structure of floating platform.
(1,4): The shallow sea accessibility required by the ultra fast interface system affects the design of floating platform.
(1,5): same as (1,3)
(1,6): same as (1,4)
(3,2): Berth structure and arrangement directly affects the function of loading/unloading. For example, the number of cranes that can access a ship, interoperability between berths, and types of crane system depend on berths. Also, stability achieved by berth system (e.g. mooring) affects loading and unloading.
(4,2): Transferring containers from sea to land includes transferring containers from berth to the transfer method, and thus is affected by berth system.
(5,2): same as (3,2)
(6,2): same as (4,2)
(7,2): Berth structure and arrangement will affect how ships can exit from the system.
(8,1): Storing capacity of the floating platform may affect the storing requirement for the land-based system.
(8,4): Land-based yard must accommodate the ultra fast interface and its high throughput.
(8,6): same as (8,4)

Using standard approaches, we see that it is a decoupled design matrix (not coupled as before); hence, it is a better design. We thus have the following result.

Proposition 2: The MFP design is decoupled.

Proof: Since the resulting matrix can be rearranged to become lower triangular, the design at this level is decoupled. □

It should be noted that there is one condition that must be assured to make this proposition valid. That is, the total weight of MFP should not be too high, which implies that the container carrying capacity and/or the weight of crane and other systems on board should be limited to a certain amount. This is due to the fact that the MFP should be sized such that it can access land-based port with a shallow depth. If this condition is violated, (4,1) and (6,1) would be non-zero, and the resulting matrix would be a coupled design matrix.

Additional decomposition and zig-zagging are required to further develop the design. By decomposing FR4, we see that three functions are necessary. These functions as well as the corresponding design parameters are given in Tables 6 and 7, respectively. It is here that mobility arises as a function.

Table 6. Child functional requirements of FR4 to transfer import containers from sea to land.

FR4.1	Move MFP from deep sea location toward land
FR4.2	Allow MFP entry to land-based port system
FR4.3	Unload containers from MFP to land

Table 7. Child functional requirements to transfer import containers from sea to land.

DP4.1	Propulsion system
DP4.2	Shallow depth of MFP (less than mega-ships)
DP4.3	Ultra-fast interface with land for unloading MFP

It is easy to see that no additional couplings arise as a consequence of our decomposition. We do not further detail the other FRs, but it is worth mentioning that the land-based port must be capable of receiving the MFP. That is, to rapidly disgorge/accept containers to/from the land-based port, the land side facility must have a companion system for enabling the ultra-fast transfer.

An overview of the operation of the MFP is as follows. First note that the MFP can be stationary and await arriving ships or it can seek them out. Once ship(s) are docked at the facility, (un)loading commences via the traditional method employing cranes. Double-sided unloading with state-of-the-art crane systems (e.g., tandem lift) should be incorporated to maximize the speed at which ships can be served. The containers are placed upon the MFP-side portion of the ultra-fast system for unloading the MFP. In one embodiment, the MFP houses multiple large rail mounted slabs upon which the containers are stacked. Once the MFP is relatively full and/or ready to return to the land-based port, the propulsion system is activated (propellers or tug boats, or some other method) and the container laden MFP sails to a land-based port. The MFP gains access to the port readily as it is essentially a barge with a shallow depth and has no difficulty with the depth of the water near the port. The MFP next docks at the port and proceeds to roll the container slabs (they may be pulled, pushed or self propelled) off the MFP and into the port. Once the MFP is empty, it is subsequently loaded with containers for incoming vessels and sets out to sea.

We conclude this section by comparing the berth productivity (i.e., throughput) of a traditional berth, a double-sided (un)loading berth and the MFP-based system. Figure 6 shows timing diagram for the three types of berth systems. Figure 6(a) depicts a traditional berth operation throughput as a reference case: a container ship arrives at a port with a berth available. It docks at the berth, and starts the (un)loading process. Once the (un)loading is finished, the ship departs, and the next ship enters the system. We call this interval – the time between two successive ships entering the system – throughput time, T0. Figure 6(b) illustrates the process for the same system but now equipped with double-sided (un)loading. By using double-sided (un)loading, the (un)loading time is reduced by approximately half, making the throughput time for this system T1 ≈ (1/2)T0. Now with the MFP, the land-based berth does not have to be occupied during the entire (un)loading time. It is occupied only during the transfer of containers to and from the MFP, whose time will be designed to be much smaller than ship (un)loading time. If we use multiple MFPs, we can work on multiple ships simultaneously, transforming a serial process into a parallel process. This is the very advantage of decoupling the function of container (un)loading at the ship side and the function of transferring containers across the land-sea interface. Depending on the number of MFPs and the speed of the ultrafast interface, the MFP-based system can achieve a much higher throughput than in the other cases. That is T2 << T0, as is shown in Figure 6(c).

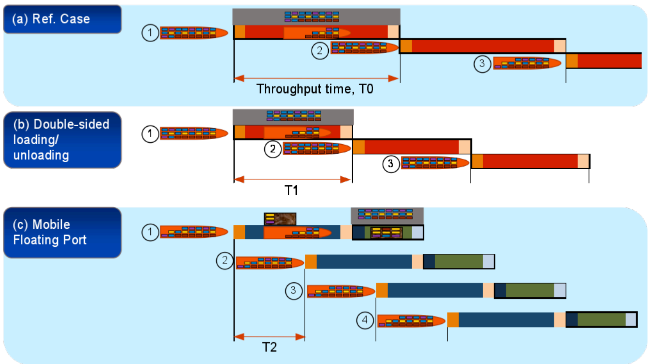


Figure 6. Mobile Floating Port decouples the transfer of containers across the land-sea interface from the (un)loading of ships, potentially greatly increasing the berth throughput beyond traditional approaches.

5.2 AGILITY AND SERVICE

There is an additional service concept that arises when one allows the port service system to be agile (mobile). First, this removes the dependence upon a single port. Hence, an agile MFP (aMFP) can be employed at multiple ports where the need is greatest. In addition to protecting the operator of the aMFP from shifts in the container handling market from port to port, the aMFP can be used to serve small ports. As container traffic increases, smaller ports will find themselves with a growing need to serve more and more containers. Also, larger ships will want to call at the hub ports (as well as smaller ports).

The aMFP can serve in two ways. Without the need to build additional berth facilities, the aMFP (by dramatically increasing the throughput of a single berth) can fulfil the port capacity requirements. Also, since the aMFP has a relatively shallow depth, smaller ports need not undertake costly deep dredging exercises to provide access for larger ships.

Taking the concept of agility to its logical extreme, one can consider the aMFP as analogous to a maritime taxi cab. The aMFP is called by a ship and/or port to provide unloading operations and deliver the containers to the land-based port via an ultra-fast interface with the land. A fleet of aMFPs could be deployed much like current feeder ships without the need for existing ports to increase the number of berths they provide or deepen existing water depths. The only requirement on the land-based port is that they provide one ultra-fast interface for the MFP and are able to handle the dramatically faster rate of container arrival and export.

6 CONCLUSION

Increasing demand for container shipping, coupled with the expected dominance of mega-container ships in the future shipping market requires a significant increase in port service capacity. While improvements and expansion of traditional port systems will be able to respond to the need temporarily, we expect that innovative solutions must be developed to meet the need in the long run.

We approached to this problem by adopting the Axiomatic Design analysis. Our analysis shows that non-traditional solutions that have been developed in the past do not properly recognize the fundamental coupling in the container transport system. The fundamental coupling occurs between FRs of container (un)loading from/to ships and the other FRs of transferring containers across sea-land interface. This coupling can be resolved by deploying an MFP-based port system. This decoupling allows transforming a serial process into a flexible, parallel process, which possibly leads to a much higher productivity for an MFP-based system.

One limitation of the MFP concept presented in this paper is that it is limited in the total weight that it can support while remaining fully functional. The severity of this constraint needs further study as it may affect the overall utility of the concept. Also, multiple alternative solutions under the MFP concept need to be developed to determine the best MFP-based solution.

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