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# Design Ballast Water Planning Simulator in Container Ship

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*ABSTRACT*

This research aims to design ballast web-based water simulators for container ships. This study conducted research and development (R&D) utilizing a modified Four-D model. The simulator design is divided into four stages: define, design, create, and disseminate, with the software eventually being utilized as a web-based ballast water simulator on a container ship. This study found that the development of the simulator is crucial due to the impact of ballast water on the maritime environment and the regulations surrounding ballast water management. The simulator will aid in planning cargo loading and unloading to ensure stability under external and internal forces and comply with the Ballast Water Management Convention. This study concluded that the simulator design could display the ship data, ballast water filling planning, ship stability calculations, displacement, and GM (metacentric height or metacentric height).



## 1. Introduction.

The development of technology is getting faster, and new technologies are emerging. It is greatly affecting human life, both in lifestyle and work. Moreover, the rapid development of science and technology has benefited human life. It makes the industrial world take advantage of technological developments used to work manually. Now, switching to auxiliary aircraft that work automatically; it will save energy. With the development of technology, humans also began to develop a system commonly known as a control system, where the control system is a system or method of automatic regulation directly or remotely. It can also be a combination of the two methods (Wróbel et al., 2018).

One of the control systems on a board ship is usually operated in the engine room manual or automatic means in the engine control room. The ballast system is one of the service system on the ship that transports and fills ballast water (Kounadis et al., 2020). The ballast pump system is intended to adjust the level of inclination and draft of the ship, as a result of changes in the ship's load so that the stability of the ship can be maintained. To control the ballast water, sound the ballast water manually to determine the height and how much water has entered the ballast tank. Apart from manual sounding, in the engine room, there is also a control system that is capable of displaying an output value automatically which is connected from the ballast tank to the engine room which is usually called a ballast control system.

Transportation is a very important facility for humans from an economic and social perspective. One mode of transportation that plays an important role in expanding the scope of distribution of goods or services is sea transportation; container ships are one of them. Container ships are cargo ships specifically used to transport standard-sized containers (Talley, 2018). As time goes by, container ships have increasingly been used to

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transport goods between islands in a country or internationally for economic, safety, and faster loading and unloading speeds.

The large number of containers that are moved during loading and unloading will create much movement on the ship, causing an unbalanced shift in the load point and causing the ship to experience a slow tilt, resulting in the ship sinking, thus disrupting the loading and unloading process. Many companies have developed sophisticated technologies to overcome this problem as time progresses, especially the ballast control system (Garrido et al., 2020; Kim et al., 2020; Makkonen & Inkinen, 2021).

Since 2004, the International Maritime Organization has approved the Bilge Water Management Convention to limit the transmission of harmful aquatic life from one location to a different one by establishing rules and procedures for managing bilge water and sediment on ships. Presidential Regulation No. 132 of 2015 approves IMO norms on ballast water management for ships on international routes, with the goal of protecting Indonesia's waters. During the previous 12 years, the International Maritime Organization has socialized this convention over the world. It required a long time to execute due to hurdles such as adding equipment for ballast water treatment, which is a significant investment (International Maritime Organization, 2009a, 2009b, 2010).

However, after the convention was implemented, the ballast water exchange norms were no longer applicable, and ships had to manage ballast water by adding equipment or using port facilities. According to Regulation B-3.6 of the Ballast Water Management Convention, ships that exchange ballast water at reception facilities are not obliged to be equipped with ballast water handling equipment. Most Indonesian ports still require welcome facilities for a variety of reasons, including cost considerations. Thus, ship owners can execute this ballast water handling strategy by installing facilities on their ships, while the government can provide reception facility services at ports. This legislation will have an impact on shipping companies because it will require more significant investments in equipment, installation, and maintenance (Gollasch & David, 2019; Ishola & Kontovas, 2022; Simeonova & Kralev, 2023).

A few researchers focused on the implementation of the ballast water convention. Therefore, this research focuses on design a web-based software for an automatic ballast control system for container ships. It is simple and capable of increasing the stability of the ship or preventing the ship from tilting which causes the ship to sink.

## 2. Literature Review.

Software for planning cargo handling on container ships so that the ship's stability results must be good, which is influenced by external and internal forces. Several movements occur on the ship (ship motion) which are caused by forces from outside or from within the ship itself. These movements include surging motion (movement of the ship towards the front and rear of the ship), swaying motion (movement of the ship to the side), heaving motion (movement of the ship in an upright direction), rolling motion (ship movement with a rotational axis that is longitudinal to the ship and through the ship's center of gravity), pitching motion (ship movement with a rotational axis that is transverse to the ship and through the ship's center of gravity), and yawing motion (rotational motion of the ship in over the wave with a vertical axis of rotation that passes approximately through the ship's center of gravity) (Soegiono et al., 2006). In addition, ship owners, ship operators, and/or agents of national sea transportation companies transporting dangerous goods are required to provide notification to the harbormaster before the ship carrying dangerous goods arrives at the port.

A container is a storage media used in the process of transporting goods (Baik, 2017; Böröcz, 2019; Dewi & Maharani, 2020; Saxon & Stone, 2017). Containers can also be called warehouses made of steel. A container is used to store goods and can be transported by water, land, or air. The maximum weight of a dry cargo container 20 feet is 24,000 kg, and for 40 feet is 30,480 kg (including a high cube container). So, the net weight/payload that can be transported is 21,800 kg for 20 feet and 26,680 kg for 40 feet.

Containers have the characteristics of being strong, weather resistant, and can be used repeatedly with fast loading and unloading and extraordinary safety guarantees and are currently equipped with electronic seals for easy monitoring (tracer). The container system makes it possible to carry out transportation with a door-to-door system. Each container is given an identity so that it is recognized by authorized parties such as the owner, transporter, customs officers, and the terminal. Containers must comply with the provisions stated in international conventions such as the UN CSC (Convention on Safe Containers) in 1972. Each container must be tested for seaworthiness and proven by a certificate (Čampara et al., 2019). The International Standards Organization (ISO) divides container types into seven groups, namely:

a. Ordinary Container (Dry Container)
   There are several sizes and models/types of ordinary containers (dry containers):
   (1) 20′ with payload (Can load) up to 28.3 metric tons. But keep in mind that the standards allowed by port managers are not the same in each country. In Indonesia, on average international shipments are only allowed up to a maximum of 20 tons, as is the case in most parts of Asia. Meanwhile, in Chile and most Central American countries, the maximum is 18 tons.
   (2) 40′ – both standard 8'6″ and 9'6″ high cube – with payload up to 30.4 metric tons. The permitted load limit is usually up to 27-28 tons. In the United States, it is 25 tons.
   (3) 45′ – with a size of 9'6″ high cube – with a total capacity of 86 cubic meters.

   Several shipping companies provide containers for special needs, including:
   (1) Containers equipped with beam hangers which are used to send garments/clothes hanging without cardboard packaging,

(2) Containers with extra payload or larger door sizes for cargo with larger weight and dimensions.
(3) Bull rings and lashing bars for load fastening
(4) Ventilated containers for agricultural products that require air circulation, for example, coffee, chocolate, onions, garlic, etc.

b. Refrigerated containers
For goods that require special treatment, for example, fish, vegetables, and fruit, both fresh and frozen, we can use refrigerated containers (reefer containers) which are equipped with a cooling machine that we can adjust the container temperature as needed. So that the quality and durability of the cargo is maintained until it is received by the buyer in the destination country.
Usually, these refrigerated containers are equipped with special features such as:
(1) Dehumidification system which guarantees the temperature and humidity of the container
(2) Even super freezer containers can maintain temperatures below -60°C/ -76°F

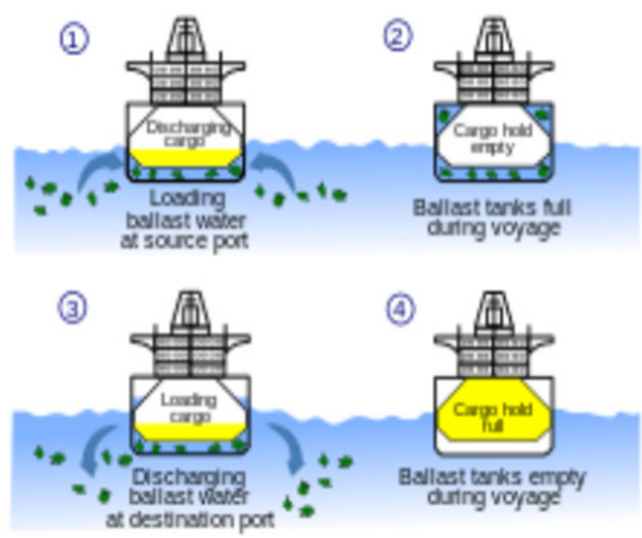
c. Special equipment container
For special cargo which dimensions and weight exceed the maximum limits for using ordinary containers, there are special containers provided for these goods.
(1) Flat racks and artificial tween decks (ATD) both 20' and 40' a container that do not have permanent walls or roofs or the container walls can be opened and closed as needed. Suitable for the process of loading goods from the top or side of the container. Usually used for heavy machinery, pipes, etc.
(2) Open top containers, 20′ and 40′ which roof can be opened or covered with a tarpaulin.

Handling of containers at the port consists of the following activities:
(1) Take the container from the ship and place it under the portal gantry crane
(2) Take it from the ship and immediately place it on the truck/trailer bed which is ready under the gantry portal that will immediately transport it out of the port
(3) Moving containers from one stacking place to be stacked in another place in the same container yard.
(4) Shifting containers, because the containers that are stacked at the bottom will be taken, the containers that are on top must be moved first.
(5) Collect (unite) several containers from one shipment to one stacking location (previously scattered in several locations/lots)

Cargo handling is the work of taking care of goods that will be loaded or have just been unloaded from transportation equipment (Anggraini et al., 2022; Fransoo & Lee, 2013; Rezaei et al., 2017; Widodo & Pratama, 2022). Cargo handling must comply with the five principles of good loading, including protecting the crew and workers, protecting the ship, protecting the cargo, carrying out loading and unloading appropriately and systematically, and using the maximum possible cargo space (Abrori & Sutini, 2017; Lesmini et al., 2019; Pramudita & Mulyanto, 2021; Zhang et al., 2021). The following explains this principle in more detail:

Ballast water is an ideal medium for maintaining the ships' balance and stability that do not carry cargo (Lacasa et al., 2013). Ballast water is pumped into a tank that has been specially designed to carry ballast water. However, the worldwide release of ballast water increases the risk of biological invasion of the environment. Microorganisms transferred through water have shown resistance to long-term shipping conditions. Therefore, ship ballast water has been identified as the main factor in the movement of these organisms for more than 90 years (Pam et al., 2013). This is what causes the need for ballast water management to minimize the transfer of microorganisms from different waters. The International Maritime Organization (IMO) has initiated the Ballast Water Management convention as an initial step to protect the marine environment from invasion by harmful organisms since 2004. According to IMO estimates, every year ships in the world carry as much as 3-5 trillion tons of ballast water and it has the potential to damage the world water environment (Stehouwer et al., 2013).

Figure 1: Blasting-deballasting process.




Source: Globallast.

The Ballast Water Management Convention will come into force simultaneously in September 2017, causing almost all types of ships to comply with the requirements of this convention. It applies to all ships even if the place where the ship is registered (flag of registry) has not ratified this convention, especially if the ship will make international voyages. The ship is required to have certificates and documents related to the establishment of a system capable of handling ballast water on ships with minor environmental impact, following the implementation instructions of this convention that ships of 400 GT (Pelorus, 2017). The certificates or documents are:

- Ballast Water Management Plan approved by flag or registry

- Have a Ballast Water Record Book
- Surveyed and issued a certificate related to International Ballast Water Management

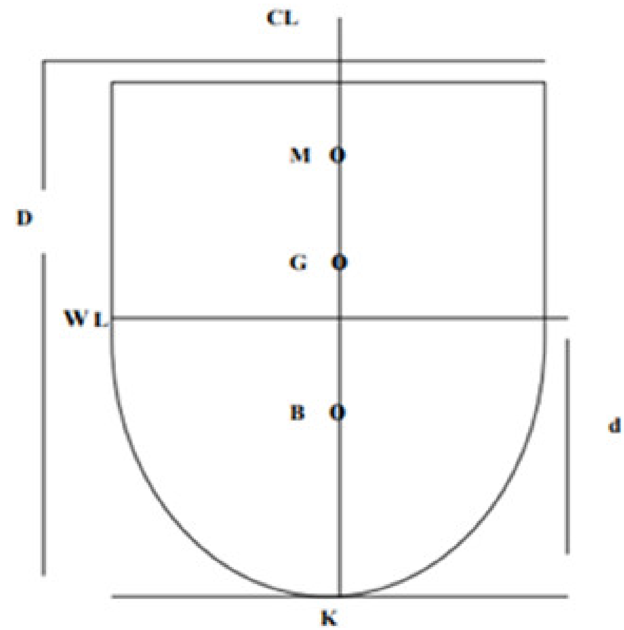
It is expected to exponentially increase the demand for ballast water treatment system equipment (Jee & Lee, 2017). Several countries that have adopted this convention have also adopted it as environmental regulations in their countries, such as America. The United States, through the U.S. Coast Guard (USCG), made regulations regarding ballast water and were established in 2012. These regulations require ships to install ballast water handling equipment that meets standards and is certified by the USCG or are temporarily permitted to use equipment certified by entities or other institutions to be able to dispose of ballast water in United States waters. Ships that do not meet the above standards can only discharge ballast water at ballast water treatment facilities at port disposal facilities (King & Hagan, 2013).

In this convention, there are two performance standards to reduce the impact of ballast water, namely performance standards D1 and D2; performance standard D1 is managing ballast water using the ballast water exchange method by exchanging ballast water in the middle of the sea and performance standard D2, which is the use of a ballast water treatment tool system. Each existing ballast water treatment technology will undergo tests before being approved by relevant parties such as the IMO and USCG (United States Coast Guard) and is ensured to produce ballast water output that complies with the IMO D2 standard, assuming that organisms that comply with this standard are more difficult to reproduce in marine and aquatic ecosystems.

There are three types of stability: Stable equilibrium is when point G is higher than point M, so a ship that exhibits stable stability when towed must have the ability to regain its balance on its own. Neutral equilibrium is a stable state in which point G coincides with point M so that the ship exhibits neutral stability when being towed with zero moments or the inability to restore balance on its own. The final unstable equilibrium is a stable state where point G is higher than point M, so a hostile ship cannot balance itself when towed; the tow angle increases, causing the ship to tilt further and possibly capsize.

Important points in stability include the centre of gravity, known as the G point of a ship, which is the catch point for all forces that press down on the ship. The location of the G point on the ship can be known by looking at all the distributions of weights on the ship; the more weight placed at the top, the higher the G point is located. The centre of buoyance, known as point B of a ship, is the catch point of the resultant forces pressing upright on the part of the ship that is immersed in the water. Catch point B is not a fixed location; it will move owing to changes in the ship's draft. Point M is a ship's metacentric point and a pseudo-point of the boundary beyond which point G cannot pass, allowing the ship to maintain positive stability. Meta implies change; hence, the metacentric point can shift its position based on the size of the angle of inclination.

Figure 2: Key points in stability.




Source: Authors.

Description:

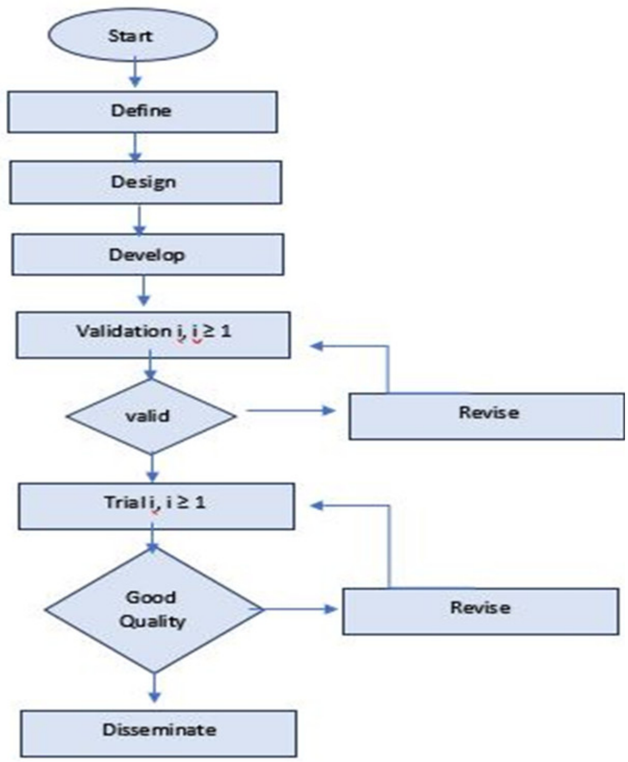
K = Keel,
B = Buoyancy,
G = Gravity,
M = Metacentris,
d = Draf,
D = Depth,
CL = Centre Line,
WL = Water Line.

## 3. Material and Method.

In this development research, the researcher develops a product based on a previously existing product with a different concept and then develops it by reviewing literature and expert studies. Researchers involved experts, lecturers, and cadets in developing the product to produce a product in the form of web-based container ship ballast water-handling planning software with good quality. This research focuses on product development through web-based container ship ballast water handling planning software at the Surabaya Shipping Polytechnic. This research uses the Thiagarajan et al., (1974) development process, known as the Four-D Model or modified 4D model. According to Thiagarajan et al., (1974), four steps are involved in product development. The four steps of the product development process can be seen in the flow chart in the following image.

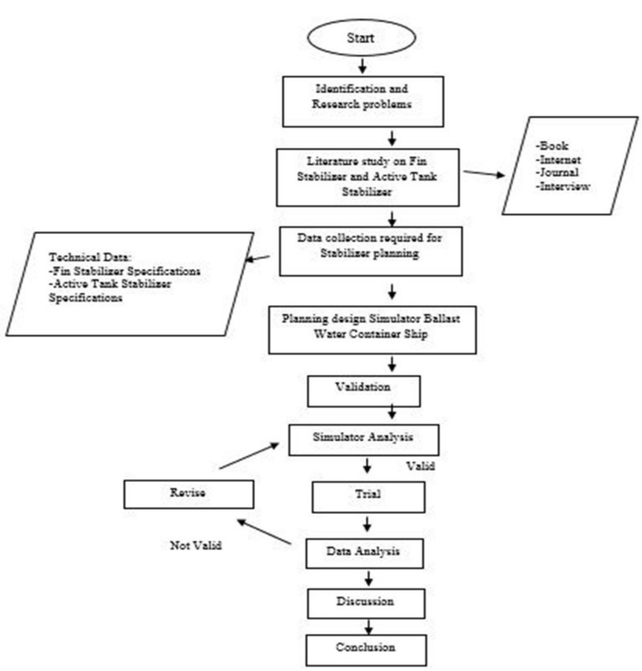
Meanwhile, the procedures for planning ballast water on container ships are shown in the following flow diagram:

Figure 3: 4D Development Model Flow.




Source: Authors.

Figure 4: Design Flow Diagram.




Source: Authors.

## 4. Results and Discussion.

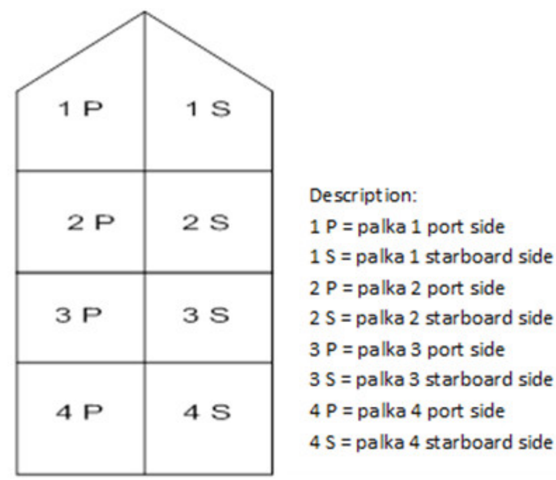
This study's development follows the stages of the Four-D Model development model or modified 4D model, which are defined, designed, developed, and disseminated. The simulator developed in this study is used for ballast water planning on container ships. The research findings at each level can be stated in greater detail as follows:

### 4.1. Description of Define.

#### 4.1.1. Identify Ship Type.

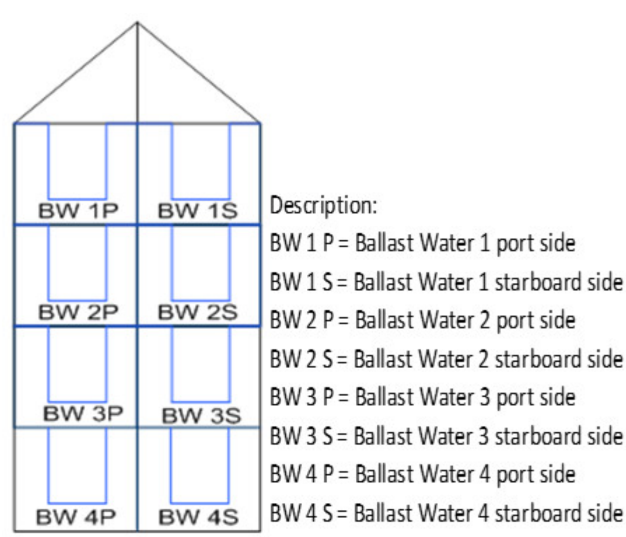
The type of ship used is a container ship, which is a ship used to transport cargo between islands in Indonesia. The following is the ship data used in this research:

Figure 5: Ship Tank Data.




Source: Authors.

Figure 6: Ballast Water Data.

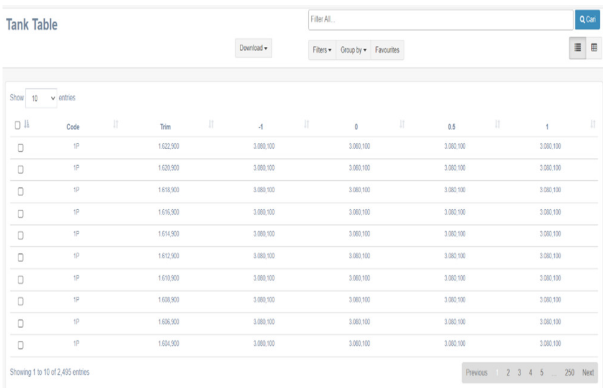



Source: Authors.

#### *4.1.2. Tank Table Identification.*

The picture below is a tank table that shows a comparative relationship between the volume of liquid contained in the tank and the depth of the liquid. It can be seen in figure 7 below as follows:

Figure 7: Tank Table.

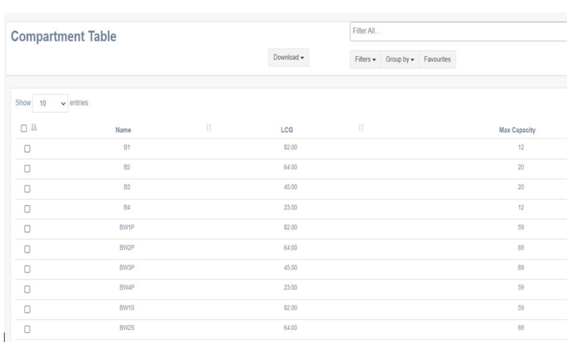



Source: Authors.

#### *4.1.3. Compartment Table Identification.*

Display compartment data includes Longitudinal Center of Gravity (LCG) and Maximum Capacity. It can be seen in figure 8 below as follows:

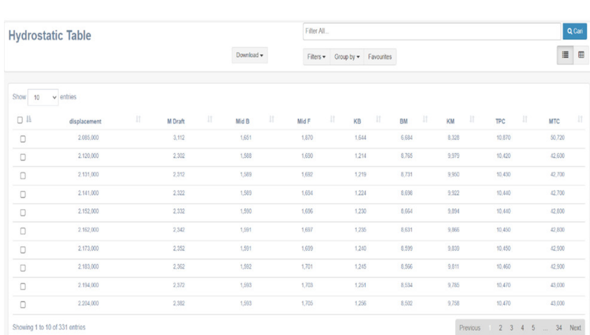
Figure 8: Compartment Table.




Source: Authors.

#### *4.1.4. Hydrostatic Table Identification.*

Figure 9: Hydrostatic Table.




Source: Authors.

### *4.2. Description of Design.*

At this level, the following is done:

a. Simulator Goals: The design stage seeks to develop a software simulator capable of displaying cargo planning, ballast water planning, and determining container ship stability.
b. Scope: The simulator focuses on cargo planning, ballast water, and determining the stability of container ships during a single journey. The loading is liquid.
c. Trial Schedule: At this point, a trial planning timetable is implemented. The planning timetable is shown in the following table:

Table 1: Trials Planning Schedule.

| No | Name | Time |
|---|---|---|
| 1 | 1st Trials | August 26, 2023 |
| 2 | 2nd Trials | September 9, 2023 |

Source: Authors.

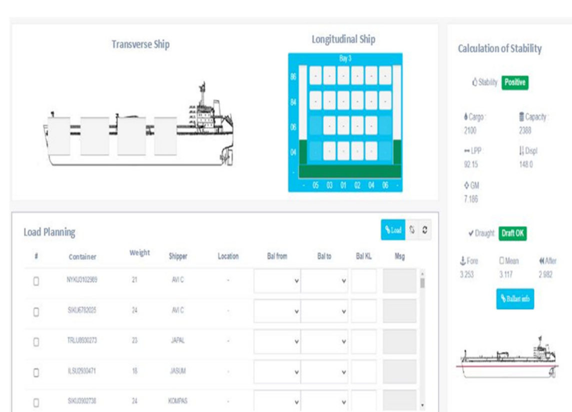
### *4.3. Description of development.*

This stage involves making a simulator based on a previously designed simulator prototype. The following are the stages of developing an initial simulator product.

a. The choice of the web as a means of creating a simulator is because the web is very flexible and user-friendly and can be used in various browsers.
b. Create a menu display for ship data input, tank table, initial conditions, compartment table, and hydrostatic table.
c. Create input data for the load to be loaded.
d. Make input of ballast water data.
e. Create a stability calculation display.
f. Create the main display.
g. The design includes color, font, and font size.

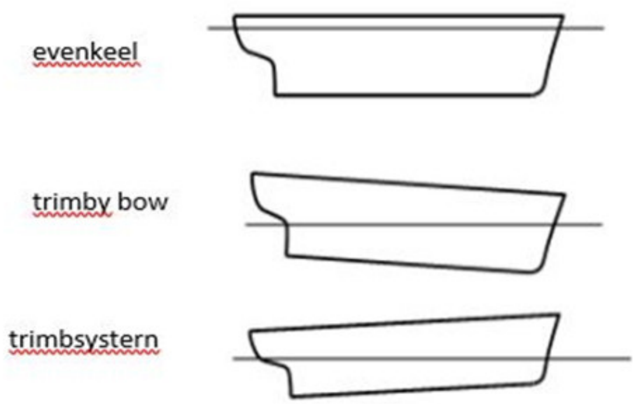
The results at this stage are software that can be used for cargo planning, ballast water, and knowing the ship's stability in one trip called a simulator. The following display of the simulator can be presented in the following image:

Figure 10: Main display.




Source: Authors.

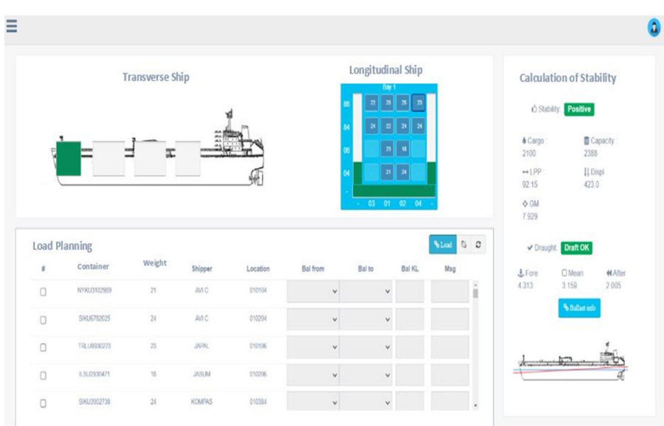
Figure 11: Longitudinal condition of the ship.




Source: Authors.

a. 1st trial: The first trial was carried out on August 26, 2023, to determine the stability of the ship when handling container cargo and ballast water management. Moreover, it can be seen in figure 12 as follows:

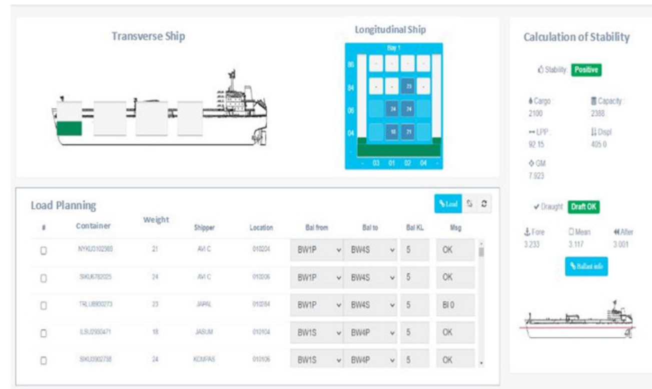
Figure 12: Loading in Bay 1 without Ballast Water Management.




Source: Authors.

In the picture above, loading the cargo in hatch/bay 1 obtained LPP 92.15, Displacement 423, and GM value 7.929, so the stability is positive. The after value is 2.005, the fore value is 4.313, and the mean is 3.159. The after value is smaller than the fore value, and the ship is in the trim-by-bow position. So, it is necessary to manage the ballast water so that the ship's position is Even keel when the front draft of the ship is the same as the backdraft of the ship.

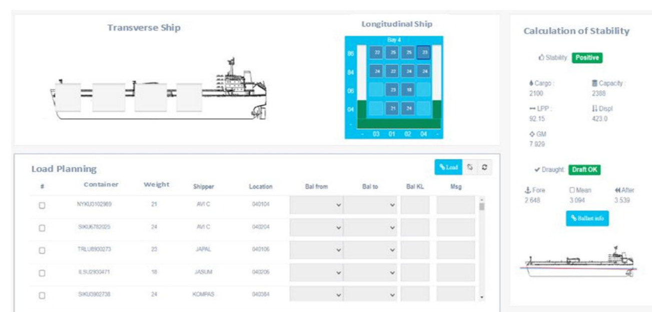
Figure 13: Loading Bay 1 and Ballast Water Management.




Source: Authors.

b. 2ndt trial: The first trial was carried out on September 9, 2023, to determine the stability of the ship when filling hatch/bay 7 and ballast water management.

Figure 14: Loading Bay 7 Without Ballast Water Management.




Source: Authors.

In the picture above, loading the cargo in bay 7 resulted in LPP 92.15, Displacement 423.0, and GM value 7.929, so the stability is positive. The after value is 3.539, the fore value is 2.648, and the mean value is 3.094. Because the fore value is smaller than the after value, the ship is in the trim by stern position. So, it is necessary to adjust the ballast water so that the ship's position is Even keel when the front draft of the ship is the same as the backdraft. Otherwise, the dissemination stage was not carried out due to limited time.

## Conclusions.

Based on the explanation above, it can be concluded that the development of a web-based ballast water simulator for container ships is crucial for improving ship stability and preventing sinking. The simulator, following the Four-D Model, aims to assist in cargo planning, ballast water management, and determining ship stability. The trials conducted showed positive stability, but adjustments in ballast water management were identified as necessary. Despite the limited time preventing the dissemination stage, the research outlined the simulator design process and provided suggestions for future research. Thus, this study covered various aspects related to ship stability, ballast water management, and maritime operations, emphasizing the importance of this research in addressing the impact of ballast water on the maritime environment and compliance with regulations.

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