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Development of Website-Based Software for Calculating Ship Stability of Container Ships Carrying Dangerous Goods

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ABSTRACT

Ship stability is crucial to the safety of sailing. Ship stability highly impacted the balance of the ship in order to prevent the ship from tilting left or right. This study aims to develop website-based software for easier calculation of ship stability for container ships loaded with dangerous goods. The study emphasizes the importance of ship stability in ensuring maritime safety, particularly when transporting hazardous materials. This study used thr 4D Thiagarajan development model which consists of Define, Design, Develop, and Disseminate stages. This study is expected to be published in a national or international indexed and reputable journal, or presented at a national or international conference. It takes special skills and a long time to calculate a ship's stability. One of the many types of ships is container ships. One of the various types of cargo in a container is dangerous goods. Any goods that potentially harm the health, safety, property, and environment are considered dangerous goods. In handling the cargoes related to dangerous goods, ship stability with particular calculations has to be taken into consideration. The research suggests further validation of the simulator with the application of stability calculations in the shipping industry to prevent accidents such as fires or tilting.

1. Introduction.

The development of a country can be achieved through economic processes, one of them being the domestic market by doing export and import. This system is supported by the role of sea transportation for international freightage. This statement is supported by the International Chamber of Shipping (ICS) that the international maritime transportation industry is in charge of the freightage of over 90% of production commodities and trading activity all over the world (Dhoop et al., 2020). Wahab, Aminah and Baturante (2022) state that 80% of the commodity is used for the activity of export and import. ICS also stated that over 90% of the commodities loaded, there are 11 billion tones loaded by container ships each year. 1.5 tons of them are loaded to fulfill the life necessities of everyone around the world per year (Dhoop et al., 2020). This is supported by the Former UN Secretary-General who stated that maritime transportation can be considered as the backbone of market activity (Dhoop et al., 2020).

However, the role of global maritime also contributed to the loading of the shipment of dangerous goods. The dangerous goods in this case is any goods contain dangerous substances which potentially risk the health and environment during the cargo transport. Dangerous goods are a group of cargo that needs special supervision in every process which includes packing, shipping, and handling during transportation (Widodo et al., 2023). Besides, Indonesia also regulated the transportation of dangerous goods by mentioning that the ship owner, ship operator, and company agent must deliver notification to the harbormaster before the cargo ship of the dangerous goods arrives at the port (Wahab et al., 2022). Hence the role of container ships to load dangerous goods as inter-island or international transportation. If the ship's safety is not prioritized, it will harm

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the ship and the ship crew as in the case of MV X-Press, a Singapore-registered container ship on its way from Hazira India to Colombo, Sri Lanka, on May 15th, 2021. The ship has a LOA (Length Over All) of 186 meters and a GT weight of over 30.000 GT, loaded with 1486 containers, 80 of which contained dangerous goods. The disaster happened due to the fire because of 25 tons of nitric acid leak. The ship drowned after being under fire for 13 days because it was sprayed with water while extinguishing the fire. Besides that, a ship fire incident also happened to MV Hanjin Pennsylvania because the dangerous goods in the container got in direct contact with the sunlight during the on-check loading position. This is due to the container containing materials consisting of Calcium Hypochlorite (Widodo et al., 2023).

Ship stability holds an important role in sailing (Bačkalov et al., 2016; Pasyah et al., 2021; Perera and Soares, 2017; Wahab et al., 2022) A study by Wahab, Aminah and Baturante (2022) have the similarity in ship stability simulation with a different software usage. This study used the same software as the study by Wahab, Aminah and Baturante (2022) designed by Surabaya Shipping Polytechnic. Wahab, Aminah and Baturante (2022) found that the commodity in container 010284 cannot be near with commodity in container 010482. Commodity in containers 010484 and 030484 also cannot be near with commodity in container 010482. The commodity in containers 030282 and 030204 also cannot be near with commodity in container 010482. Consequently, if this regulation is broken, a "Danger" report will appear in the Dangerous Goods Report with information stating that the container is prohibited from being in one hatch.

Ship stability greatly impacts the balance, so the ship does not tilt left or right during sailing. The ship stability calculation is related to its cargo, ship type, draft, and measure of value. A few things to be paid attention to in calculating the ship stability include; light displacement or empty vessel weight, gross content or weight of the load, which is the displaced water weight when the ship sinks; and Operating Load or OL is the weight of the instruments used for sailing. This calculation takes a long time and special ability.

There are various types of ships, one of them is container ships. A container ship or cellular vessel is a ship specially made for loading standard-sized containers (Afandi and Sumanta, 2013; Setiawati et al., 2017; Soludale, 2013). Container placement is cellular with vertical frames. Sizes range from about 500 TEU to about 22,000 TEU. Container ships can carry 20ft and 40ft sized containers.

One of the various cargoes that can be carried by container is dangerous goods. Dangerous goods are goods that potentially harm the health, safety, property, and environment (Alfatiyah, 2017; Hartati, 2019; Rusman, 2019; Widyastuti, 2022). Goods in this category could be solid, liquid, or gas, either in the form of packaged dangerous goods or non-packaged dangerous goods. The handling and loading of these goods need special treatment.

2. Review Literature.

In Ship stability can be considered as one of the factors of shipping safety. If the ship's stability is not taken into consideration, it could endanger the cargo due to flammable goods which could lead to a fire disaster on the ship (Pasyah et al., 2021). Dangerous goods are characterized by explosive materials, gas, flammable liquid, peroxides, toxic materials, radioactive, corrosives, etc. Thus, ship stability is considered to be an important thing in loading cargo (Bačkalov et al., 2016). These are the characteristics of ship design according to Hughes (Kraus et al., 2012);

1. Hull shape:
    - Hull Linearity: The hull outline can affect the ship's performance, speed, and fuel efficiency.
    - Beam: Ship width at its widest point.
    - Draft: Vertical distance between the waterline to the keel of the boat.
2. Stability:
    - Lateral Stability: The vessel's ability to recover from lateral sway.
    - Longitudinal Stability: The vessel's ability to recover from surging forward and back.
3. Hydrodynamics performance:
    - Hull Resistance: Ship's resistance to water movement.
    - Propulsion Efficiency: propulsion efficiency to optimize the speed and fuel consumption.
    - Maneuverability: Ship ability to maneuver well.
4. Ship structure:
    - Construction Material: Types of material used to construct the hull and ship structure.
    - Structure Reliability: Guarantee that the ship can withstand the load and pressure of the marine environment.
5. Load capacity:
    - Cargo Capacity: The ship's capacity to load cargo.
    - Trim and Stability: Maintains the balance of the ship when filled with cargo.
6. Navigation and communication system:
    - Navigational Equipment: The navigation system such as radar, GPS, sonar, etc.
    - Communication System: Used to communicate with other ships, ground control stations, and shipping agencies.
7. Economics aspects:
    - Fuel Efficiency: Increasing the operational efficiency to reduce the fuel cost.

- Construction and Maintenance Cost: Economics factors in the construction and maintenance of the ship.

8. Safety:
    - Safety System: Including safety equipment, emergency exit layout, and maritime safety regulations.
9. Crew and Passengers comfort:
    - Interior Design: Including the comfort, safety, and facility for the ship crew and the passengers.
10. Legal compliance and International standard:
    - Regulatory Compliance: Ensure that the ship meets the requirements of international maritime laws and regulations.

2.1. Ship Stability and Calculations.

Stability is the ship's ability to be steady, which is the ship's tendency to recover to its original position after being hit by a tilt caused by forces from outside the sail, (Bačkalov et al., 2016; Pasyah et al., 2021; Wahab et al., 2022). It also can be defined as the ship's ability to straighten back up when the ship is pulled because the ship is affected by external factors such as wind, waves.

In general, things that affect the ship's stability can be categorized into two groups; internal factors (cargo layout, shape and size of the ship, leaks due to ship grounding or collision) and external factors (wind, waves, currents, and storms). Furthermore, previous findings stated that, on sinusoidal waves, the obtained value of the righting arm (GZ) with a wavelength of 16.215 m at a wave height of 1 m is 2,594 m, at a height of 2 m it is 2,509 m, at a height of 3 m it is 2,464 m, at a height of 4 m it is 2,436 m, and at a height of 5 m it is 2,417 m. These results indicated that the ship has good stability and can increase the success of fishing operations and provide safety guarantees to fishermen (Wahab et al., 2022).

Ship stability is determined by three important points. The stable position of the ship follows these three points, namely center of gravity, metacenter, and center of buoyancy. An intermodal container or ISO Container is a big box of various sizes made of various construction material and used for transporting cargo through land, sea, or air (Afandi and Sumanta, 2013; Setiawati et al., 2017; Soludale, 2013). According to its usage, containers can be categorized into general cargo containers, thermal containers, dry bulk containers, tank containers, open-top containers, open-side containers, and platform containers.

2.2. Dangerous Good Cargo.

Dangerous goods are defined as goods that potentially risk the health, safety, property, and environment (Alfatiyah, 2017; Rusman, 2019; Widyastuti, 2022). Dangerous goods also can be defined as any solid, liquid, or gas that could harm humans, other living organisms, property, or the environment. Dangerous goods could be in the form of radioactive, flammable materials, explosives, toxic materials, corrosives, biohazards, oxidizers, asphyxiants, pathogens, allergens, or materials that may have other characteristics that become dangerous under certain conditions.

SOLAS (Safety Life at Sea) Convention is related to various aspects of sailing safety as an obligation to supervise the handling of dangerous goods in container or bulk (Guevara and Dalaklis, 2021), which is later known as the International Maritime Dangerous Goods (IMDG Code). IMDG Code has to be carried out starting from January 1st of 2004 with several classes of dangerous goods or materials. The handling of dangerous goods that will be carried by the ship has to be understood by all the stakeholders and service users to actualize sailing safety which is one of the parameters for the realization of Indonesia to be the axis of global maritime (Rifai et al., 2022).

2.3. Design of Ship Stability Calculation.

The design constructed in Surabaya Shipping Polytechnic is in the form of software designed to show the calculation of container ship stability with a cargo of dangerous goods according to standards in Safety of Life at Sea (SOLAS) set by the International Maritime Organization (IMO). A good quality software has to comply with aspects of validity, practicality, and effectiveness (Wahab et al., 2022). Wahab, Aminah and Baturante (2022) stated a similar matter in a study carried out in 2022 regarding the design of ship stability calculations.

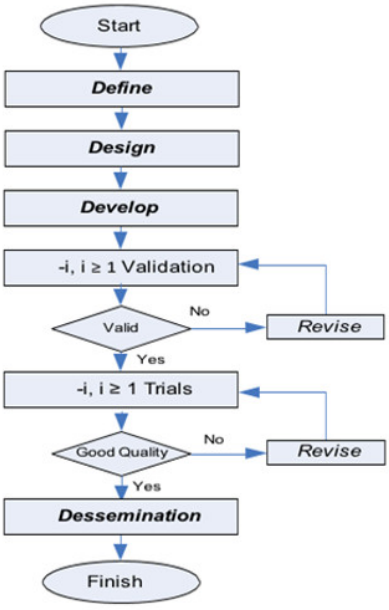
The research on the design of calculation of container ship stability containing dangerous goods is developed by a previous study conducted by Cahyadi, Mirianto, Harini and Krisnawati (Cahyadi et al., 2022) stated that the RnD type could result in the design of a simulator that could show the ship mileage, container data, ship data, container arrangements in the ship, stability calculation, and ship movement.

Furthermore, the finding is supported by Widyaningsih, Yuda, Mirianto, Zuhri and Harini (2022) who stated that the simulator used for calculating the ship stability has the advantage of saving the time of calculation so the results are easily and efficiently obtained. It is in line with Purba (2019) and Wiratno (2021). The similarities and differences with previous studies show that the obtained references are acquired heterogeneously so the results of the study can be combined with previous studies.

3. Methodology.

This study is a developmental research. The study aims to develop a product based on previous products with different concepts, the product later will be developed by reviewing literature and experts' studies. This study includes the lecturers and cadets to take part in active collaboration in developing products so that products can be produced in the form of designs for calculating the stability of container ships for dangerous goods with good quality.

Figure 1: Development process.



Source: Authors.

This study used the development process, which is known as the Four-D Model or modified 4D model. Thiagarajan, Krishnan, Ei, Shafie, Arapoc, and Bahari (2019) stated that there are four stages to develop a product.

3.1. Define Stage.

This first stage is the preparation for the study and development. The preliminary study is conducted to collect information on the needs related to product development in the form of calculation of the stability of container ships for dangerous goods.

3.2. Design Stage.

After reviewing the need analysis, the product draft of the software design for the calculation of the stability of container ships for dangerous goods is compiled. In this stage, the objectives, scope, and scale of the trial are determined,

3.3. Develop Stage

This stage aims to design and develop the product in the form of a calculation of the stability of a container ship for dangerous goods and its supporting devices to obtain a prototype.

3.4. Disseminate Stage.

The fourth stage is the dissemination and implementation of the end product. This stage failed to be conducted due to the limitation of the time. The dissemination to various shipping agencies is expected to be carried out in the future to test the product's effectiveness.

This study is conducted at Surabaya Shipping Polytechnic. The data on the process and the result of designing calculation of the stability of container ships for dangerous goods were obtained through the stages of defining, designing, and development.

The data analysis method used in this research is quantitative descriptive. The data is in the form of a number from the validation sheet and analyzed based on the determined scoring scale. The detailed scoring scale is as follows;

- Very Valid: 4 (good quality, easy to understand, following the context of explanation).
- Valid : 3 (good quality, easy to understand, the context of the explanation needs to be refined).
- Fairly Valid: 2 (good quality, hard to understand, the context of explanation needs to be refined).
- Not Valid : 1 (bad quality, hard to understand, the context of explanation needs to be refined).

The software for calculation of the stability of container ships for dangerous goods is considered valid if each aspect is at least in a valid category (3 scores).

4. Results and Discussion.

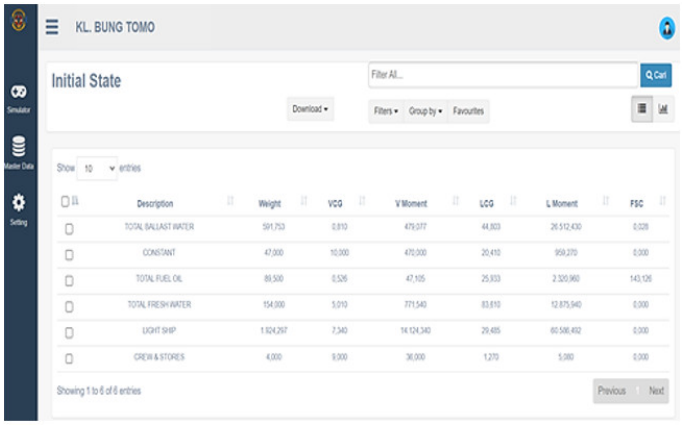
The development carried out in this study follows the Four-D Model modification, namely Define, Design, Develop, Disseminate. The developed simulator in this study is a simulator to calculate the stability of container ships for dangerous goods. The detailed descriptive results on each stage can be seen below:

4.1. Define Stage.

This stage aims to design and develop the product in the form of a calculation of the stability of a container ship for dangerous goods and its supporting devices to obtain a prototype.

1) Ship type identification: The ship type used in this study is a container ship. The particular container ship is owned by PT Meratus Line, which is used for inter-island cargo transportation in Indonesia. The ship data used in this study can be seen below:

Figure 2: Ship data.

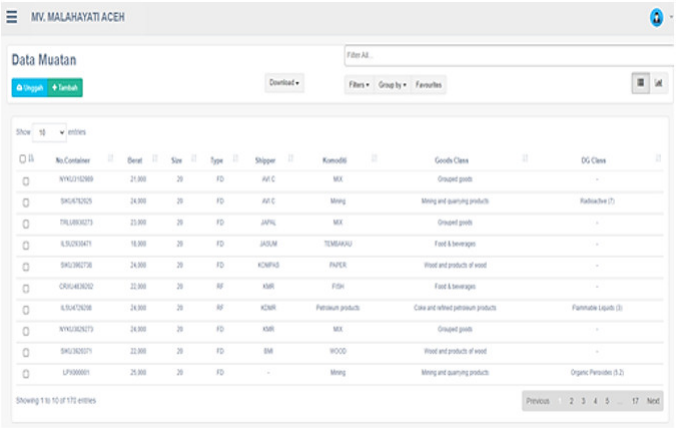


Source: Authors.

The table above displays the ship data input, the data input includes total ballast water, constant, total fuel oil, total freshwater, light ship, crew and stores.

2) Container Identification: The container used is a regular container, measuring 20 ft with a maximum weight of 24 tons, by the standards permitted by port managers in Indonesia. The data of the container used in this study can be seen below:

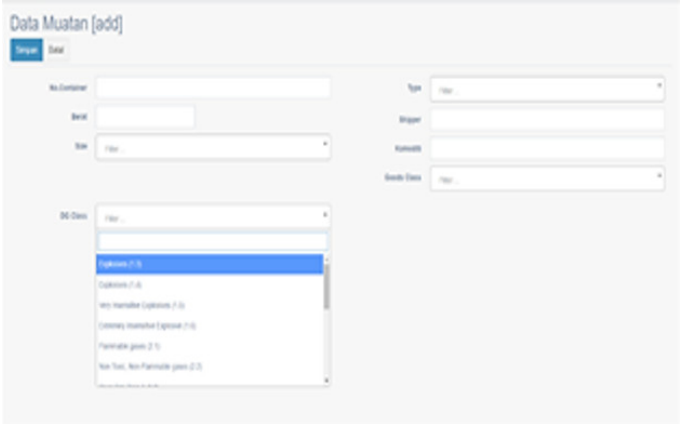
Figure 3: Container data.



Source: Authors.

Figure 3 is the display of container data input, the data input including container number, weight, size, type, shipper, and commodity. To input the load data, the user must determine the container number, weight, size, type, shipper, commodity, and the good class as in the following image:

Figure 4: Container load data input.



Source: Authors.

3) Identification and Classification of Dangerous Goods in Packages: The container used is a regular container, measuring 20 ft with a maximum weight of 24 tons, by the standards permitted by port managers in Indonesia. The data of the container used in this study can be seen below:

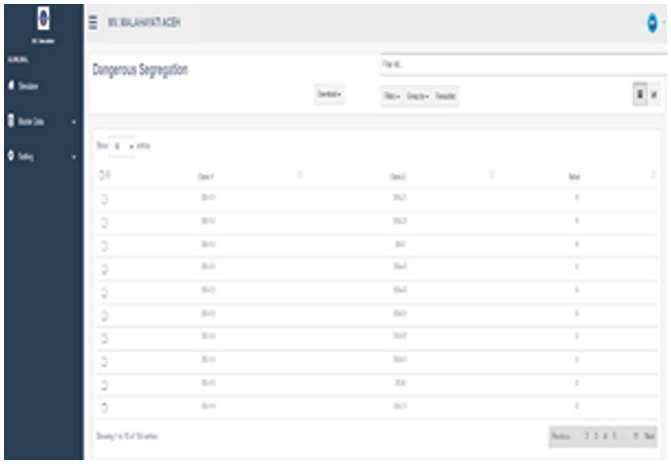
According to The Regulation of the Ministry of Transportation Number PM 16 of 2021 regarding Procedures for Handling and Transporting Dangerous Goods at Ports, dangerous goods in the form of liquid, solid, and gas are classified as follows:

1. Class 1 consists of explosive materials or goods
2. Class 2 consists of a gas that is compressed, liquefied, or dissolved under pressure
3. Class 3 consists of flammable liquid
4. Class 4 consists of flammable items or flammable solid materials
5. Class 5 consists of oxidizing materials or goods
6. Class 6 consists of toxic and contagious materials
7. Class 7 consists of radioactive materials or goods
8. Class 8 consists of corrosive materials or goods, and
9. Class 9 consists of various other dangerous materials or substances.

The following is the classification of dangerous goods in packages in the simulator:

Figure 5. Classification of dangerous goods in packages

Figure 5: Development process.



Source: Authors.

4) Identification of Stability Calculation: The container used is a regular container, measuring 20 ft with a maximum weight of 24 tons, by the standards permitted by port managers in Indonesia. The data of the container used in this study can be seen below:

Figure 6: Ship stability calculation.

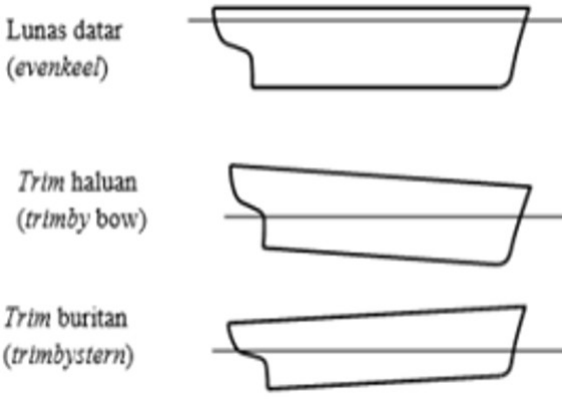
Source: Authors.

Generally, there are three conditions that happen to a ship, namely:

- Even keel, where the ship's front draft (water level) is the same as the ship's back draft
- Trim by bow, where the back draft is lower compared to the front draft
- Trim by stern, where the back draft is higher compared to the front draft

Below is the illustration of the ship conditions:

Figure 7: Ship trim illustration.



Source: Authors.

4.2. Design Stage.

1) Simulator Purpose: The purpose of the design stage is to construct a simulator, which in this case is software that can display and calculate the stability of a container ship for dangerous goods.

2) Scope: The developed simulator is focused on planning the load of dangerous goods and calculating the container ship's stability. The load used is a 20ft container

3) Trials Schedule: At this stage, the trials are scheduled. The schedule of trials can be seen in the table below:

Table 1: Trials schedule.

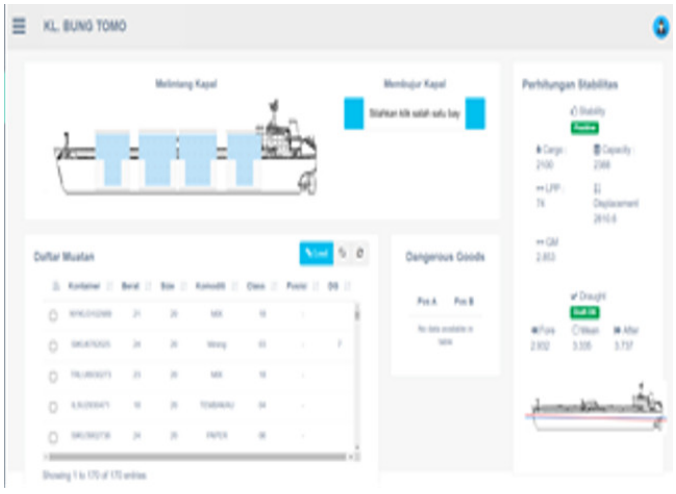
No	Name	Time
1	1st Trial	August 23, 2023
2	2nd Trial	September 6, 2023
3	3rd Trial	September 21, 2023

Source: Authors.

4.3. Define Stage

This stage involves making a simulator based on a previously designed simulator prototype. The following are the stages in developing the simulator prototype; 1) web selection as the facility in developing the simulator, web is used for its flexibility, user-friendly usage, and accessibility in various types of browsers, 2) creating a display for ship data input menu, 3) creating a display for container data input menu, 4) creating the main display by plant, and 5) designing the color, fonts, and font size. The result obtained in this stage is software that can be used to plan the load and calculate the stability of a container ship for dangerous goods. Below is the display of the simulator:

Figure 8: By plant.



Source: Authors.

1) First Trial: The first trial is carried out on August 23rd, 2023 by conducting load arrangements and stability calculations in bay 1.

Figure 9: Trial of load arrangements and stability calculation in Bay 1.

Source: Authors.

Based on the figure above on the first trial of load arrangements in bay 1, commodity in container 010282 cannot be near with commodity in container 010182, commodity in container 010282 cannot be near with commodity in container 010104, commodity in container 010182 cannot be near with commodity in container 010282, commodity in container 010104 cannot be near with commodity in container 010282. Consequently, if the rule is broken, a "Danger" notice will appear in the Dangerous Goods Report with information stating that the container cannot be put in one hatch. According to the ship stability calculation, the displacement value is 3060.6, the GM value is 2,372, the after value is 3,585, the fore value is 3,171 and the mean value is 3,378. Since the after value is less than the fore value, the ship is in the trim by bow position.

The first trial is in line with the Wahab findings (Wahab et al., 2022) which found a similar result. However, this result is different from the Wiratno findings due to the differences in GM value and several container position commodities (Wiratno et al., 2021).

2) Second Trial: The second trial is conducted on September 6th, 2023 by arranging the load and calculating the stability in Bay 7.

Figure 10: Trial of load arrangements and stability calculation in Bay 7.

Source: Authors.

According to the second trial result regarding the load arrangement in Bay 7 illustrated in Figure 4.5, it can be seen that commodity in container 070284 cannot be near with commodity in container 070484, commodity in container 070284 cannot be near with commodity in container 070282, commodity in container 070284 cannot be near with commodity in container 070184, commodity in container 070484 cannot be near with commodity in container 070284, commodity in container 070282 cannot be near with commodity in container 070284. If the rule is broken, a "Danger" notice will appear in the Dangerous Goods Report with information stating that the container cannot be put in one hatch. According to the ship stability calculation, the displacement value is 3076,6, the GM value is 2,334, the after value is 5,092, the fore value is 3,142, and the mean value is 4,117. Since the after value is more than the fore value, the ship is in the trim by stern position. The results from the second trial have a significant difference with previous research, however, it concluded the same conclusion that ship stability is crucial (Wahab et al., 2022).

3) Third Trial: The third trial is conducted on September 21st, 2023 by arranging the load and calculating the stability in Bay 1, Bay 3, Bay 5, and Bay 7.

Figure 11: Trial of load arrangement and stability calculation in Bay 1, Bay 3, Bay 5, and Bay 7.

Source: Authors.

Based on the third trial on the load arrangement and stability calculation in Bay 1, Bay 3, Bay 5, and Bay 7 illustrated in the figure above, it can be seen that all the bays are loaded. In Bay 1, the commodity in container 010204 cannot be near with commodity in container 010482, the commodity in container 010482 cannot be near with commodity in container 010204, the commodity in container 010482 cannot be near with commodity in container 010284, the commodity in container 010482 cannot be near with commodity in container 010484, the commodity in container 010284 cannot be near with commodity in container 010482, the commodity in container 010484 cannot be near with commodity in container 010482, the commodity in container 030484 cannot be near with commodity in container 010482, the commodity in

container 030282 cannot be near with commodity in container 010482, the commodity in container 030204 cannot be near with commodity in container 010482. If the rule is broken, a "Danger" notice will appear in the Dangerous Goods Report with information stating that the containers cannot be put in one hatch. Based on the ship stability calculation, the displacement value is 4185,6, the GM value is 1,131, the after value is 6,427, the fore value is 4,122, and the mean value is 4,117. Since the after value is more than the fore value, the ship is in the trim by stern position. The results above indicated the importance of ship stability in each type of ship. This is in line with Wahab (2022) who stated that ship stability is affecting the ship's condition. The results in the third trial share the same value as the previous study (Wiratno et al., 2021).

Conclusions.

Based on the explanation and analysis of the simulator design using the modified Four D development model, it can be concluded that, generally, the simulator design consists of four stages namely Define, Design, Develop, and Disseminate. Furthermore, the developed simulator design could display the ship data, container data, container arrangement in the ship, Dangerous Goods Report, ship stability calculation, and displacement. The limitation of this study is the data is obtained through one ship and the container size is limited to 20ft, which means the data have the same characteristic (homogenous). Hence, future studies could use different data obtained from various types of ships and various sizes of containers for a more comprehensive level of reliability of the simulator, so the data analysis process of each ship could be more accurate. This research is expected to recommend to related parties the importance of designing the calculation of stability of container ships for dangerous goods. So, Surabaya Shipping Polytechnic could be the first college among the Human Resources Development Agency for Transportation to develop the concept to be used in the application system.

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