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Developed Methodology for Ship Retrofitting (Case Study: RV Baruna Jaya)

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Abstract

Ship retrofitting is one alternative solution to extend a ship's life. As one of the ships that require regular renewal, especially in research equipment, retrofit processes are often carried out on research vessels. The current problem in the retrofit process for research vessels, especially in Indonesia, is that retrofits are not carried out with established methodology and planning. Thus, some retrofit projects are limited to major repairs and do not extend the ship's life or performance. To solve this problem, this study proposed a developed methodology for ship retrofitting, which consists of selecting the ship and the type of retrofit and its components, determining retrofit requirements, and designing the ship based on the retrofit project. The main purpose of this study is to develop a methodology for a ship retrofit process that can follow the ship's needs and problems so that the retrofit outcome can improve the performance and life of the ship. Developing the newly designed methodology starts with designing the method, modifying the design spiral, and analyzing the effectiveness by implementing it into a real case study. The results show that the methodology can be systematically applied in designing and mapping the retrofitting project. Moreover, the method can solve the problem of selecting the ship and the component to retrofit based on criteria. Stakeholders can use the developed methodology to guide the ship's retrofitting process.

1. Introduction

The average end of life for a ship is generally between 25- 30 years [1], [2] for merchant ships and inland ships, it is 40 years [3]which also depends on the ship's quality of maintenance and the number of sailing days. When the ship approaches its end life cycle, the owner sometimes has two choices: recycling or extending its life by several methods. However, even with the regulation of ship recycling and emission, the owners of the ships tend to refrain from purchasing or building new vessels. At the same time, their existing fleet can still be utilized, and this is where various SLE (Ship Life Extension) methods come into sight. There are several ways to increase the ship's life: maintenance and repair, retrofit, or ship conversion. Several authors have conducted the method of SLE by preventive maintenance, the improvement, and implementation of preventive maintenance to extend ship life [4], [5], and a study of preventive maintenance before the component reaches its end-of-life [6], [7].

The choices of SLE are dependent on the owner's judgment and preferences. The maintenance and repair are suitable for extending a ship's life for the company or owner with limitations in financial funds. The alternative way to SLE is by retrofitting a vessel by adding or replacing a component in an existing system [8]. The primary purpose of the retrofit is to extend ship life, increase system efficiency, improve the economic value of the vessel, and comply with the latest regulation regarding emissions. Several ship retrofitting projects than has been undertaken; Krikke [2] published the report "Retrofit Project," which covers the retrofit process from choosing a ship to retrofit, methods for simulation of ship main and auxiliary, design for Retrofit (Green technologies solution), and project management. Kotakis [9] compared several retrofit technologies, such as fuel switching, Scrubbers, Dual Fuel, CAPEX, OPEX, and payback analysis, to comply with IMO regulations.

Meanwhile, retrofit technologies based on economic, energy, and environmental impacts on a European scale for Ro-ro and Ro-Pax using an aggregate simulation model performed by Aronietis [10]. LCA analysis was also performed to analyze alternative retrofit technologies installed on the Ro-Ro ship, such as photovoltaic, lithium, and cold ironing [11]. Retrofit for a specified component of the ship also has been undertaken. For the propulsion system, the concept design of replacement from fuel oil to LNG has been performed by Tam et al. [12]. Meanwhile, for the propulsion system itself, the installation of ducted propellers and energy-saving devices in trawlers has been conducted by Laurens et al. [13]. Hekkenberg [3] modified to improve propulsion performance and modified the ship hull model for hydrodynamics by trape. The ship retrofit that mainly focuses on the structural department has also been performed for Tanker ships by replacing side hull plating, reinforcing two stiffeners, flange, and transverse stiffener with the primary purpose of being subjected to corrosion [14]. Also, retrofitting by lengthening ships was part of the "Move-it" project by investigating cost-effective options for lengthening small vessels. Structural scantling was verified, manouvering simulated, and power was calculated. The results show that lengthening has a positive effect from an environmental point of view[15].

The retrofit project is also imminent for research vessels (RV) since the vessel owner must regularly update the survey equipment with newly sophisticated technology to improve the research's data quality. Moreover, the retrofit project is common on the RVs since the vessel needs a ship life extension when approaching middle age or near the end of the lifespan (averaging from 40-50 years). Thus, because most RVs are owned by the government or institutions, with the beneficial aspect less considered, they want to utilize their research vessel for as long as possible rather than building a new one. Several retrofitting projects of RV mainly focus on improving the propulsion and research equipment, for instance, installing a dynamic positioning system (DP), a Remotely Operated Vehicle (ROV), and establishing a fairing/gondola for hull-mounted survey equipment. The research vessel's Retrofit projects documented were RV Roger Rovelle in 2019, RV Vizconde de Eza in 2019, and RV Urania in 2016. The first project was replacing all generators and propulsion motors, changing a new bow thruster, and adding an azimuth thruster[16]. For RV Vizconde de Eza in 2019, the retrofit was performed on frequency and propulsion control[17]. RV Urania 2016 was retrofitted by lengthening the hull, installing a DP system, a new bow and stern thruster, and three more powerful generators.

Retrofit project of research vessels is also inevitable for Indonesian research vessels, with the condition that most government-owned research vessels in Indonesia are reaching 25 years old and nearly reaching their end-of-life period. In addition, most vessels are not equipped with the latest and state-of-the-art technology of propulsion system, thruster, electrical, and survey equipment such as DP system, ROV system, or capability for cable laying projects. The RV must be retrofitted to increase Indonesia's potential for marine research. he RV in Indonesia needs to be up to a legitimate retrofit standard. Most of the fleet only had a significant repair and corrective maintenance, not significantly increasing the ship's life. Some cases of "retrofitting" carried out by ship managers in Indonesia are the modification of Baruna Jaya 2 into a Seismic Research Vessel from a Hydrographic vessel in 2008. This retrofit was carried out massively by changing the ship's function into a completely new one. A generator in the hold is added, and the creation of a similar structure at the stern of the ship for seismic boomers. Baruna Jaya 1 (BJ 1) and BJ 3 also have retrofitted survey equipment that changed the underwater hull carried out in 2017 for BJ 1 and 2020 for BJ 3. n the retrofit, overhauls were also carried out on the engines and gearboxes of the two ships, but the results needed to be more satisfactory and increased the ship's performance by around 20 - 30%. Modernization is only done on survey equipment because the ship is still sufficient to operate in Indonesian waters. Even though the ship's age has reached 30 years, it is necessary to retrofit its propulsion system. The problems of the retrofit are caused by a need for a clearer methodology for selecting and implementing the retrofit plan of the R/V. Often, after the vessel has been repaired, the repaired component is damaged again shortly after the repair. The consequence of this inaccurate retrofit method and execution is financially detrimental to the ship′s owner.

This paper aims to provide the developed method intended to provide a systematic approach and a solution to generate an effective and efficient retrofitting process by designing and optimizing the developed methodology with its implementation into the concept design retrofit project for RV Baruna Jaya I. This paper will also analyze the methodology with the previous retrofit project on how the developed method can improve and correct some errors in the concept design ship retrofit.

2. Methods

2.1. General Methodology

In this research, the methodology used is attached in the flowchart in Figure xx. The first step is to design a method for ship retrofitting based on the existing process and alter some steps to improve the methodology. Secondly, the modified design spiral for retrofitting process will be generated. Thirdly, the implementation process of the method on the case study, in this case, RV Baruna Jaya Fleet. In this stage, the process starts with ship selection, what components to be retrofitted, the concept design of the retrofit, risk analysis, and project execution plan for the ship selected to be retrofitted. The last step of the method is to analyze the feasibility, effectiveness, and weakness of the technique after the case study implementation.

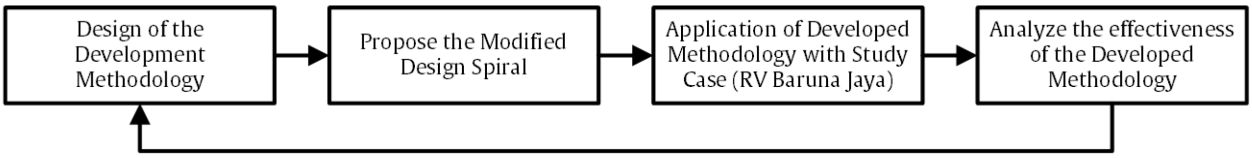


Figure 1. Research's Methodology

2.2. Proposed Methodology for Ship Retrofitting

Methods used in this ship's retrofit concept design are modified from previous retrofit methods that have been entirely executed. The first step is deciding which ship will be retrofitted within the fleet, which is vital for shipowners or shipping companies with enormous fleet numbers. This step focuses on listing the current condition of vessels and will be assessed using three criteria (economic, energy, and emission) [10]. This step's main output is the vessel's urgency rank within the fleet.

After the selected ship has been decided, the next step is to prioritize which components or parts will be retrofitted, closely related to the previous step. The elements or system that will be retrofitted should improve the ship's capabilities to achieve specific improvements economically, less emission, and efficient operation. This step's output ranks the retrofit system and component based on three criteria mentioned earlier and urgency level.

After determining the ship components to be retrofitted, the next step is to decide the ship's targets or requirements after completing the retrofit process. In this case, the retrofit requirement is an increase or change to a ship's primary dimension, including payload capacity, speed, endurance, range, and new equipment or system installed as part of the retrofit process.

Next, after the retrofit requirement has been stated, this part will focus on the technical aspect of how to apply and implement the retrofit process. In carrying out the design for the implementation of the retrofit process, the methodology used is the design spiral process, in which there are several iterations of the process. Each iteration process is called a phase that consists of a concept, preliminary, and detailed design. In this design spiral for a retrofit project, the design process will differ slightly from the conventional spiral design for newly built ships. There are some differences since the design spiral for retrofit is more focused on the design and implementation of the new retrofit system. However, there may be interference between the two phases, which is inevitable because the retrofit is being carried out on an operated ship, so the level of conformity between design and requirements is relatively high.

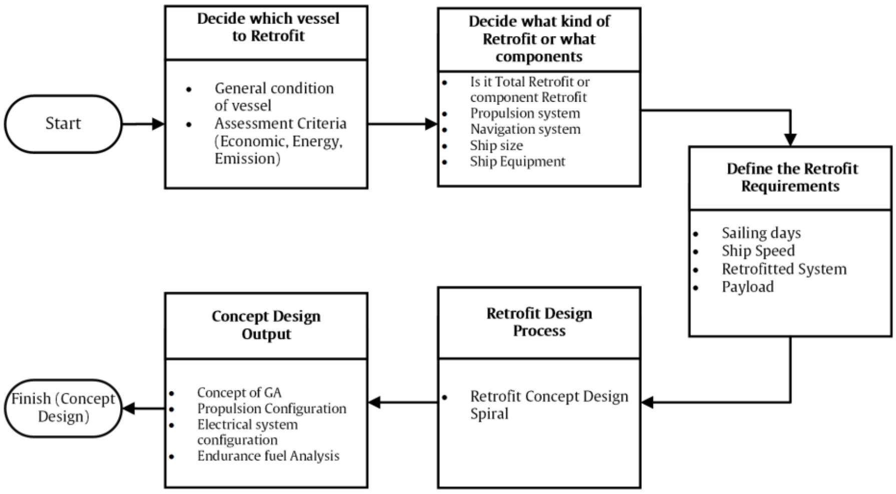


Figure 2. Developed Method for Ship Retrofitting

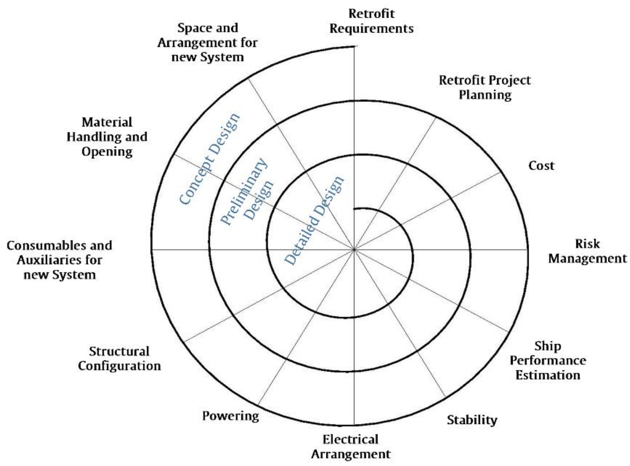


Figure 3. Modified design spiral for ship retrofitting

Figure 3 shows the modified design spiral for ship retrofit. The first three processes are essential for ship retrofit design. The priority analysis of the study is about the space within the ship. The new proposed retrofit system should look at the system's and the ship's dimensions. Another concern is handling material, how to transport the latest equipment, and where the new equipment should be placed. Another implication is the consumables regarding the new equipment, i.e., fuel, lube oil, water, and spare parts. For example, if the retrofit plan includes the installation of the new generator, the fuel consumption per hour/daily should be calculated to determine whether it can comply with previous vessel capabilities (sailing days and range). Also, risk management consists of risk identification and analysis, which is one of the crucial steps in the design spiral, since it can map the risk and its probability that can occur during the retrofit process. The method for risk analysis varies according to the availability of data and experts. After that, the next step in the design process is considerably similar to the conventional design spiral. Every operation on the retrofit design spiral must comply with class society's regulations and IMO's rules.

As the last stage of the ship retrofit process, the outputs of the concept design of retrofitted vessels are general arrangement, propulsion configuration, electrical distribution arrangement, and strategic plan, which contains steps to execute the retrofit plan. The definition of concept design in ship design is according to some experts; in general, concept design is the first stage where it is required to plan the design according to the design requirements and criteria[18],[19]. At this stage, the development of CONOPS (Concept of Operations) is carried out, which is the operational conditions of the ship, environment, payload, speed, distance, and travel time. Also, at the concept design stage, a feasibility study was carried out for several improvements in the design that had yet to be done. The concept design is very closely aligned with the preliminary design, so it is possible for interference between the two stages.

2.3 Ship Selection

It is essential to set the parameter or level of urgency as a consideration for the shipowner to undergo a retrofit to their fleet. This following parameter will be more suitable in extensive fleets and having more than one type of ship. The first parameter that should be considered is the machinery and propulsion system. Since the main engine is the most important component in the ship, the shipowner should look to the ship with the most terrible condition of their machinery. Secondly, the economic projection of the vessel, whether the ship will be valuable after the retrofit or with the installation of new technology, can save operational costs. Thirdly, the hull's underwater condition, thickness, and corrosion should be assessed to determine whether it can be repaired only by annual docking or needs significant plate replacement. Lastly is the technology level of the ship; the shipowner should prioritize the ship with the older most technology to be retrofitted.

Table 1. Current Condition of RV Baruna Jaya Fleet

Ship System	**BRIN's Research Vessel**			
	Baruna Jaya I	**Baruna Jaya II**	**Baruna Jaya III**	**Baruna Jaya IV**
Hull Construction	• Overall is in good condition. Several plate areas need to be re-plated	• Overall is in decent condition. Several areas on the main deck need to be re-plated	• Buckling on the navigation deck • Several areas on the top deck need to be re-plated	• Corrosion in forecastle deck, navigation deck • Several areas on top, navigation, and the main deck needs to be re-plated
Main Engine	• Only reaches 47 % power from its maximum capability • High exhaust temperature hindering engine performance	Not prepared for sailing, the new gearbox has not been tested	• Only reaches 60% power from its maximum capability • High exhaust temperature hindering engine performance	Not prepared for sailing, leakage of simplex seal system for CPP
Propulsion	• Major lubricant leakage in the gearbox system • Minor leakage of hydraulic in CPP	• Leakage in the cooling system for the gearbox • Leakage in the thrust bearing pump	• Lubricant leakage in the steering gear • Lubricant leakage in the gearbox system	• Corrosion on the steering gear body • Pipe leakage on the steering gear
Navigation	• Automatic steering system is not functioning • Minor problem with the GPS system	• Leakage in magnet compass of gyro • Deviation between rudder and actual	• Deviation between the rudder and panoramic view	• Deviation between the rudder and panoramic view
Auxiliary Systems	• Emergency generator functioning properly • Corrosion in seawater and freshwater cooling system • Fuel purifier is not working	• Emergency generator only reaches 38% of its maximum power • Leakage in majority of piping system • Deviation between CPP indicator in	• Corrosion of seawater cooling system • Sewage treatment plant is not functioning • Oil water separator is not working	• Emergency generator's efficiency only reaches 68% of its efficiency • Fuel purifier is not working • Reverse osmosis system is not working

Ship System	BRIN's Research Vessel			
	Baruna Jaya I	Baruna Jaya II	Baruna Jaya III	Baruna Jaya IV
	• Leakage in central air conditioning system • Sewage treatment plant is not functioning	steering gear and wheelhouse		properly, due to membrane problem

Table 1 shows the present condition of BRIN's RVs to determine the vessel's retrofit urgency from the internal inspection undertaken in 2022. Regarding the engine and Propulsion department, RV Baruna Jaya I is currently having a severe hindrance, the main engine is below 50 % of effectiveness, and its gearbox system has significant leakage that will consume 30 litres of lubricants per hour[20]. While, for the deck department, Baruna Jaya IV is in the most terrible condition since it has several corrosions on each deck level. On the other hand, most of the auxiliary systems of RV Baruna Jaya II are unavailable since the components have been moved to support the operation of other ships. For the navigation department, every ship is concerned with differences in angle deviation between the actual rudder and panoramic in the wheelhouse. Moreover, every ship needs to be installed with leading-edge navigational equipment.

In economics, it must be analyzed which vessel will produce more benefit, either financially or in terms of research data, after the retrofit. According to the Foresight of Indonesian Oceanography Research 2020-2035 [21], oceanography research will focus on exploring new sources of energy, food, and new biodiversity of the ocean. In the non-research sector, in the future, work that is urgently needed for a research vessel is cable and pipe laying and maintenance work, survey for extended continental shelf, and ROV activities. According to the foresight, to satisfy the demand and gain the most profit possible, the RV that will be prioritized is the vessel with the superior capabilities of mapping the ocean, with the maximum depth of the multi-beam, RV Baruna Jaya I. Moreover, RV Baruna Jaya I can also be utilized as a multipurpose research vessel with spacious deck space. Regarding energy and emission, since every ship uses the same main engine and propulsion system, the level of retrofit urgency is considered similar. Since RV Baruna Jaya I has the advantage in survey equipment, and its main engine and propulsion system needs major retrofitting, RV Baruna Jaya I is selected.

2.4. Systems and Components to be retrofitted

The primary system that must be retrofitted on the RV Baruna Jaya I is the main engine and propulsion system. Since the main engine and most propulsion systems are in severe condition, the option to execute the retrofit process to solve the existing problem is changing the central propulsion system from conventional diesel mechanic propulsion to greener propulsion, such as a diesel-electric propulsion system.

Diesel-electric propulsion is a method that uses an electric generator or alternator powered by an engine to provide power to an electric engine that propels the propeller[22]. The primary function of the Diesel-electric system is to regulate the rotation of the electric engines to manage the ship's speed. Previously, the main propeller of RV Baruna Jaya I was driven by a diesel-powered main engine whose RPM was reduced by a gearbox. The diesel-electric system uses a diesel generator as the main power, and it is connected to a propulsion motor by cable and through a switchboard and converter. Therefore, the diesel generator and the electromotor can be on a different deck or position.

Moreover, the DE system can reduce emissions by approximately 10 % to 20% [22], [23]. Expectantly, after the diesel-electric propulsion is installed, it will reduce GreenHouse Gas (GHG) emissions to ensure the environmental sustainability of shipping. Another advantage of the DE system is that it is more suitable for dynamic electric load, especially in manoeuvring stop crash performance. The advantage in dynamic load happens because the electric engine (propulsion motor) has more control over propeller rotation, and a quick direction shift results in a shorter stopping distance and stopping time.

Regarding navigation and manoeuvrability of RV Baruna Jaya I, the manoeuvrability capabilities on the stern area are limited since the ship is only equipped with one single screw CPP propeller without the stern thruster. The solution is to install a Dynamic Positioning (DP) system to improve its manoeuvring capability. The intention to establish the DP system aligns with the ship's plan to change the propulsion system to diesel-electric. Since the existing propulsion system will be changed, including the propeller, there is a possibility to install new thrusters or change the system into a twin screw propeller.

2.5. Requirements for Retrofit Project

The requirements for the retrofit project have similar roles to the design requirements of a new-built vessel, which guides the entire project through the design spiral phase. Based on the explanation in section 3.1.2, the retrofit requirements are:

Changing the propulsion system from a conventional mechanic diesel system to a diesel-electric system

- Installing the DP system that consists of a power, control, and thrusters system

- The service speed of the vessel should be eight (8) knots
- Sailing days must be a minimum of thirty (30) days

3. Dynamic Positioning on Research Vessel

3.1. General Review of Dynamic Positioning System for Research Vessel

The dynamic Positioning system is critical for RV due to its capability to maintain ships in certain positions (stationk`eeping) to improve the accuracy of data acquisition[24]. Moreover, the DP system is desirable for effective and efficient operations. Several activities, such as ROV deployment, sediment sampling, CTD, and AUV deployment, benefitted from the DP system's highly accurate ship positioning. Therefore, the DP system is required to be installed in the RV.

3.2. Preliminary Calculation of Dynamic Positioning System

The preliminary calculation for the DP system required using the step-by-step design of Dynamic Positioning for the Glomar CR Luigs Drillship [25]. Since the thruster system of Baruna Jaya 1 is already established and installed, the DP capability plot will be based on the stationkeeping ability of the existing and the suggestion of thruster power and arrangement. The inputs for the calculation are:

1) The environmental input for the studies is Sea State Three, with a wind speed of 20 knots and a current speed of 1.5 knots for all angles.
2) Thruster configuration based on existing one propeller with 1639 kW power and bow thruster of 150 kW.
3) Primary vessel data as input is based on ship particular.

There are three cases to analyze different thruster power and configuration which are;(Case 1) Based on existing vessel configuration – one propeller and one 150kW bow tunnel thruster; (Case 2) Increased bow tunnel thruster rating from 150kW to 450kW to accommodate force from bow side; (Case 3) Additional stern tunnel thruster 450kW and increased bow tunnel thruster 450kW.

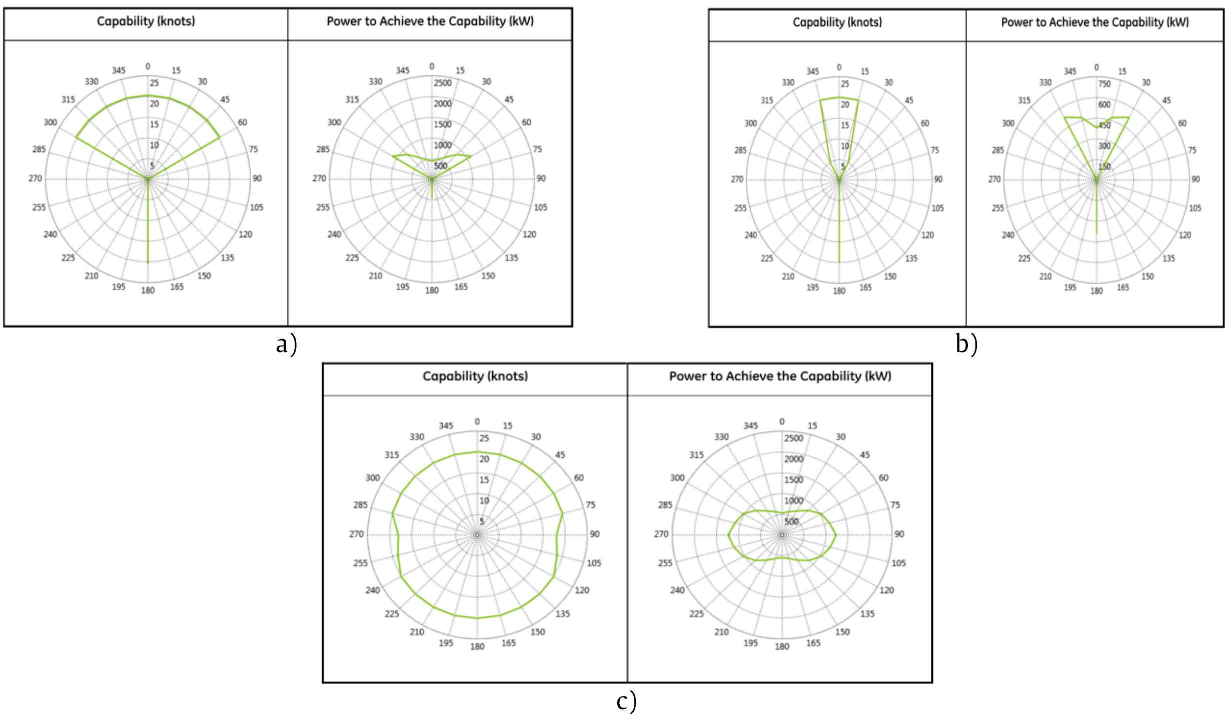


Figure 4. DP Capability plot for three cases; a) Case 1, b) Case 2, and c) Case 3.

The results for these three analyses are as follows: for case 1, minimal DP capability is mainly due to only one propeller at the stern. Single screw propeller and rudder are inadequate for the Dynamic Positioning system, where the propeller and rudder are nowhere near as efficient as tunnel thrusters for accommodating the load from side forces. Meanwhile, case 2's results are indistinguishable from the previous case. The bow tunnel thruster's increased power is incapable of the thruster limitation at the stern side. For the last case, Dynamic Positioning capability is significantly enhanced and can achieve sea state three at most angles. Therefore, case 3 was used onwards for thruster power and configuration for the DP system.

3.3. DP Notation for RV Baruna Jaya 1

According to BKI and ABS, there are four DP notations, DP0, DP1, DP2, and DP3. Each note has different requirements regarding its redundancy [26], [27]. DP0 and DP1 require vessels to be controlled automatically without any system redundancy. In contrast, DP2 needs ships to be automatically moved with additional equipment for each DP system (thrusters, generator, control system, and sensors. In comparison, the DP3 system requires vessels to be automatically controlled, equipped with additional equipment, and located in separate compartments. For RV, if the vessels operated in open water and do not have interference or work closely related to offshore installations, rigs, and aquaculture cages, DP 1 is considered sufficient[24]. Moreover, by comparing the RV Baruna Jaya 1's ship particularly with another RV with a similar length, most vessels have the DP 1 system installed. Therefore, DP 1 system will be incorporated into the existing system of RV Baruna Jaya 1.

3.4. Implementation of Dynamic Positioning system into RV Baruna Jaya 1

3.4.1. Power Demand of Propulsion system for Diesel Generator

Based on the DP capability plot calculation, if RV Baruna Jaya 1 is in satisfactory condition to be installed with a DP system. It must be added with a 450 kW stern thruster and Bow thruster power to 450 kW. With retrofit requirements, where the propulsion system becomes a diesel-electric system, all existing propulsion systems (2 x Main Engine, Gearboxes, Alternators, Shafts, and CPP Propellers) will be replaced with 2 x Azimuth Propellers, 2 x Diesel Generators, and Improved power of bow thrusters. The azimuth propellers are used because of the advantage of manoeuvrability, and they can move in 360 degrees and help the ship maintain its position[22]. The Azimuth Propeller Schottel SRP 240D x 2 will be selected to accommodate thrusters and a propulsion load of around 1650 kW. Meanwhile, 1x STT 1 Schottel with an input power of 500 kW is preferred for the bow thruster. The hotel load is assumed to be identical to the conventional propulsion system at 500 kW.

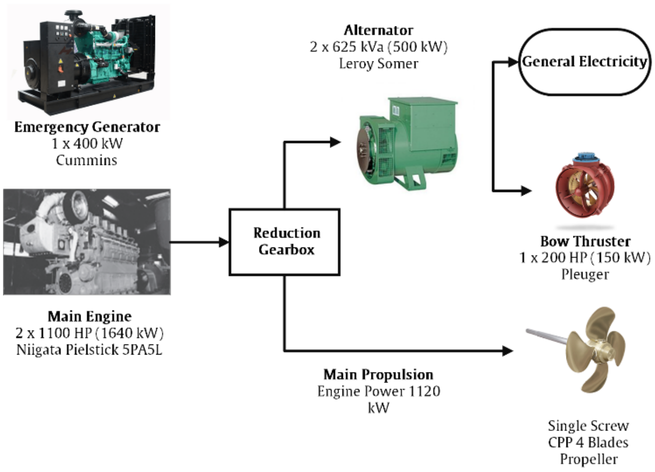


Figure 5. The existing condition of the power and propulsion arrangement of RV Baruna Jaya I

Table 2. Power Demand based on DP Capability Plot Calculation

Power Demand for DP1		Power Estimated from Thruster	
Propulsion (P_B) (kW)	1140	Propulsion (Azimuth Schottel SRP 240D x2 (kW)	1700
Bow Thruster (kW)	450	Bow Thruster Schottel STT 1 (kW)	500
Stern Thruster (kW)	450	Hotel Load (kW)	500
Hotel Load (kW)	500		

A diesel generator with a total input power of around 2700 kW is needed to support these requirements. For this case, CAT 3512C is selected. With each power stand at half of the total input power, if one engine experiences a malfunction or breakdown, the other can still power the ship's propulsion. At the same time, the electrical hotel load will be covered by the emergency generator Cummins 500 kVA.

3.4.2. Material Handling, Opening, and Space of Arrangement of new System

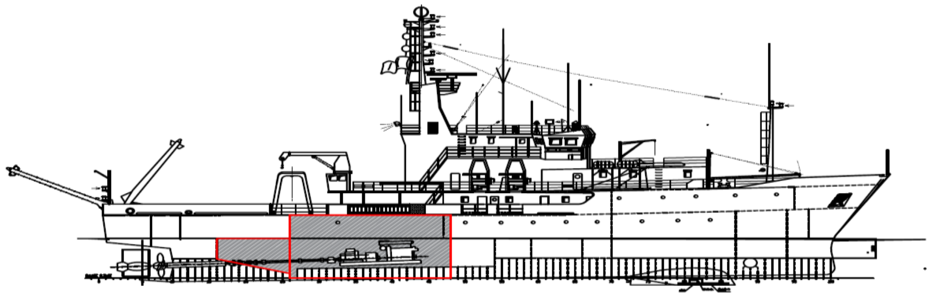


Figure 6. The availability of space arrangement on RV. Baruna Jaya I (hatched space means the volume of engine room space)

Based on the drawing plan, RV Baruna Jaya 1's engine room has an area of 150.28 m^2, with details of a length of 13.28 meters and a width of 11.60 meters. The average engine room height is 3.1 m, so according to calculations, it has a room volume of 477.55 m^3. An analysis of space requirements and availability on the ship is performed to accommodate the needs of the existing space arrangement. The challenge in retrofitting is the limited engine opening, which is only 1.7 m x 4.1 m. In addition, an emergency generator has been installed above the engine opening. In practice, the engine replacement can only be moved by dismantling the semi-permanent engine housing structure, which also houses the emergency generator.

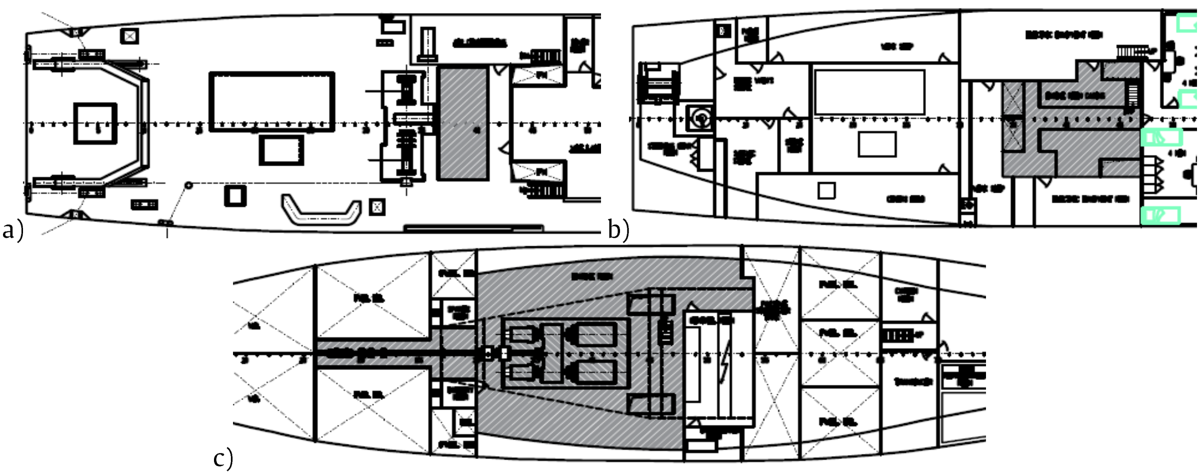


Figure 7. Engine room opening for maintenance is depicted in a). The engine room opening in the lower deck is depicted in b), and the engine room space is depicted in c).

Installation through the engine room hull is the only practical option available at this stage. With consideration, if passing through the portside, the pneumatic pipe system, oily water separator, sewage system, freshwater and seawater pumps, air conditioning system, and HVAC ducting supply system need to be taken apart to replace the engine. On the other hand, if done through the starboard side, the survey equipment electrical system, electric motors, survey aid panels, and reverse osmosis module must first be eliminated. Both of these options need to be further analyzed economically and technically to determine the effectiveness and efficiency of the retrofitting process.

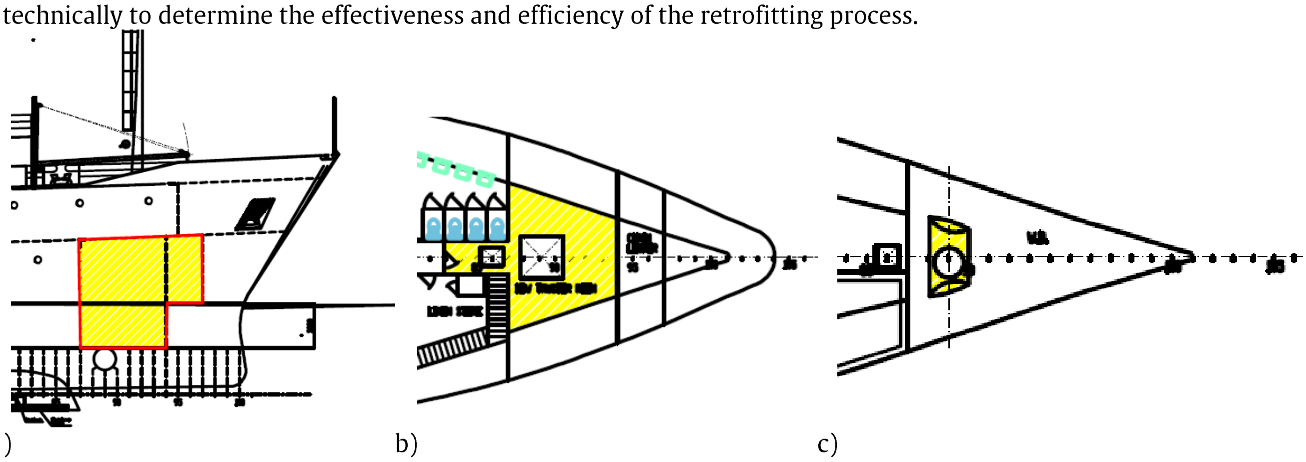
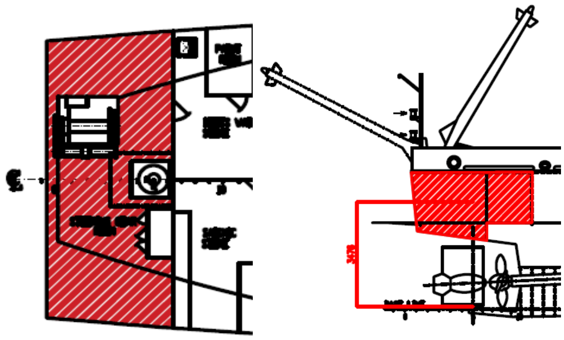


Figure 8. Pictures a) and b) display the availability of bow thruster space at the current arrangement, and picture (c) depicts the thruster tunnel.

The existing thruster room area of 3.86 m x 4.2 m x 5 m is large enough to accommodate one bow thruster installation. However, seeing the dimensional requirements of the Schottel SRP 240, there needs to be a new tunnel modification with a difference of 0.2 m. For the installation of the stern thruster, the available space is still very sufficient. However, the steering gear room needs modification, and the winch device needs to be eliminated to accommodate the electric motor from the stern thruster.



a) b)

Figure 9. Drawings a) and b) illustrate the space available for the stern thruster engine, and (b) also illustrate the availability of free space outside the hull for the thruster

Figure 9 is the drawing explanation for the azimuth thruster and steering gear room. The propeller diameter does not change much; instead tends to shrink by 35 mm because the thrust load is divided into two propellers, although the engine power increases significantly. So there is no need to change the shape of the stern area. The steering gear room is spacious, and there is still much free space, plus the elimination of the steering gear system.

The results of the analysis of needs and availability are shown in Table 3.

Table 3. Space requirement and availability of Diesel Generator and Thrusters

Retrofit Item	**Space Requirement**	**Space Availability**
Diesel-electric system	Diesel-electric 3512C • Length 3.232 m • Height 2.205 m • Width 2.16 m	Engine bed length - from engine to gearbox and generator 6.083 mm Engine bed width 3.719 m Engine headspace to lower deck 3.167 m
Bow Thruster	Schotel SST 1 • Diameter 1.240 m • Tunnel wall thickness 0.02 m • Tunnel length 1.5 m • Approximate weight 3000 kg • Basic dimension without prime mover 1.545/1.890.5 m	Installed bow thruster • Diameter 1 m • Tunnel length 1.996 m
Azimuth Thruster	Schottel SRP 240 D x2 • Diameter 1.7 m (ducted)	Diameter of the existing propeller 1.735 m Skeg to rudder hydraulic 3.475 m

The conclusion drawn from the new system's material handling, opening, and space arrangement is the retrofit ability, where ease of handling determines transportation needs. Transportation dictates the need for the equipment installation path, which also chooses the need for handling machinery and equipment [2]. All stated requirements must be met to ascertain whether the ship is retrofittable. RV Baruna Jaya 1 was found to have space that met the criteria, though the access required cutting the hull and disassembling pipes and machinery.

3.4.3. Voyage Requirement Analysis

With the new system installed on ships, specifically for two diesel generators, it is necessary to analyze fuel consumption and the storage needed. Changes in the propulsion system from a conventional diesel system to a diesel-electric system that relies on a diesel generator and several electro motors, causing the diesel generator as this system's primary focus. With RV Baruna Jaya 1 that has not previously been installed with a DP system, the load and power requirements for the propulsion, thruster, and electricity systems will increase, so the required tank capacity will also be escalated.

The direct relationship between tank capacity and fuel consumption determine the number of days and the distance that can be travelled by ship according to the requirements of the ship's retrofit. The sailing days that have been required are thirty days which is the minimum number of days that need to be achieved by the ship if the fuel tank is at its maximum capacity.

Table 4. Generator Specifications

Ship Specifications	**Value**
Fuel Tank Capacity Total (m^3)	260+47.1
Power Generated by Generator (P_G) assumed at maximum power (kW)	2724
Fuel Consumption of Generator (gal/hr)	84.7
Fuel Consumption of 2 Generators (m^3/day)	15.38

Table 4 explains that the total capacity of the fuel tanks in RV Baruna Jaya1 is 260 m^3, which must be expanded with the increased power of the new generators. The AL2 tank will be converted into the fuel tank To increase fuel tank capacity,, previously used as an empty tank with a capacity of approximately 47 m^3. The modification will be performed by applying the standards and regulations of the classification from the water tank to the fuel tank.

Using a CAT 3512 C diesel generator, the daily fuel consumption is 15.38 m^3/day, assuming both generators work thoroughly for one day without any load factor, which is considerably inaccurate since it is not considering the actual loading condition. Power requirements are analyzed to improve the accuracy of fuel tank requirements from diesel generators on four needs: port, transit from and to survey locations, survey operations, and at maximum conditions.

When sailing for research purposes, the ship's propulsion and electrical load are only sometimes in top condition. Therefore, an influential loading factor was carried out for each requirement during a research expedition to estimate fuel consumption per day from the generator. The element was based on the amount of time for each condition during a research expedition. The assumed effective loading factors are 5% for port, 30% for transit, 55% for survey operation, and 10 % for critical operation. The results of each condition are stated in Table 5. The maximum power for the ship operation in critical condition is 2540 kW. With this load presentation and after modifying the AL2 tank, the number of sailing days is twenty-three. However, the sailing days need to meet the requirements. Hence, in the following design phase, it is necessary to make adjustments or re-design the fuel tanks to meet the criteria for 30 sailing days.

Table 5. Power demand for four conditions during research operation

System	**Power Demand per Condition**			
	Port (P_{port})	**Transit ($P_{transit}$)**	**Survey Operation ($P_{operation}$)**	**Maximum Operation ($P_{critical}$)**
Propulsion (kW)	285	1140	570	1140
Thrusters (kW)	900	-	900	900
Hotel Load(kW)	125	500	500	500
Total Power	**1310**	**1640**	**1970**	**2540**
Fuel Consumption of 2 Generators m^3/day	7.782	11.85	14.02	15.41
Sailing Days	33	22	18	17

3.4.4. Electrical Arrangement

The demands of installing a DP system on the RV Baruna Jaya I resulted in a change in the power system from initially using a conventional diesel engine system to a diesel-electric system. The changing powering process affects the ship's electrical powering system, changing the existing systems into electric ones. Therefore, as shown in Figure 10, modifications relating to the RV's single-line electrical system are needed. Baruna Jaya I.

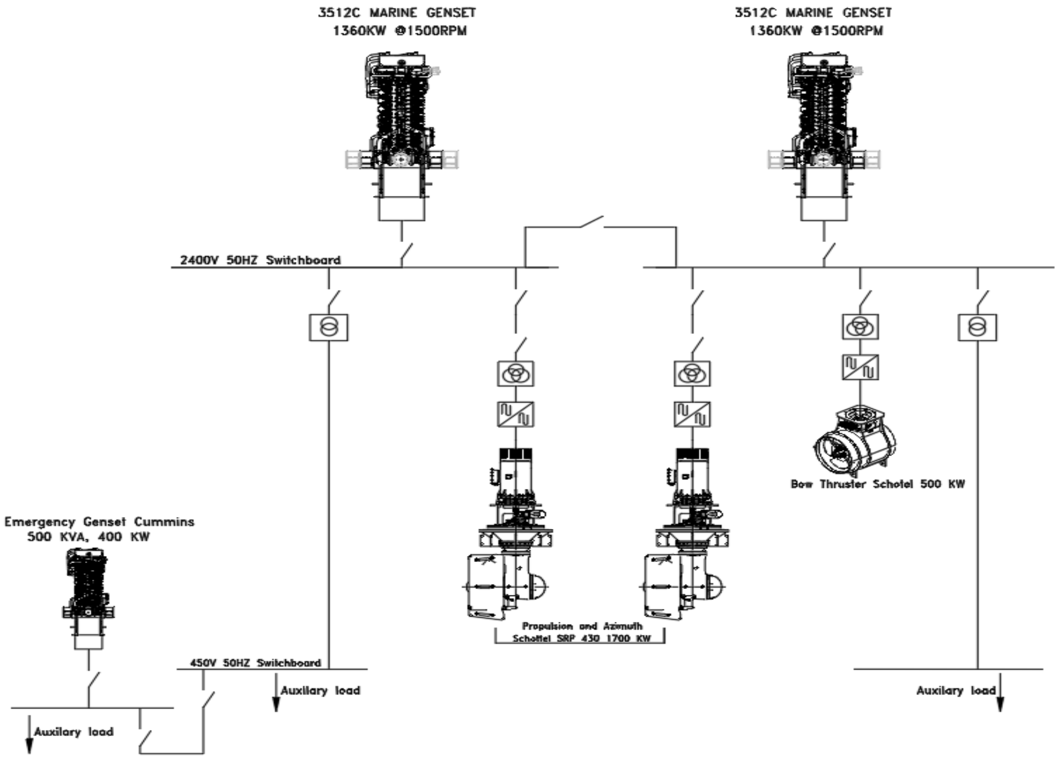


Figure 10. Single-line electrical configuration of the Diesel-electric system

The concept of the designed diesel-electric system is that there are two main power diesel generators, each having a capacity of 1350 kW, where the two diesel generators are connected in parallel to each other with the main switchboard with a total of 2400V, 50 Hz. The extended feeders pass through the transformer and converter from the main switchboard. The transformer is used to adjust the equipment's input voltage, while the converter is used to adjust the input current for the equipment. The existing feeder circuit provides power to the loads used on the ship, including two motors that drive the azimuth propeller, one bow thruster, and the auxiliary load. The emergency generator was installed with an ACOS (Automatic Change-Over Switch) system as a redundancy. When a failure occurs on a diesel generator as a central system, it can automatically back up equipment that must operate during an emergency (lighting, navigation lights, radio communication, fire alarm detection systems, information systems, navigation equipment, automatic sprinkler pump, and watertight door systems) situation [28].

For the requirements of the DP system, it is necessary to have a power management system, which is a set of functions that manage and monitor all production and consumption of the ship's electrical power system[29]. The power management concept created in RV Baruna Jaya I can be divided into four primary functions: Load management and control, Circuit breaker control, Monitoring critical parameters, and Blackout conditions. Load management and control are used to maintain the condition of the power used for electric loads, especially for thruster loads which are essential for DP systems and control the system to prevent overload. The circuit breaker protects the electrical circuit from overloading/overcurrent. Monitoring of critical parameters is used to assess and control the condition of electric systems. If parameters are abnormal, preventive action can be taken immediately. The power management system's blackout condition is advantageous when the blackout occurs. It maintains the emergency system to cover and helps the main system to restart. The power management system control will be installed in the engine control room and DP's control room in the wheelhouse.

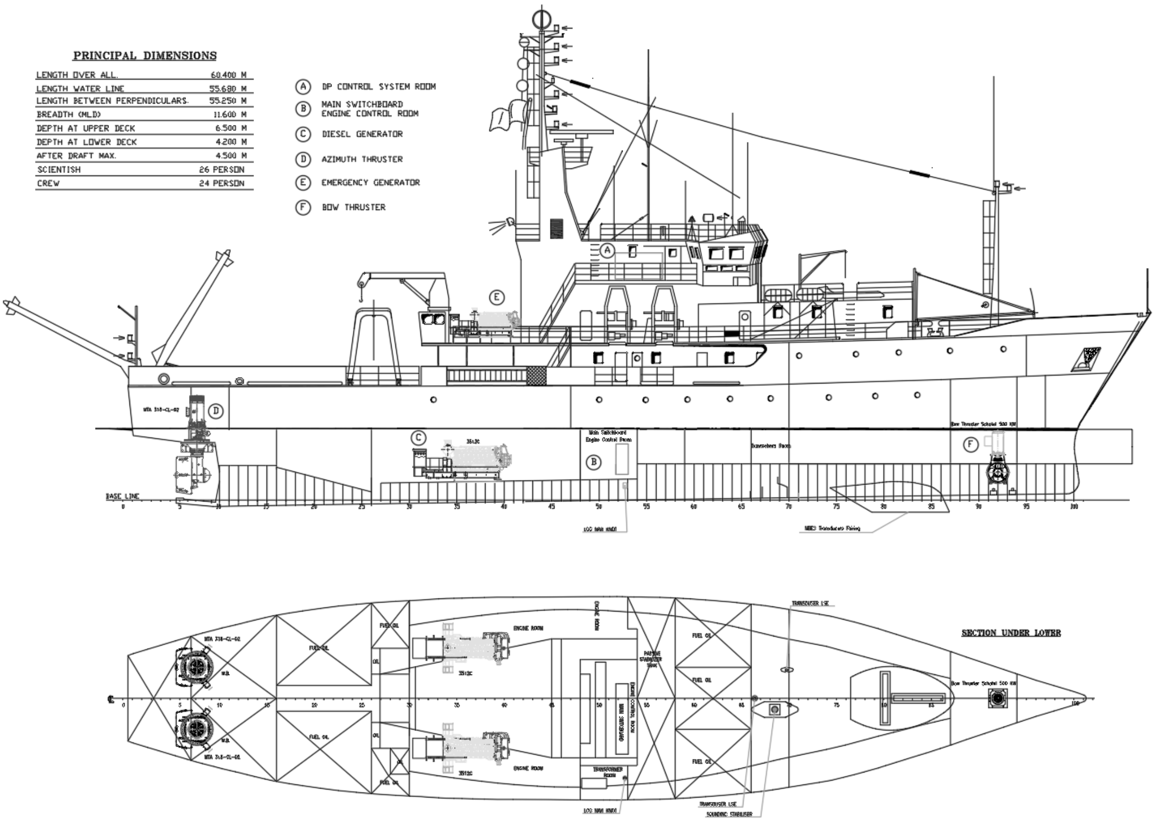


Figure 11. General Arrangement of Diesel-electric system with Bow Thruster, two Azimuth Thrusters, and two Diesel Generators

3.4.5. Retrofit Risk Analysis

In this concept design process, the approaches that can be taken in conducting risk analysis are limited. The risk analysis for research vessels has been studied [30]; however, it focused on the survey operation rather than ship operation. There are two approaches available: qualitative and quantitative. Using quantitative methods requires a deeper analysis and historical data from similar ships undergoing retrofitting. Because data were scarce, it was decided that this paper would use a qualitative approach as the first step and description. Ships are used as "risk object" parameters. Subjects of risk, including retrofit processes, new equipment and machinery, lost old components, survey operations, and ship operations, are used. In group discussions, new and emerging risks were explained in Table 6.

Table 6. Severity Scale

Scale	Severity	Effect on Ship
1	Minor	Local Equipment Damage
2	Significant	Non-Severe Ship Damage
3	Severe	Severe Damage
4	Catastrophic	Total Loss

HAZID (Hazard Identification) was used to describe the risks that may arise due to the installation of the diesel-electric system, bow thruster, azimuth thruster, and dynamic position system. Risks were classified based on the installed systems and were analyzed for possible failures sourced from previous studies[31]. Risks that arise are then analyzed for probability and severity. For this study, we used the severity scale from IMO (International Maritime Organization) FSA (Formal Safety Assessment) method [32] and the scale from the "Move it" project [31] for the frequency measurement.

Table 7. Frequency Scale

Scale	Frequency	Definition
1	Remote	Unlikely to occur during and after the retrofit process
2	Occasional	Can occur during and after the retrofit process
3	Probably	Will occur several times during and after the retrofit process
4	Frequent	Will frequently occur during and after the retrofit process

Table 8. Risk Matrix of ship retrofit

Severity	Probability				
	Scale	1	2	3	4
	1	Low	Low	Medium	Medium
	2	Low	Medium	Medium	High
	3	Medium	Medium	High	High
	4	Medium	High	High	Intolerable

Table 8 shows the risk matrix that defines the retrofitting project's risk level. The low-risk level means that the prevention and mitigation of the risk are unnecessary, while the medium level is the risk is still acceptable. However, the re-design could be beneficial. The high-risk level must be handled during the retrofit process or ship operation. Thus, Preventive or mitigation for high-risk systems is mandatory. The Intolerable risk is unacceptable to apply in a retrofit project requiring a design or system change.

Table 9. Risk Analysis of retrofit project for RV Baruna Jaya 1

No	Risk	Description	Proba bility	Seve rity	Risk Level	Mitigation & Prevention
General Retrofit Process						
1	Low capability of survey operation days	The increase in fuel tank capacity cannot accompany the increase in fuel consumption.	3	2	Medium	The additional fuel tank needs to be analyzed and calculated in the next step of the design spiral. Consider the option of hull lengthening to accommodate a new fuel tank.
2	Changes in waterline	Changes in ship displacement could affect wetted hull area and impact overall ship resistance.	2	2	Low	In the next step of the design spiral, a detailed hydrostatic calculation needs to be conducted.
3	Excessive load during loading and unloading	During the cargo handling, an excessive bending moment and shear force were transferred to the hull structure.	2	1	Low	Using wagon or train shippers to distribute the load, the weight load does not come into contact directly with the ship plate. The engine changes should be done in controlled load areas, such as concrete blocks at the graving dock.
4	Fire on Converted AL2 Tank	With the tank previously designed for water ballast, there is a possibility that a fire will occur.	2	4	Medium	The tank wall should be insulated according to standard.
5	The initial requirement of parts replacement may be	The parts and equipment could increase by additional navigation items, new survey equipment due to hull dismantling, and a new electrical panel.	2	2	Low	Equipment requirement analysis should include the complete arrangement of replacement probability.

No	Risk	Description	Probability	Severity	Risk Level	Mitigation & Prevention
	underestimated					
6	Temporarily removed parts cannot be re-installed	Removing a large amount of electrical and mechanical equipment during retrofitting process may cause a failure in the re-installing process.	3	2	Medium	Replace the parts with new ones.
Thrusters Systems (Azimuth and Bow Thruster)						
1	Structural stress on the construction of the steering gear room	Caused by unsuitability of structural configuration in an area that is not for its purpose.	3	3	High	Performing a stress analysis simulation on the construction and adding reinforcement to the room based on the findings in the simulation.
2	Major replacement on the construction of the electrical panel	The electric motor and research auxiliary equipment panels must be dismantled entirely if the replacement process is carried out through the starboard side. Almost no contractor is capable of replacing conventional equipment made in 1989.	3	2	Medium	Carry out the engine replacement process efficiently and effectively so the hull is not dismantled on a large scale. If inevitable, include the removed parts as retrofit items.
3	Engine Power is not sufficient to meet the service speed requirements	The change in the type of propeller from single screw to azimuth propeller affects the resistance in the stern area of the ship.	1	4	Medium	Conducting resistance and capability analysis with the result from concept design.
Dynamic Positioning System						
1	Under Classified Crew	New systems are harder to understand and control for current seafarers. This could result in a higher human error probability.	2	3	Medium	Conducting intensive training for the seafarer.
2	Additional Layout Rearrangement	DP Systems need more space at the wheelhouse.	4	1	Medium	The Survey Acquisition Room needs to adapt with the new system. Old Radio Room needs to be eliminated.
3	Failure on the thrusters during stationkeeping	Thrusters do not move or process commands from the control system.	2	4	High	Always do a test run before stationkeeping work to check for any failure in the system.
4	Failure of DP Controller	The DP controller system cannot function in carrying out stationkeeping	2	4	High	Always perform periodic maintenance on the DP control system. Bypass the manual control system.
Diesel-Electric System						
1	Structural stress on the girder and stiffener on the engine mounting area	Due to the difference in load between the two new generators and the previous propulsion system.	2	2	Medium	Conducting structural analysis of girder and stiffener on the engine mounting.
2	Failure on one diesel generator affecting ship manoeuvrability	If one generator fails and the other cannot supply the propulsion and DP loads.	1	4	Medium	Always perform a running test and planned maintenance on the generator. Ensure the emergency generator can supply the electrical needs of all basic vessel necessities.

Table 9 shows three categories of risk level High, where based on analysis, two of the three risk levels high occur in the Dynamic Position system, namely failure on the thruster and DP controller during the stationkeeping process. This happens because in the DP system that works automatically, if there is a failure in one of the components, the ship's movement is disrupted, which can endanger safety. Some actions can be taken to do a test run before the stationkeeping and always perform maintenance on the control system. The last "high risk" category is the structural reliability of the construction in the steering gear room. Previously it was designated for the rudder, but with the plan to replace the rudder system with azimuth, there is a potential for structural failure in strength or deflection. In the retrofit process, the risk assessment is in the Low and Medium levels, meaning the retrofit process can apply safety following the standard.

3.4.6. Retrofit Project Execution Plan

According to Allen[33], several factors can cause a project to fail to meet its objectives. External factors can cause the project to be delayed or halted, while internal factors may also cause the project to be delayed or to consume more resources than necessary. According to Pandit[34], a project plan is a roadmap that shows how a project progresses through all stages. When referring to the Project Management Institute, Project Execution Plan is used to:

- Guide the execution of the project document's assumptions, constraints, and alternatives.
- Provide a tool to communicate with stakeholders.
- Establish project milestones and deliverables.
- Set scope, cost, and schedule baselines for progress measurement and control.

Figure 12. The element of Project Execution Plan [34]

The goal of this paper is to propose a retrofitting methodology. In this study, the project execution plan is used as a guideline to achieve a goal: to complete the RV Baruna Jaya 1 retrofitting. The project execution plan outlines the steps required to carry out a revitalization project on a ship over thirty years old, which includes replacing the main propulsion system and installing a DP system.. Pandit describes the project execution plan's nine elements. A method for establishing a PEP was proposed after all stakeholders had approved the final retrofit design. The PEP is vital to the project manager's and project team's armoury. It sets out the scope, mandate, and plans of what the project will deliver. It is a vital communication tool and should not be treated lightly

Table 10. Project Execution Plan of Retrofit Project

Main Element	Sub Element	Initial Plan
Goal Statement	Why the project carried out, the purpose, and expected benefit	• The project is retrofitting the aging Indonesia research vessel fleet in 2023 • Equipment retrofit was carried out in 2017, but vessel retrofit is yet to be executed by the end of 2022 • BRIN expects the ship should operate for twenty more years with good sailing capability and reliability. Project based on Oceanographic Research Foresight from Indonesia Institute of Sciences in 2017
	The unique challenges that follow	• Probably the first major research vessel retrofitting project in ASEAN. Massive challenge for the shipyard in the area.
	The risk associated with the project	• Following risk in this project, laid out in the retrofit risk analysis
Quality and Technical Specification	Requirement of material, equipment, and testing and inspection that may follow	• All required items should follow the needs of forecasted Net Zero Emission and GreenHouse Gases requirements for 10 to 15 years onwards • All equipment should have standard marine material, IMO certification, and a class-acceptance certificate • Commissioning tests and sea trials need to be planned and assessed to comply with Ocean Going Research Vessel
Resource Allocation	Labor and staff knowledge needed	Hire a complete project team with a naval architect, marine, electrical, and system engineering educational background.
	Funding	This project is planned to be done in a year or several years. Cash flow

Main Element	Sub Element	Initial Plan
		requirements should state clearly in the project execution plan
	Time consideration	The time goal of this project is the end of 2025 or 2026.
Project Scheduling	Considering using robust and executable based on the resource	Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) could be employed to support the project schedule
Organizational Consideration	Kind of organization needed to Execute the plan for retrofitting	• The needs of an agile and resilient project team. There should be one project management overviewing the project. Decision-making authority should specify whom for what components • Structure for the organization is also detrimental to coordinating and reporting • Monitoring and status updates should adopt the best practice available
Milestone	Setting a milestone, breaking up the project based on the progress needed.	The project could be divided into several key points: • Procurement of engine, material, and shipyard selection • Removal of the existing engine • Installation of New Engine • Synchronizing • Commissioning • Sea Trial
Tolerance	Setting a tolerance, the project may deviate from planning. Setting a boundary at the project's beginning may help set the course ahead.	• Quality boundaries, what is the acceptance rate for quality • The improvisation that is acceptable for future performance • Buildable design with acceptable tolerance • Create a quantitative range for project targets and goals
Dependencies	Stating what is under our control and what is outside our control	What is under project control: • Number of Staff • Man Hour • Facility • Project Management Tools What is outside project control: • Weather • Economic Inflation • War
Risk	Assess risk and prevent and mitigate based on the findings	The Risk Control Option should be laid out at the start of the project. This project could employ qualitative and quantitative methods or even use FMEA (Failure Mode Effect Analysis) or FMCA (Failure Mode and Criticality Analysis) to further reduce the impact of risk on the project

Table 10 shows that the Project Execution Plan for Retrofit Project has nine main elements, along with its sub-element and initial plan, which must be prepared. This stage is crucial in retrofitting because it is the last planning stage before the start of a project. A project manager must be able to ensure that the goals of the project are achieved. In the retrofit project, it must be noted that in its implementation, there may be changes both in concept and design. The adaptation to the project must be considered and designed to mitigate these changes per the design requirements.

4. Discussion

4.1. Overall Results

It was found that retrofitting a research vessel can use a different methodology and approach than a commercial vessel. This difference is due to the fundamental difference in the function and purpose of the vessel. Therefore, several changes and modifications were made to the spiral design in this study, including several additional retrofitting steps. These are space arrangement for the new system, material handling and opening, voyage requirement analysis, and electrical arrangement. The risk assessment and project execution plan stages are also provided in the developed methodology. However, it is understood that this stage is optional because, at the concept design stage, very little information can be obtained, so the approach taken to these two things is considered inadequate unless the user has sufficient information regarding the actual data.

Material handling, opening, and space arrangement are performed to see if the requirements of the ship can be applied and whether or not hull modifications are required. In the case of applying this methodology, the propulsion system requirements can be carried out without modifying the hull. This early method simplifies retrofit work generally, but not all retrofits can be done without changing the hull. It all comes back to the purpose of the ship retrofit. This stage also analyzes the mobilization to accommodate the replacement of engines or survey equipment. Voyage plan analysis is the follow-up of the propulsion system replacement and its implications on the ship's ability to sail. In the case of BJ 1, the propulsion system was replaced, so there will undoubtedly be changes in engine fuel consumption. This variable determines the ability to sail a ship for a long time, apart from the ability of the fresh room to store food. This fuel consumption is then processed into the sailing day's length, which is matched against the ship's requirements. Whether additional fuel tanks are required or existing tanks are sufficient to accommodate. We also divide sailing capability based on fuel consumption into four categories; port, transit, survey operation, and maximum operation.

Risk analysis as part of mitigation and prevention from the results of the previous stage analysis. HAZID was used to describe the risks that can occur when carrying out the retrofit process, where the risks are divided into four major groups; general process, thruster system, dynamic position, and diesel-electric. Risks are quantified and qualified at the beginning to illustrate the challenges that will occur and possible steps that can be taken. Based on the risk matrix, the most significant risks in the Baruna Jaya I retrofit process are "Failure on the thrusters during stationkeeping", "Failure of DP Controller", and "Structural stress on the construction of the steering gear room". A project execution plan was conducted to conclude this methodology. The basis of ship retrofitting is project management, so in the early stages, we must be able to create a guideline for this process. Therefore, the author added a project execution plan to the methodology to complement the Baruna Jaya I ship retrofit.

The electrical arrangement needs to be more concerned and analyzed because modernizing the machinery will change the ship's electricity completely. So that adjustments are made related to load power with the power generated. The Electrical Arrangement on the RV Baruna Jaya I also consider the existence of a DP system which will increase the amount of load power. The retrofit that was carried out included replacing the main engine (changing diesel engines with diesel generators), replacing CPP (Controllable Pitch Propeller) with Azimuth propellers, changing bow thruster capacity, and installing electrical systems with adjustments to the DP system. The electrical system will implement a power management system that will be used to distribute load power. With the electrical arrangement being carried out, it is hoped that all the load power in the ship will be fulfilled and RV Baruna Jaya I can conduct a survey smoothly.

The developed method will be compared to the RPI (Retrofit Priority Indicator) method that Krikke has proposed To analyze the effectiveness of the retrofitting methodology [2]. The method developed by Krikke is more detailed in analyzing how new equipment will be installed on the ship, both in terms of handling and transportation, using a fishbone diagram. In contrast, the developed method uses a spiral design. However, In the method proposed by Krikke, there is no analysis of consumable and auxiliary needs for the new system, and the voyage requirement stage has not been developed in this study. In addition, in the developed methodology, there is also a risk analysis in the retrofit process, which aims to analyze every risk in the retrofit stage, which is not yet contained in the method proposed by Krikke.

4.2. Advantages and Limitations of the Methodology

Like any new methodology, it needs to be tested on a real case, and in this study, the newly developed methodology has been implemented to the retrofit plan of RV. Baruna Jaya I. From experimenting with this methodology at the concept design stage for the retrofit of RV. Baruna Jaya 1, we found some advantages and limitations.

It was discovered that the methodology has the advantage of being systematic because it is based on spiral design, which is already widely utilized in the ship design process. Therefore, the retrofit methodology's procedures are easier to follow or duplicate. Additionally, we discovered that the method may be used for multiple ships simultaneously if they are sister vessels and have the same retrofit objective. Additionally, the methodology is flexible and may be modified to match any research vessel that must be refitted. The method also emphasizes the requirements of the journey plan, prioritizing the demands of the voyage and its effects on the needs of the ship.

In the case of Baruna Jaya I, Cost Benefit Analysis (CBA) is required when planning a retrofit. However, a CBA was not carried out due to the lack of data and retrofitting possibilities. The relevance of CBA to this methodology and its consequences for the spiral design process requires extensive investigation. The methodology's most obvious flaw is that it is rigid and cannot be utilized in parallel since it is built on a spiral design constrained by a predetermined order of operations. For instance, this methodology can be modified by grouping the stages of the journey plan and electrical layout. However, this process must be followed in sequence.

With this methodology, stakeholders are expected to consider a more appropriate and careful approach in planning and executing ship retrofit projects in the future. This methodology can help systematically design and retrofit project management so that work planning can run regularly. In addition, this methodology can help stakeholders determine which parts of the ship to retrofit so that the budget used for the retrofit process can fully improve the ship's performance.

5. Conclusion

A systematic approach is imperative to execute the retrofitting process on ships, particularly research vessels, as most retrofitting efforts are limited to major repairs and fail to prolong the ship's lifespan. This study proposes to develop a methodology for ship retrofit. The design of the developed methodology has several essential steps, such as: Selecting the ship to be retrofitted based on an analysis of economics, energy, and emissions, choosing which part or system will be retrofitted, determining the retrofit requirements, and designing the ship retrofit. The design phase of ship retrofitting employs a dynamic design spiral with various modifications throughout the steps, particularly in the early stages that emphasize considerations such as spatial requirements and arrangement, ease of material handling, propulsion and thruster systems, consumables and tank capacity prerequisites, risk analysis during and post retrofitting, and execution of the retrofit project.

An analysis of the retrofit concept design process was conducted in a case study featuring the RV Baruna Jaya 1 to evaluate the efficacy and performance of the devised methodology. The implementation of this case study yielded favourable outcomes, demonstrating the successful application of the retrofitting project's design concept. From the implementation case, the results show that the methodology has successfully applied the design concept of retrofitting project, starting from the ship selection and components to be retrofitted and ending with the retrofit execution plan. Moreover, the developed methodology can solve the recent problems of ship retrofitting, especially for the special vessel, which is the components to be retrofitted, by prioritizing the critical equipment of the vessel. A comparative study was also conducted between the developed methodology and a previous retrofit project. The comparative analysis revealed that the developed method needs more detailed guidance regarding equipment handling and transportation. However, it compensates for this by incorporating considerations for voyage requirements, risk analysis, and consumable analysis. It It is important to note that the developed methodology does have a limitation, as it needs to incorporate the retrofitting budget with the Cost Benefit Analysis, which could pose challenges for shipowners with financial constraints. Nevertheless, shipowners, shipyards, and engineering companies can effectively use the developed methodology to plan and optimize ship retrofit project management

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