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The market and economics of mobile port-based Ballast Water Treatment solutions

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Abstract

While vessels need to carry ballast water for safe and efficient operations, this poses serious environmental and economic problems due to the multitude of marine invasive species carried in it. The Ballast Water Management Convention (BWMC) which came into force in September 2017 requires that vessels manage their ballast water according to specific standards. For most vessels, compliance will require fitting a ballast water treatment (BWT) system. However, in some cases, a mobile solution e.g. a BWT system fitted in a container as an alternative to an onboard system might be a more viable solution. These mobile treatment systems are also particularly suitable for barges, supply vessels, vessels engaged in short sea shipping or those with minimal and predictable ballasting operations. These mobile systems are an excellent solution as a contingency measure, in line with the latest discussions at the IMO. To that extent, this paper presents the findings of a comprehensive market analysis and economic feasibility study that analyses the costs and benefits of the proposed system under various scenarios.

Keywords: *ballast water management, maritime regulations, environmental regulations, port-based ballast water treatment systems*

1. Introduction

Commercial vessels are used for the transport of various goods or passengers and when they are not fully laden, i.e., when the carrying capacity in terms of deadweight (DWT) is not adequately exploited, additional weight is required mainly for stability reasons. This implies that most vessels use ballast water to be seaworthy (David and Gollasch, 2015).

While ballast water is essential for safe and efficient maritime operations, it poses serious environmental, economic and health problems due to the multitude of species carried in it. These include for instance bacteria such as Cholera which may survive in the discharging port area and establish a reproductive population. These species might become invasive and, thus, out-compete the native species. According to IMO (2018), scientists first recognized the signs of an alien species introduction in 1903 after an occurrence of the Asian phytoplankton algae Odontella in the North Sea but the scientific community began studying the problem in the 1970's.
The problem of invasive species in ballast water has been significant especially due to the expanded trade over the last decades. The effects in many areas of the world have been devastating.

The IMO Ballast Water Management (BWM) Convention (full name "International Convention for the Control and Management of Ships' Ballast Water and Sediments", 2004) is a treaty adopted by the International Maritime Organization (IMO) to help *"prevent the spread of potentially harmful aquatic organisms and pathogens in ships' ballast water"*. At present there is no direct EU Law on Ballast Water, however Regulation (EU) No 1143/2014 on "the prevention and management of the introduction and spread of invasive alien species" recognizes the IMO BWM Convention as one of the possible management measures for invasive species. At the same time, the United States (US) is not signatory to the BWM Convention and vessels must comply with stricter requirements.

The most common way to comply with the regulations (IMO or US) is by using an approved ballast water treatment system. However, in some cases, a mobile port-based solution e.g. a BWT system fitted in a container might be a more viable alternative to an onboard system. These mobile treatment systems are particularly suitable for barges, supply vessels, vessels engaged in short sea shipping or those with predictable ballasting operations – such as those engaged in liner shipping. In this case, an owner may invest in a small number of mobile treatment systems that could be shared between multiple vessels, thus, avoiding the retrofit each vessel. In addition, these mobile systems can be also used as contingency measures. Vessels with a failing BWT systems or other contingencies, will be forced to keep ballast water onboard resulting in less loaded cargo and potential delays. In these scenarios, an emergency solution in ports is essential for a vessel's continued trade and compliance with the regulations. We investigate the case where a port/terminal operator is offering the service of treating ballast water onshore for a fee. Our approach can be generalised to cover other service providers such as Port Reception Facility operators, port authorities, shipowners or shipowner associations.
Currently, these port-based ballast water management systems are not widely used. For various reasons that will be analyzed in this paper, including to cover cases of contingency, there is a huge business opportunity for these systems.

To that extent, Section 2 analyses the relevant regulations, Section 3 presents the market for port-based systems, including some systems that could be used, and Section 4 presents the relevant costs and benefits of the proposed system under various scenarios.

2. The Regulatory Framework

As mentioned above the IMO has adopted the so-called Ballast Water Management (BWM) Con*vent*ion. From 8 September 2017, ships must manage the ballast water carried so that organisms and pathogens are "removed or rendered harmless" before the discharge. At present there is no direct EU Law on Ballast Water, however Regulation (EU) No 1143/2014 on the "Prevention and Management of the introduction and spread of invasive alien species" recognizes the IMO Convention as one of the possible management measures.
Finally, note that the US has not acceded to the IMO BWM Convention but has instead adopted its own ballast water management requirements, see Section 2.2 below. Interestingly enough the State of California enforces its own BWM regulations applicable to *"vessels that arrive at a California port, are 300 gross registered tons or more, and are carrying or capable of carrying ballast water"*.

This paper will mainly focus on the IMO BWM Convention, and thus to mobile treatments that are compatible with the IMO regulations. The US regulations will be briefly presented in Section 2.2 below. Port-based systems to comply with the US regulations follow the same rationale, the main difference is the type-approved equipment that should be used.

2.1 The IMO Ballast Water Management Convention

In 1997, the MEPC adopted Guidelines to address the problem in the form of "Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens" (MEPC resolution A.868(20)). The IMO members were initially requested to follow these Guidelines, which called for the "exchange of ballast water in the open ocean" to reduce the risk of transfering harmful species.
After many years of negotiations, the IMO BWM Conventions was eventually adopted in February 2004.

IMO's International Convention for the Control and Management of Ships' Ballast Water and Sediments came in force 8th of September 2017 after ratification of 53 countries representing 35% of the global tonnage. The actual convention was adopted in 2004 after 13 years of process. After its enforcement, all vessels over 400 GT trading internationally and loading and unloading ballast water are required to withhold a ballast certificate, a management plan for ballast water and a ballast record log book (Alfa Laval, 2017). Controlling a vessel's BWM may be through the inspection of a certificate, record book and sampling of ballast water. This is controlled by the Port State Control (PSC). If a vessel does not comply with the convention, it may be detained, warned or excluded from a port where the vessel is operating or its flag state. Currently, there are no published fines for ballast water violations. Note that the adoption and the profitability off the proposed port-based service heavily depend on the enforcement and the implementation of the BWM Convention by the Member State.

Performance standards

IMO has agreed on amendments to Regulation B-3 of the Convention, to implement a new schedule for the D-2 requirements (i.e. ballast water treatment). For new ships the requirements are unchanged. That is, ships constructed (keel lay date) on or after 8 September 2017, to which the Convention applies, will be required to be fitted with a ballast water treatment system at delivery. For existing ships the amendments give vessels 2 to 7 years from entry into force before needing to fit a treatment system. There are different performance standards a vessel needs to comply with depending on the first renewal of the IOPP certificate (Lloyd's Register, 2017). Figure 1 below shows the new implementation schedule for existing ships.

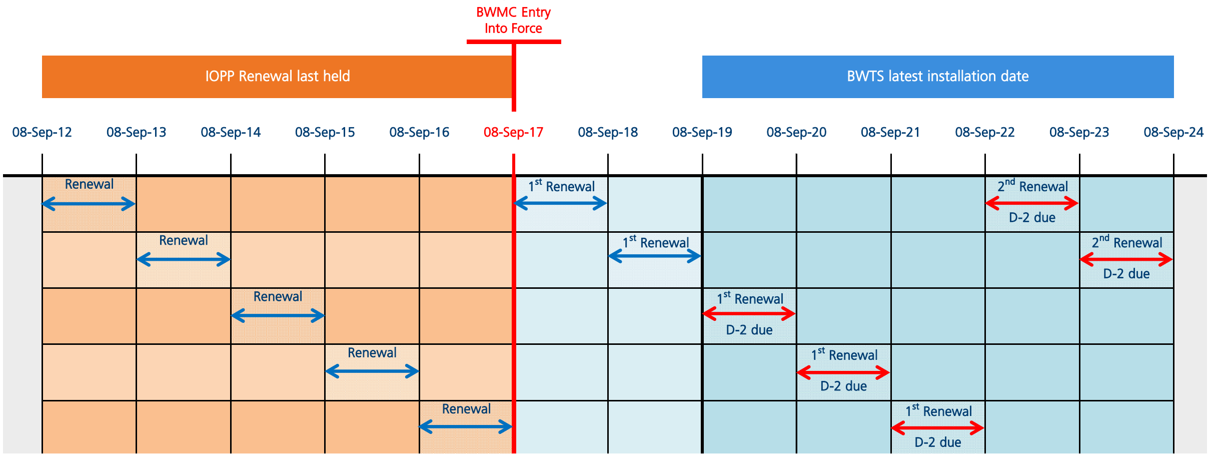

Figure 1 – Entry into force depending on IOPP renewal
Source: Lloyd's Register (2017)

The D1 standard requires the vessel to exchange 95% of the ballast water at the beginning of a voyage when at deep sea. It needs to be at least 200 metres deep and at least 200 nautical miles from shore (Alfa Laval, 2017). Water taken close to shore usually contains more organisms than in deep-sea and by exchanging the water at the start of a voyage, fewer organisms will be in the ballast water. Ballast water exchange can affect ship stability and take time (Gov UK, 2012). The D2 standard requires treatment systems to treat water for discharging allowance according to the summary in Table 1. Alternative treatment systems are further discussed in section 2.3. D3 standards require the BWMS to be IMO approved with the Procedure for approval of ballast water management systems that make use of Active Substances (G9).

Table 1 – IMO D2 Performance standards

Microorganism category	Regulation
Plankton size > 50 micrometres	< 10 viable cells / m3
Plankton size 10-50 micrometres	< 10 viable cells / ml
Toxicogenic vibrio cholerae	< 10 colony forming unit / 100 ml
Escherichia coli	< 250 colony forming unit / 100 ml
Intestinal enterococci	< 100 colony forming unit / 100 ml

2.2. The US Coast Guard regulations

The US Coast Guard has adopted similar regulations regarding ballast water management requiring compliance from ships trading in the United States. The regulations came into force in 2012 and contents the same standards as the ballast convention with additional requirements. These include rinsing the anchors and chains, cleaning ballast tanks, removing hull fouling and include these in the BWM Plan, as well as recording these actions. A ballast report must be submitted 24 hours before ETA to a port in the US (DNV GL, 2018).

In March 2012, the USCG published its "Standards for Living Organisms in Ship's Ballast Water Discharged in U.S. Waters", commonly referred to as the USCG Final Rule. The USCG Rule requires vessels to be fitted with approved ballast water treatment systems by a specific date, see Table 2. Until then, they must perform ballast water exchange (BWE) in an area 200 nautical miles from any shore before discharging ballast water. Vessels that have ballast water tanks but do not discharge ballast into US waters are unaffected.

Table 2 – USCG Final Rule implementation schedule

	Ballast capacity	Construction date	Compliance date
New vessels	All	On or after 1 December 2013	On delivery
Existing vessels (retrofits)	< 1500 m^3	Before 1 December 2013	First scheduled dry-docking after 1 January 2016
	1500-5000 m^3		First scheduled dry-docking after 1 January 2014
	> 5000 m^3		First scheduled dry-docking after 1 January 2016

Source: Alfa Laval (2017)

Note that the USCG type approval process is stricter than that of IMO, therefore IMO type-approved systems may fail to meet the USCG type approval requirements.

3. The market for mobile port-based BWT systems

The new regulations entered into force in September 2017 demand vessels to exchange the ballast water and after the first renewal of the IOPP certificate, the performance standards of treating the water will be effective. Ships that for some reason do not have the possibility of installing an onboard system, are not able to meet the D2 standards. Vessels with a failing BWMS or other contingencies will be forced to keep ballast water onboard resulting in less loaded cargo and potential delays. In these scenarios, an emergency solution in ports is essential for a vessel's continued trade and compliance with the regulations.

3.1 As a compliance measure

As previously outlined, the vessels to which the Convention applies will need to install an onboard system that meets the standard. Installing a mobile solution e.g. a BWT system fitted in a container as an alternative to an onboard system is viable only under specific scenarios and is not currently considered as a mainstream solution. However, there is evidence that this may be a good alternative for some vessels i.e. vessels with few ballast water discharges per year and for old vessels, fitting an onboard unit is a costly investment.

These mobile treatment systems, either fitted onboard or port-based ones, are also particularly suitable for barges, supply vessels, vessels engaged in short sea shipping or those with minimal and predictable ballasting operations – such as fixed-route container vessels and liner services. In this case, an owner investing in a small number of mobile treatment systems could share them between multiple vessels, avoiding having to retrofit each vessel individually.

In any case, the most obvious application of these mobile systems are as contingency measures, as will be described in the following Section. In this case, proving the cost-effectiveness of the system might not be that crucial as contingency measures such as port-based BWM systems might be mandatory. Again, this heavily depends on the enforcement and the implementation of the Convention by the Member States.

3.2 As a contingency Measure

In July 2017, the IMO issued BWM.2/Circ.62, 'Guidance on Contingency Measures under the BWM Convention'. BWM.2/Circ.62 defines a contingency measure as, *"a process undertaken on a case-by- case basis after a determination that ballast water to be discharged from a ship is not compliant, in order to allow ballast water to be managed such that it does not pose any unacceptable risks to the environment, human health, property, and resources."*

The IMO's Guidelines for Ballast Water Management and the development of Ballast Water Management Plans (G4), Resolution MEPC.127(53), do not specifically include contingency measures. However, BWM.2/Circ.62 states that in the case of non-compliant ballast water, the ship and the Port State should consider the contingency measures contained in the Ballast Water Management Plan (BWMP) of the ship.

As of February 2019, there is no existing implementation framework for contingency measures for ballast water management. Such a framework would guide stakeholders: including Administrations, Port State Control (PSC) officers, ship operators, and technology providers and may also encourage the development and adoption of contingency measures (MEPC 71/INF.30). The issue is currently being debated within the IMO. If such measures become mandatory, it is obvious that there will be an increased uptake of port-based systems.

Table 3 below provides a sample implementation framework for various circumstances.

Table 3 – Contingency measures implementation framework

Circumstance	*Treatment standard*	*Port State control role*
Emergency, such as a ship grounding	None. To be determined by on-site authority based on the situation and the available options.	Determine if treatment is practical given circumstances, i.e. ship can be safely boarded, etc. Treatment may not be practical. Approve selected management method and dosing regimen, i.e. dose, hold-time, neutralization.
Contingency, such as equipment failure	At least as good as D-1, ballast water exchange	Confirm situation is a contingency, i.e. not a routine circumstance. Ballast water exchange may be considered. Approve selected management method and dosing regimen.
Alternative management	D-2, treatment standard	Approve shore-based alternative management method as equivalent to meeting regulation B-3. Approve application for subject ship(s), i.e. old ship, infrequent ballasting, special circumstance.

Source: MEPC 71/4/25

Contingency planning has been receiving much attention as it can be witnessed by the increasing number of submissions to the IMO. In a recent submission by India, potential scenarios in which contingency measures could be required are described in the figure below (MEPC 71/4/25)[1]. The document outlines 3 main port-based contingency measures, namely a Port-based reception facility, a Port-based reception and recirculation facility and a Port-based treated water delivering facility. In the first case, the ship is proposed to discharge the non-compliant water directly to a shore reception facility or mobile reception facility, e.g. barge with storage tank to transfer the same to a bigger separate floating facility (e.g. oil tanker) or a shore treatment facility with sizable holding tanks. In the second case, the ship passes the non-compliant ballast water to an external port-based facility, e.g. ballast water treatment boat, a barge, container truck, etc. on which such ballast water can be filtered, treated externally and again recirculated back to the ship ballast tanks via air pipes. Both facilities should be equipped with IMO type-approved ballast water management systems.

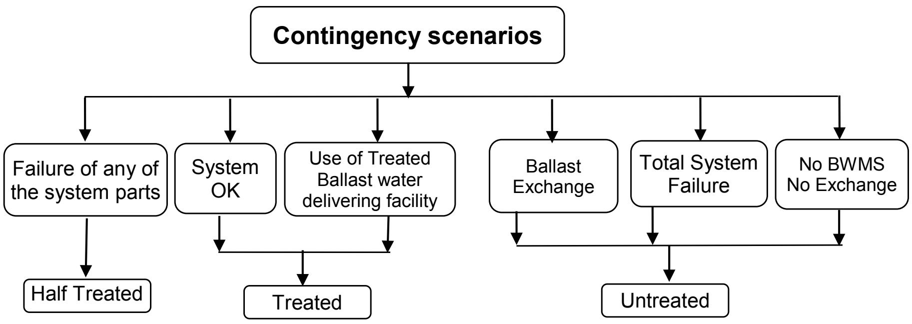

Figure 2 – Scenarios in which contingency measures could be required
Source: MEPC 71/4/25

[1] In this paper we cite IMO documents using the standard code for MEPC publications: MEPC x/y/z, where x is session, y is agenda item, and z is document number of agenda item. IMO documents do not appear in the reference list of this paper.

Besides, a recent submission to the IMO by Intertanko, amongst others, several shore-based approaches have been highlighted as part of their proposed "Ballast Water Contingency Measures for Tankers", see MEPC 73/INF.8, which provides a framework for reporting on inoperable BWMS and requesting the use of a contingency measure from the port State. Under 'CM.5 Shore-based mobile treatment systems at the ballast discharge port,' it is highlighted that *"a number of entrepreneurs are developing mobile shore-based treatment options to act as contingency measures or more permanent options for vessels without BWMS installed"*.
These options are broadly grouped into three categories (MEPC 73/INF.8):

- CM.5.1 Using a specifically designed ballast water treatment boat or barge that would either provide the vessel with treated ballast water and/or receive untreated ballast water for treatment. This option is closely aligned to the US requirements, §151.2025(a)(5).
- CM5.2 A mobile treatment facility transported on a barge or truck at the ballast discharge port to receive untreated ballast water from the ship.
- CM.5.3 A small mobile ballast water treatment equipment that can be deployed on a ship by a small riding crew to inject and then mix an active substance into the ballast tanks before discharge. A small time would need to be allocated to allow the active substances to work and then a neutralising agent would need to be added prior to discharge.

When a vessel is experiencing a contingency, different scenarios could be expected (see Fig. 2). An evaluation of the system should be conducted, and measures should be based on the evaluation. If total failure of BWMS or if water exchanged at sea, the water is considered untreated and cannot be discharged according to regulations. If in this situation, an alternative is to use a shore-based BWMS to treat the water and can be discharged compliantly. If a vessel is considered to be in an emergency, authorities will decide if treatment is practical. If no other options, the vessel should be allowed to return to ballast origin location, retain ballast water onboard and risk loading less cargo or any other solution the port state control officer suggests.

3.3. Suggested solutions

Several documents support mobile or port/on-shore solutions, especially as contingency measures. In response to the outline for the development of contingency measures under the BWM Convention, Netherlands submitted MEPC 71/4/13 which introduces InvaSave as a mobile port reception facility or contingency strategy for ballast water. This system has received type approval by the Dutch maritime Administration and is the only IMO type-approved mobile treatment system, see Section 3.4.1 for a detailed description.

India has submitted several documents to the IMO, see for example MEPC 65/2/20 and MEPC 66/2/8. MEPC 65/2/20, which was submitted to MEPC in March 2013 presented a mobile concept i.e. a vessel equipped with a ballast water management system.

IMAREST presented a list of mobile solutions that could be used as contingency measures. According to the submission the key systems, the summary of which is presented in Table 5, are the following (MEPC 71/INF.30):

- **BWTBoat concept:** presented by the Indian Register of Shipping, has continued development. This system, in concept design, would deliver and receive ballast water at a network of ports throughout various trading areas. In this manner, a ship could be loaded with treated ballast water for future compliant discharge. Alternatively, a ship could discharge untreated ballast water to the BWTBoat, for treatment.
- **Top Water Flow mobile concept:** developed by a private company in Norway, uses a barge-based treatment system. This system is in the concept phase. The barge connects to the ship's hull at the ballast water discharge pipe using an electromagnetic tip with a rubber seal.
- **Damen InvaSave system:** allows placement of any number of InvaSave treatment containers on board a barge, truck, dock, or another suitable platform. The ship then pumps ballast water off to the treatment modules for treatment. This is a commercially offered product and has been certified to meet the D-2 treatment discharge standard.
- **Glosten inResponse:** is a mobile kit that is deployed on board a ship. The system lowers a device into the ballast water tanks where an Active Substance is mixed into the ballast water, a hold time recorded, and a neutralizing agent then applied. This system is continuing full-scale prototype demonstration trials.

3.4. Description of Mobile-based BWT systems

It is important to stress out that most of the mobile port-based BWT solutions that were mentioned above are at conception stage; the Invasave 300 system by DAMEN is currently the only one that is IMO type-approved, for which adequate information could be found; see Section 3.4.4. It should be noted that our analysis applies to any similar non IMO approved or future systems that follow the same rational. At the time of the revision of this paper (March 2019) Denmark has submitted a Statement of Compliance for the Bawat BWMS mobile treatment unit for ballast water (see Section 3.4.3) with the requirements of resolution MEPC.153(55) on Guidelines for ballast water reception facilities (G5). The mobile Bawat system is not IMO type-approved but is based on an onboard system that has been type approved by the IMO (see MEPC 68/INF.9- February 2015).

Note that some IMO certified solutions could be offered in "containerized" versions, especially for tankers that have no pump rooms, but these are not much related to the mobile BWT systems that we are referring to in this paper. The main difference is that we are referring to systems into which whatever ballast water passes through the units, it comes out D-2 certified in a single pass, without delays of any kind. In fact, for almost all certified systems a holding time, around 3 days, of the ballast water to complete the reaction is needed. This is a critical factor for vessels undertaking multi-port voyages such as short sea tankers, container ships, and RO-ROs. It is a less critical factor for large tankers and bulk carriers undertaking long sea passages.

As mentioned earlier the mainstream way to comply with the BMW regulations is to install a fixed system. Other solutions do not involve installing a BWMS onboard, including port-based systems. They often appear as containers which contain the treatment system. The advantage of these systems involves the mobility to move the unit from port yard, to trailer, to the deck of a ship or a barge alongside ship. Land-based solutions could be suitable for aging vessels, where installing a BWMS onboard is not economically sustainable or if the onboard system is malfunctioning, for example, if the system has a mechanical failure. Contingency situations are planned ballast water discharges that do not meet the regulations and therefore need another solution quite urgently to discharge the ballast water to continue cargo operations. By investing in a port-based system, ports and authorities will have a better overlook over ballast water management convention compliance (Damen Green, 2018a).

The following sections describe the main port-based BWM systems that are currently available.

3.4.1 TopWater Flow BWMS

The Top Water Flow system is a concept design by a Norwegian company. According to the news, the BWMS will be available by barge and by land, either as a mobile or permanent unit. The company has developed a special barge for the purpose, which could be an option when no space onshore is available. Vessels need to connect their ballast water pipe with an electromagnetic tip and a rubber seal to the barge. The ballast water is then treated through two filters followed by SafeRay UV radiation. The capacity of the filter is 1000 m^3 per hour. The organic remaining waste (sludge) from the treatment is processed as compost, which is a resourceful solution of using the systems to full (TopWater Flow, 2018). Based on our research the company has only performed some small test of the concept and this system is currently not available. The whole project may have also be abandoned.

3.4.2 BWTBoat Concept

The BWTBoat (Port-based Mobile Ballast Water Treatment Facility) is a concept design created by the Indian Register of Shipping (IRClass) and functions by BWM systems being installed on barges that will operate in an area of ports, in the same manner as tugs and supply barges. The system would be available to load compliant ballast water onboard vessels (Figure 3) and to receive untreated ballast water to the barge, for treatment. Vessels need to install a shore connection and a TRO neutralizer for neutralizing chlorine from the treatment process (Safety4Sea, 2016). There are several different options to operate the BWTBoat e.g. by using filtration when loading and UV when discharging or filtration and UV at both ports or by using filtration and electrolysis alternatively filtration and electrolysis, UV and TRO neutralizer.

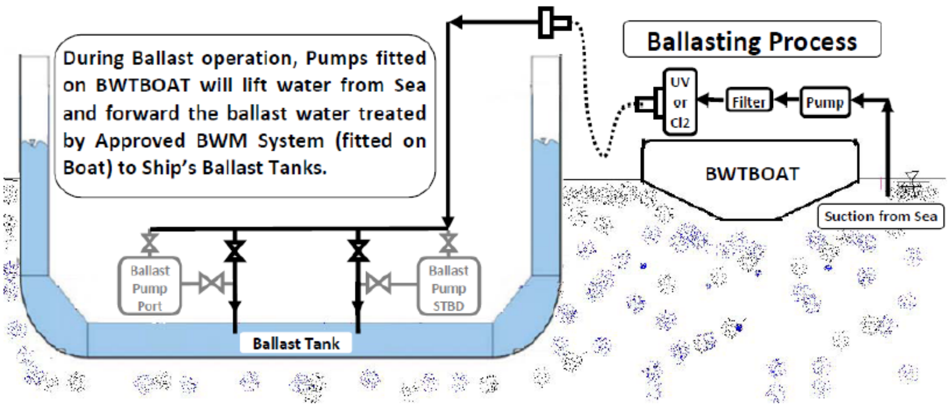

Figure 3 – Ballasting process with a BWTBoat
Source: MEPC 71/4/25

The BWTBoats are equipped with a diesel generator, azimuth thrusters, type approved BWMS and ballast water sample collection points, see Figure 4 (MEPC 66/INF. 17). If required by the vessel, several units connected parallelly is possible. For use of a BWTBoat, the vessel will be charged approximately $0,25 per ton of ballast water.

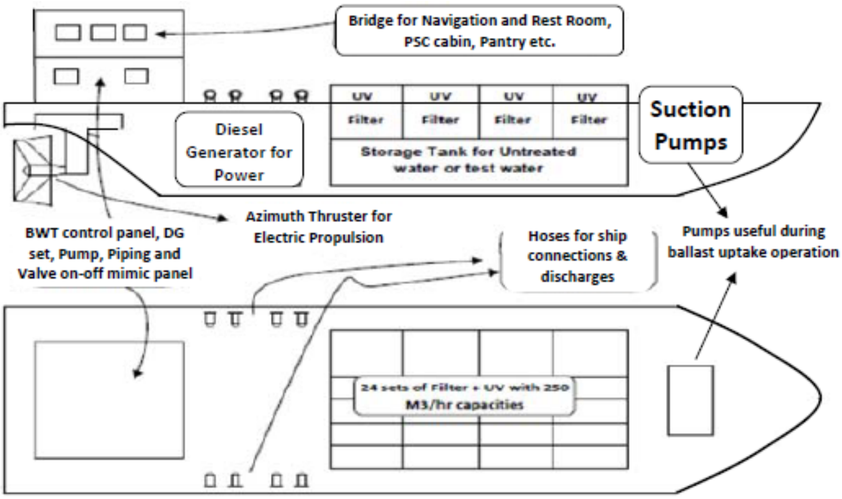

Figure 4 – The general arrangement of the BWTBoat
Source: MEPC 66/INF. 17 (India)

India has submitted various papers related to the concept. They proposed that the Member States could cooperate and decide to deploy BWTBoats in specific ports so that ships plying only between such ports could use these mobile facilities for executing ballast water management on a shared basis. An economic study has also been presented (MEPC 65/2/20, MEPC 66/INF.17) for the global implementation of the concept. The concept, which in our opinion is not much viable, suggests the use of 21,173 boats in approx. 2,500 ports worldwide.

3.4.3 Bawat BWMS

Bawat offers both onboard and port solutions; see Bawat (2018). The on-board BWMS draws on the waste heat from the ship's main engine jacket water cooling system whereas the off-vessel system is powered directly by fuel. The system is based on pasteurization, involving heating ballast water to a certain temperature that will kill all living organisms. Therefore, no UV, filters or chemicals are used, and the system is not sensitive to either salinity, temperature or turbidity. The layout of the Bawat system can be seen in Figure 5. No backflush filter needs to be handled for this method. The Bawat BWMS was type approved by Danish Authorities in 2015 and MEPC was informed of the certification by DNV GL in document MEPC 68/INF.9.

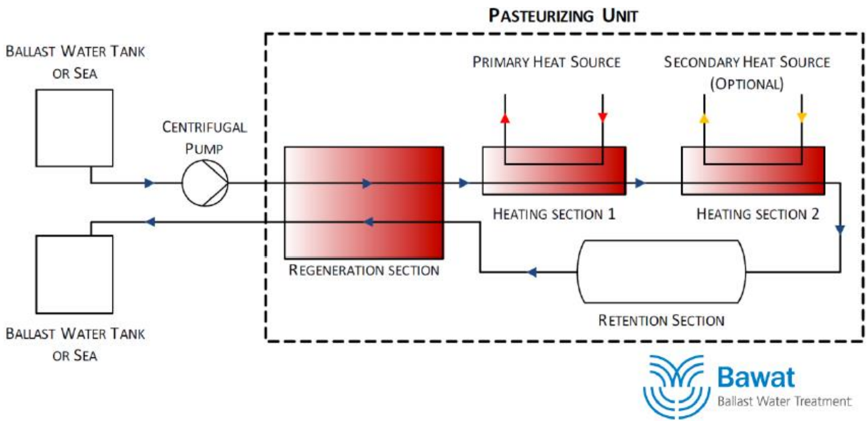

Figure 5 – The general arrangement of the BWTBoat
Source: MEPC 74/INF.21 (Denmark)

The Mk2 Mobile Treatment Unit is available as a containerized version of the Bawat BWMS. It is deployable on a barge, on-site or as a mobile land-based unit. The current design employs a custom-made 30-foot container (200 m3/h system) with oil fired boiler system (1,350 kW), heat exchangers, power supply, hoses, connectors, etc., to ensure efficient operation in ports and for smaller ships. As the BWMS does not require a holding time, the water is not intended to be stored. The treated water will be discharged to the harbour immediately in full compliance with the D-2 standard. In March 2019, Denmark has submitted to the IMO a statement of compliance with Guidelines (G5) of the Bawat BWMS Mk2 Mobile Treatment Unit issued by Lloyds's Register (see MEPC 74/INF.21) presenting the system as a reception facility for untreated ballast water to deal with *"planned ballast water discharges, e.g. in ship repair yards or as a part of contingency measures in ports for discharges that do not meet port State control requirements"*.

3.4.4 Invasave 300 BWMS

A port-based BWMS that has been type-approved according to IMO's D2 standards is the InvaSave, innovated by Damen Green. Its appearance is in the form of a 40 foot high cube container, as seen in Figure 6. The booster pump has the capacity of treating 300 m^3 per hour and starts by treating the ballast water through mechanical fine filtration, followed by a low-pressure UV system. There is a second filter to clean organisms that got filtered in the first treatment, to comply with the regulations when discharging the filter backwash (Damen Green, 2018b).

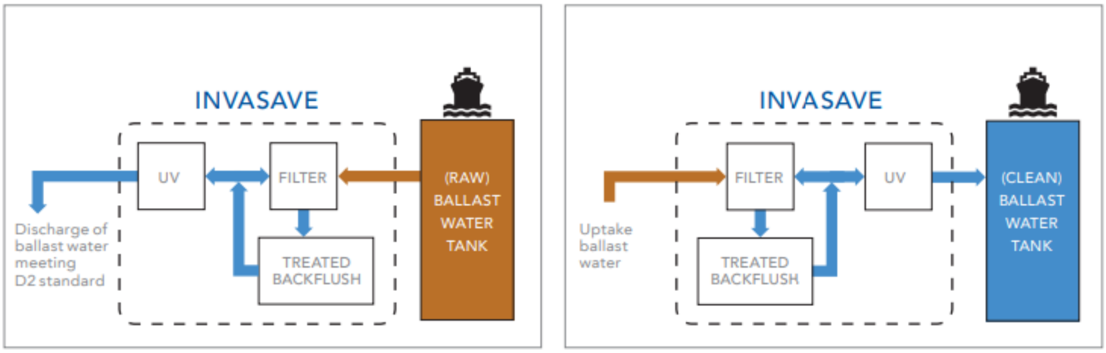

Figure 6 – The system explained for discharge respectively intake of ballast water

Source: Damen Green (2018b)

InvaSave is safe to install onboard a vessel according to the approval certificate, even though that is not the purpose of the system (Netherlands Shipping Inspectorate, 2017). According to its manufacturer, it is self-sufficient in terms of power supply and pumping capacity and no chemicals are needed. Ballast intake is possible with the gravity and it is designed for low maintenance. The clear advantage of InvaSave is that the water only needs to pass the system once to be fully compliant according to D2 regulations, either at ballasting or de-ballasting – this is referred to as 'single-pass'.

InvaSave is currently on the market and units are placed in Rotterdam, Amsterdam, Brest, Dunkerque, Vlissingen, Den Helder, Stellendam, Harlingen and Groningen (Damen Green, 2018b). To our knowledge, this is currently the only proven solution to port-based treatment that is commercially available and used by several operators.

4. The economics of Port-based Ballast Water Treatment Solutions

4.1 Total costs: The methodology

As briefly described in Sections 3.1 and 3.2 there is a huge market for mobile port-based BWMS either as an alternative compliance measure or as a contingency measure. The main focus is to present the costs for the operator of such a system. The scenario we investigate in this paper is one where a port/terminal operator is offering the service of treating ballast water onshore against a fee. Our approach can be generalised to cover other service providers such as Port Reception Facility operators, port authorities, shipowners or shipowner associations. Therefore, our approach can be extended to cover shore-based treatment systems as well. In the latter, the transportation cost (e.g. to a shore-based reception facility) or other costs may need to be included.

Based on the costs, and the potential benefits, i.e. revenue, from the proposed systems, operators could have some good insights on whether this could be a service that they might wish to add to their services portfolios or not. Given that this service is not currently mainstream so that the pricing of the service is not that easy to be estimated. There are many situations where a seller or service provider must come up with a price for a service or product that does not already have a price. The first approach to this is the consideration of the service's costs, a process which is known as cost-based pricing. A service provider should ask a fee that covers at least the total costs. The idea of starting with costs is intuitive, and cost-based prices are relatively easy to calculate. There are several disadvantages to this, such as that it does not consider the willingness to pay by the customer or the price set by competitors -not the case at the moment.

In this paper, we present the total cost of operation for the investment from a port operator's perspective. When a port (or any other service provider) invests in a port-based system, they will pay a capital cost and during operation, the system will demand crew, maintenance, service and, in some cases, transportation. In this paper, we use the Annual-Equivalent Cost method, where the revenue needs to cover the annual operating (OPEX) and annual capital (CAPEX) costs. Normally, capital costs are non-recurring, as in this case, whereas operating costs recur for as long as the system is being utilised. We calculate the annual equivalent of the capital cost (CAPEX) assuming that the initial cost (C) will be paid back in equal installments over the N-year period at an interest rate of i, as follows:

$$CAPEX = C \times \frac{i \times (1+i)^N}{(1+i)^N - 1}$$

To handle the uncertainty of the main parameters that affect the total expenses, we perform a Monte Carlo simulation by assuming that these parameters, some of which are based on expert judgment, follow a PERT-distribution. The PERT distribution is a version of the uniform distribution or triangular distribution and is mainly used in expert judgment due to its simplicity i.e the continuous probability distributions defined by the minimum (a), most likely (b) and maximum (c) values that the variable can take. In short, a Monte Carlo simulation is a technique that builds a model of possible outcomes by substituting a range of values (taken from a probability distribution) for a factor that we consider uncertain. During the simulation, values are randomly sampled from the input probability distributions and for each set of values (called an iteration) the output is calculated. This is performed for a thousand times and the result is a probability distribution of possible outcomes.

4.2 Inputs

In our analysis, we assume a typical treatment unit of 300 m^3/h. In our opinion, this low rate is the main drawback for the applicability of the proposed treatments, especially to servicing very large vessels, or more specifically, vessels that require ballasting or de-ballasting of large amounts of ballast water. However, this rate is the one used in most proposed solutions and also in the only IMO certified solution. The treatment capability of a port could be further increased by the use of extra units. The usage of the system varies between 20 and 80 hours per week, with a mean value of 60 hours. This corresponds to an annual treatment of an average of a bit less than 1,000,000 tons of ballast water. Note that the usage of the systems is a key parameter as it affects the fuel consumption and the need for repairs and maintenance for instance given that the UV lamps of the treatment systems need to be changed after a specific number of hours. The usage also influences the cost of personnel that is needed to operate the system, which in our case is not considered as we assume that this is covered by existing staff.

Fuel cost, which is one of the main cost components, is assumed to have an average price of 500 €/ton; modeled as distribution with a minimum of 300 €/ton and a maximum of 650 €/ton. Note that the major operating cost component is the energy required to use the system. We assume that diesel generators will be used so that the system is truly mobile. In our analysis, we use the consumption data of a typical diesel (total power of approximately 150kWe) similar to the one used in existing systems. Therefore, an average value of 24.2 liters per hour is assumed. Other operating costs, including spare parts for main and support equipment, consumable materials (oil, clean-in-place, coolant, grease), certification for engine and ballast water compliance, average repair costs are also taken into account.

We assume an investment lifetime of 8-12 years and with an average capital interest rate of 5%. The inputs are in line with the ones presented in COWI (2012) and Glosten (2018).

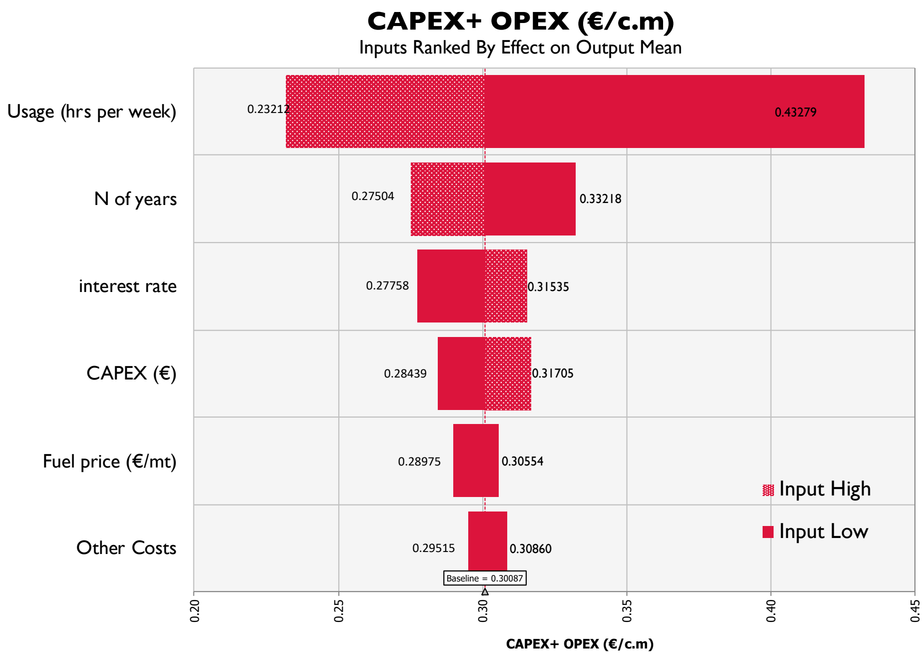

Figure 7 – Capital (CAPEX) and Operating (OPEX) expenses – Main parameters

Source: Authors' calculation using Palisade's @Risk software

4.3. Total Costs – Results

Our preliminary analysis reveals a total operating cost (OPEX) of a median of around 0.10 € per ton of ballast water treated. If we include the cost to acquire the mobile BWT system (CAPEX) we can then estimate the total cost of the system. Given the uncertainty of many of these parameters, we have performed a Monte Carlo simulation by using an academic version of the @Risk software by Palisade. We assume an investment for 8-12 years, with an average capital interest rate of 5%. The rest of the inputs are described in the previous section.

As we can see in Figure 7, the main parameters that affect the calculations in order of importance are the usage of the system (hours per week), the number of years that the system will be used, the interest rate, the capital cost (mainly the cost to acquire and install the system) and the fuel price. In this Figure, you can see the results of our simulation, and the minimum and maximum values of the total costs for each parameter. As discussed earlier the usage of the system is the single most important factor. Low utilization of the system, around 20 hours per week, corresponding to treating only 312,000 tonnes of ballast water, will lead to a total cost of 0.43 € per ton. On the other extreme, a high usage of around 80 hours per week, that is 1,248,000 tonnes treated per year, will bring the total expenses down to 0.23 € per ton.

As expected, our analysis reveals that the capital cost to purchase and install the equipment, as well as the related to the Annual Recovery Costs, such as the interest rate and the lifetime of the investment, do largely affect the results. The cost of the equipment is not well documented in the literature and the values we obtained varied a lot. Nevertheless, our simulations resulted in an average total cost (including both CAPEX and OPEX) of 0.26 to 0.3 € per ton of treated water; see Figure 8.

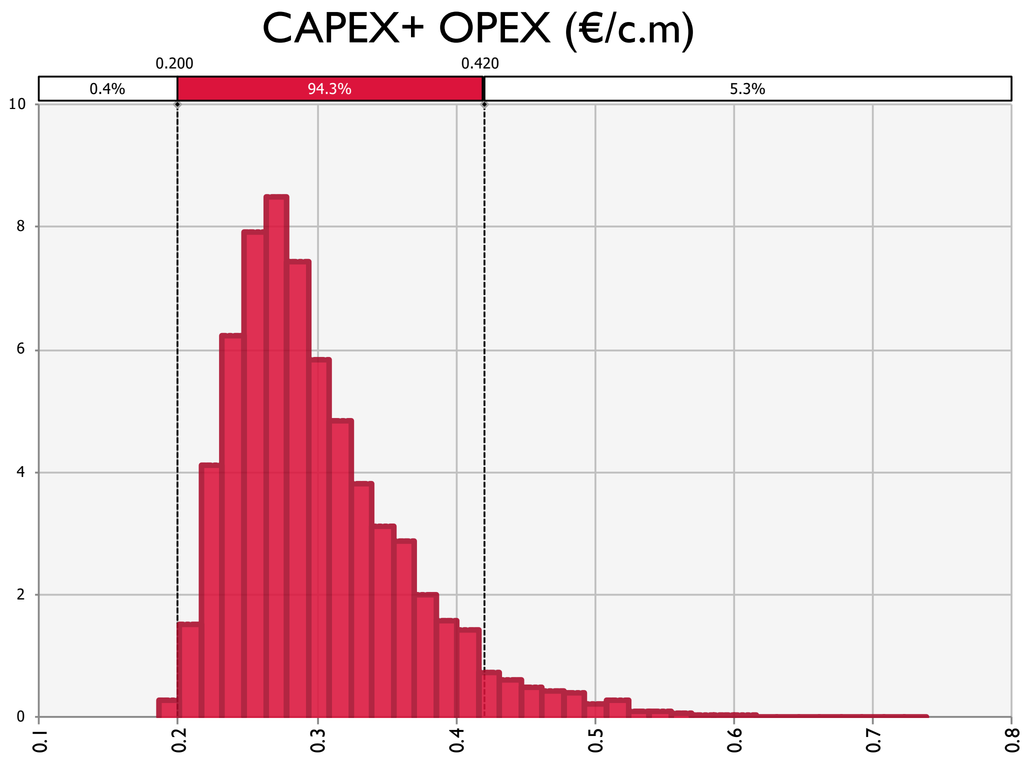

Figure 8 – Capital (CAPEX) and Operating (OPEX) expenses distribution
Source: Authors' calculation using Palisade's @Risk software

4.1 Revenue/Charges

The analysis above reveals the total cost of a mobile system for a port operator. We assume that port operators will operate a mobile system to treat ballast water to provide a service to ship operators either as an alternative to onboard systems or as a contingency measure. We do not investigate alternative scenarios, i.e. ports being forced to provide such a service or receiving State support or subsidies to offer this service as a contingency measure. It might be the case also that a group of ports may acquire such a piece of equipment and share it. This is extremely easy as a containerized system can be placed on a truck and be easily transported, or even placed in a barge and serve multiple ports. Clearly, profitability does not only depend on the operating expenses but also revenue. This, in turn, mainly depends on the price that the system operator will charge the owner. This price may consist of a fixed cost e.g. per use and/or a variable cost depending on the amount of water treated. Pricing of the service requires further investigation. At a minimum, the charge needs to be equal to the break-even price. Break-even pricing is the practice of setting a price point at which a business will earn zero profits on a sale. The intention is mainly to use low prices as a tool to gain market share. There are more advance pricing techniques though, such as ones based on determining the customer's maximum willingness to pay for such a service. Although this is an interesting task, it is out of the scope of this paper to discuss the pricing methods that could be used. There is a vast literature dedicated to this topic; the interested reader is referred, for example, to Avlonitis and Indounas (2005).

4.2 Profitability and Discussion

The profitability of the service will depend mainly on the revenues, which, in turn, depend on the price of the service and the vessels served, more precisely on the amount of ballast water treated. In our analysis we have assumed an average quantity of 1 million tonnes per year, roughly corresponding to using the equipment for 60 hours per week. These volumes could be grossly underestimated in case that such systems are considered mandatory in case of emergencies (i.e. as a contingency measure). This is still an open topic at the IMO.

Unfortunately, there is no reliable data on the amount of ballast water loaded or unloaded in European ports. On contract, in the United States, the National Ballast Information Clearinghouse (NBIC) collects, analyzes, and interprets data on the ballast water management practices of commercial ships operating in US waters of the United States. We base the following data on US data, in line with Glosten (2018), noting that further analyses should be performed to capture the operating profile of vessels in specific EU ports.

Table 4 – The ballast volume discharged from different types of vessels per year.

	Average vessel	Containership	Bulker	Tanker	Passenger	RoRo	Other
Ballast water discharges per year	259	223	375	570	167	10	210
Volume per discharge in m3	6,840	3,680	15,313	10,605	816	853	9,771

Source: Adapted from Glosten (2018)

According to Glosten (2018) the average vessel performs 259 ballast discharges each year; see Table 4. The average vessel is de-ballasting 6840 m^3 of ballast water per discharge. This will result in that the average vessel discharges 1,771,474 m^3 of ballast water per year. Therefore, it seems that the assumed volume can be a realistic assumption especially to cover the volume handled in case of emergencies. Note though that Table 4 presents the average volumes discharged by vessels is US ports. The profitability of the investment in a mobile system for specific ports depends heavily on their operating profiles. The low treatment rate of 300 m^3 per hour is probably not suitable for ports that accommodate vessels that handle large quantities of ballast water. This might be the case for ports that are major cargo loading or discharging ports; see Table 5 that presents for various vessels the nominal tonnage of the vessel, the ballast water carried on board, the maximum capacity and the amount the vessels discharged in specific US ports.

Table 5 – The ballast volume discharged from different types of vessels per year.

Type	Name	Tonnage	BW capacity	BW Onboard	BW discharged	Port	Last port
Bulker	Sakura Wave	48,022	32,854	30,275	30,275	Long Beach (USA, CA)	Wakamatsu, Japan
Bulker	Carme	23,433	21,229	9,897	2,684	Long Beach (USA, CA)	Vancouver (Canada, BC)
Bulker	Orient Hope	19,828	11,521	3,748	3,748	Long Beach (USA, CA)	Longview (USA, WA)
Container	NYK Adonis	105,644	23,698	11,140	256	Long Beach (USA, CA)	Yantian, China
Container	CMA CGM New Jersey	54,309	14,519	11,236	960	Long Beach (USA, CA)	Busan, Korea
Cruise	Carnival Imagination	70,367	3,575	1,215	640	Long Beach (USA, CA)	Ensenada, Mexico
Tanker	Gem No. 1	156,501	96,934	84,063	1,909	Long Beach (USA, CA)	Pacific Area Lightering (USA, CA)
Tanker	Megara	113,263	61,924	52,571	51,047	Sabine Pass (USA, TX)	Isle of Grain, Uk
Tanker	Gener8 Constantine	154,133	90,824	84,215	82,070	Corpus Christi (USA, TX)	Singapore
Tanker	Silverway	81,545	54,309	5,520	419	Corpus Christi (USA, TX)	Freeport, Bahamas

Source: Authors based on data from NBIC

5. Conclusions and Discussion

In this paper, we have presented the use of mobile port-based ballast water treatment systems by a service provider to offer shipowners and operators an alternative way to comply with the BWM Convention. As previously outlined, the vessels to which the Convention applies will need to install an onboard system that meets the standard. Installing a mobile solution e.g. a BWT system fitted in a container as an alternative to an onboard system is viable only under specific scenarios, e.g. vessels with few ballast water discharges per year and for older vessels, which need to be further investigated. The proposed system is not currently considered as a mainstream solution. However, there is evidence that this may be a good alternative for some vessels i.e. vessels with few ballast water discharges per year and for old vessels, fitting an onboard unit is a costly investment. These mobile treatment systems, either fitted onboard or port-based ones, are also particularly suitable for barges, supply vessels, vessels engaged in short sea shipping or those with minimal and predictable ballasting operations – such as fixed-route container vessels and liner services. In this case, an owner investing in a small number of mobile treatment systems could share them between multiple vessels, avoiding having to retrofit each vessel individually.

In any case, the most obvious application of these mobile systems is as a contingency measure, for example when the onboard system is not functioning. Now, depending on the approach used by the State, the ship operator might be required to use a port-based system or a Port Reception Facility. Note that this is not currently the case but there are ongoing discussions at the IMO on how to handle emergencies.

There are currently some proposals of mobile port-based systems; the only solution that is currently IMO type-approved is the Invasave 300 system by Damen. The main reasons that there are not many manufacturers that offer such a solution might be the high costs associated with receiving the certification, the fact that the market does not seem large enough for this type of treatment system, or the fact that companies are focusing on selling onboard systems. Note that the system we describe is a "single-pass" one. Any IMO type-approved treatment system can theoretically be fitted into a single container. The main difference with the solution that we are proposing is that we are referring to systems into which whatever ballast water passes through the units, it comes out D-2 certified in a single pass, without delays of any kind. That is what single-pass means. In fact, for almost all certified systems a holding time, around 3 days or more, of the ballast water to complete the reaction is needed. This is a critical factor for vessels undertaking multi-port voyages such as short sea tankers, container ships and Ro-Ros. It is a less critical factor for large tankers and bulk carriers undertaking long sea passages. Another alternative solution to the one we analyse in this paper is a containerized system, with preferably a higher handling capacity, that is coupled with a storage tank. The need for a holding tank is mandatory for all mainstream systems since the type of approval requires that the treated water should not be discharged before the end of specified retention time.

Our preliminary analysis reveals a median total operating cost of around 0.10 € per ton of ballast water treated. If we include the cost to acquire the mobile BWT system we could then estimate the total cost of the system. As we can see in Figure 7, the main parameters that affect the calculations in order of importance are the usage of the system (hours per week), the years of the investment, the interest rate, the capital cost (mainly the cost to acquire and install the system) and the fuel price. As discussed earlier the usage of the system is the single most important factor. Low utilization of the system, around 20 hours per week corresponding to treating only 312,000 tonnes of ballast water will lead to a total cost of 0.43 € per ton. On the other extreme, a high usage of around 80 hours per week, that is 1,248,000 tonnes treated per year will bring the total expenses down to 0.23 € per ton.

We assume in this paper that port operators will only offer this service if it is a sound economic investment. Clearly, profitability does not only depend on the operating expenses but also revenue. This, in turn, mainly depends on the price that the system operator will charge the ship operator. Pricing of the service requires further investigation. At a minimum, the charge needs to be equal to the break-even price. The other important parameter is the quantity of water that needs be treated. These quantities vary across ports, as some ports are mainly used to load or unload cargo, other ports act only as intermediate destinations. For example, one extreme case, is a main oil-exporting port where large vessels enter with high quantities of ballast water that needs to be discharged before the oil is loaded. Our focus though is mainly small to medium-size vessels, and ports, where the ballast quantities handled, are not that high.

To conclude, this is not a solution that fits all ports and all vessels but we have identified various cases where the proposed system can be a viable alternative. We have also provided a simulation-based methodology that can be used to evaluate the cost-effectiveness of the mobile BWMS. As a final remark, more data need to be collected by individual ports on the amount of water that needs to be treated given the fact that relevant information is rather scant, especially for European ports. Simulation could also be used in line with Pereira and Prinati (2012). It is hoped that given this input data, the methodology presented could assist in the assessment of the economic viability of a mobile treatment system for specific ports.

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Disclaimer: The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the official position of the consortium.

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