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Design and Cost Multi-Objective Optimization of Small-Scale LNG Carriers using the Value Engineering Approach

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Abstract. Nowadays, liquefied natural gas (LNG) carriers are the main merchant fleets for the transport of natural gas for energy. The large LNG carrier has a more efficient freight cost (approximately 7.8 USD/MMBTU) than a small-scale LNG carrier (SSLNGC; approx. 12,8 USD/MMBTU). Another method must be introduced to make SSLNGCs more cost-efficient. As such, this work conducted an experiment to improve the design of SSLNGCs via design and cost optimization by combining a value engineering approach and multi-objective optimization to decrease hull resistance and lower construction material costs by adjusting the ship dimension ratio. By improving the conceptual design and using semi-integrated numerical simulations, the final result showed improvements in SSLNGCs by decreasing the hull shell area by 1.57% to reduce the construction material needed and total ship resistance by 8.3%.

Keywords: Hull resistance; Hull surface area; Multi-objective optimization; Small-scale LNG carrier; Value engineering

1. Introduction

In the natural gas logistics industry, liquefied natural gas (LNG) carriers have played a major role in the trading, distribution, and shipping logistics processes in terms of transportation, loading, and unloading activities. The LNG supply chain can be defined as a natural gas network that begins with the natural gas from gas fields that move to the liquefaction plant to be changed into liquefied gas that is then stored in LNG storage tanks. LNG is distributed to gas users or end users. In the LNG supply chain, the final logistics costs of providing LNG are highly dependent on the length of the logistics chain, with parameters that include net selling price, LNG liquefaction location and final destination, size and route of LNG vessel size and location of unloading terminal, boil-off gas (BOG) utilization, and the availability of gas need. The lower transportation cost per tonnage of cargo compared to other modes of transportation is an advantage for LNG carriers. In line with this, the LNG industry has continued to grow from large-scale refineries and industries to medium- and small-scale refineries and industries (Rensvik, 2013). This growth has been followed by the need for medium- and small-scale LNG carriers (SSLNGC). However, the constraint in operating small-scale LNG vessels is that the transportation costs are significantly higher (approximately 1.5 USD/MMBTU in shipping costs) than those for large-scale LNG carriers (approximately 1.1 USD/MMBTU in shipping costs).

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Small-scale LNG vessels are ships with a small capacity that carry liquefied natural gas to supply gas needs to archipelagic countries that are difficult to access or do not support the installation of gas pipelines. The volume of this LNG carrier is in the range of 2,500–20,000 cbm, with a voyage of 1000 nautical miles. Based on economic principles, distribution with a larger volume would be more profitable. However, there are some special conditions in which the use of small-capacity vessels would be more efficient due to several factors. One factor is the distribution of LNG to archipelagic countries. Considering that Indonesia is limited by the sea and surrounded by volcanoes and tectonic plates, this means it is not conducive to establishing pipelines because Indonesia has high-intensity earthquakes. Compared to the small-scale LNG vessels, the medium- and large-scale LNG vessels see costs of 1.3 and 1.1 USD/MMBTU. As such, larger ships would carry more cargo and be more efficient. However, as we know, the demand for LNG is not only large scale, but also small and middle scale. Inefficiency could make the transport of small-scale LNG unfeasible because shipping costs are high and unfavorable. This is especially true in Indonesia. Most LNG demand arises on a small scale for gas power generation in eastern/western Indonesia, which are separated and have small-scale gas storage capabilities for power generation. Based on these main issues, this research aims to optimize small-scale LNG shipping to improve efficiency and competitiveness in the shipping market.

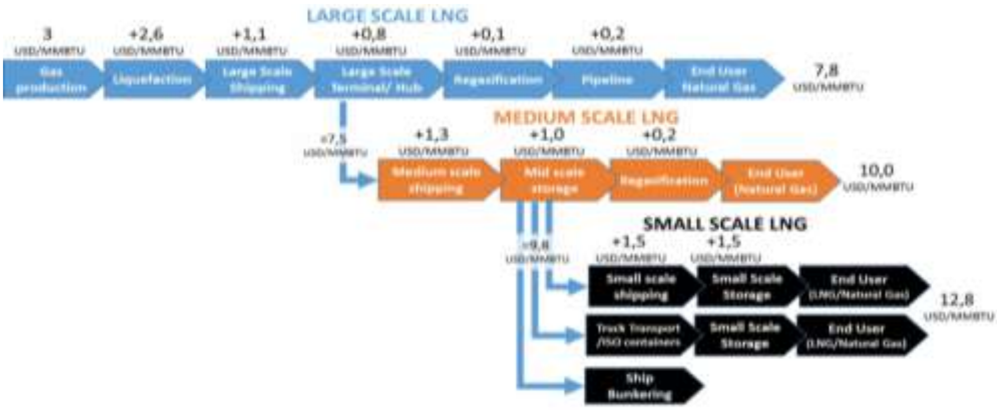

Figure 1 Comparison of the average freight rate of LNG carriers (Engblom, 2016)

Several studies on the optimization of the SSLNGC sector have been optimization studies, including supply chain studies (Bittante et al., 2018; Budiyanto et al., 2019). Several previous studies have shown that SSLNGC can be optimized from the perspective of hull efficiency by minimizing ship resistance (Kim et al., 2014; Pak et al., 2020). The development of an optimization method for modifying hull shape has also been conducted (Marinić-Kragić et al., 2016; Hakim et al., 2021). Other research is optimizing the selection of boil-off gas handling to determine which gas treatment system is the most competitive in terms of price, based on the size of the LNG carrier. Several studies have also executed optimization analyses of energy optimization on board by selecting dual-fuel engines (Budiyanto et al., 2020a; Trinklein et al., 2020) or propulsion plant (Grzesiak, 2018; Gunawan et al., 2018; Meana-Fernández et al., 2020; Muhammad et al., 2021). The most widely conducted research has been based on ship route optimization for LNG (Wang et al., 2021) or other ship operations (Ma et al., 2020). The selection of cargo tank types and diesel dual fuel conversion has also been studied earlier (Kim et al., 2019; Budiyanto et al., 2020b; Guererro, 2020) to find the safest, optimal, and most economic tank for several different sizes and needs of an LNG carrier (Muttaqie et al., 2020).

2. Methods

This In this project, the methodology developed for the optimization process from the design concept level to the detailed design phase was executed by performing value engineering to reduce development costs and by an optimization algorithm to determine the optimal ship size ratio–hull shape to obtain low construction costs and lower fuel costs as a result of the minimization of total resistance, which are advantages and unique methods in this new experiment. This unique method can become an optimization process that looks at the general aspects of the concept to the detailed aspects using computer-aided engineering and numerical calculations. In this experiment, a new multi-objective optimization method to simultaneously reduce ship resistance and construction weight was carried out by changing the ship size ratio variable using the help of computer-aided engineering with shape optimization and combining optimization basic design with detailed engineering design. This experiment was executed using a case study of a technical feasibility study of 5000 CBM SSLNGC for an LNG supply operation to a gas power plant in the western Indonesia area (Budiyanto et al., 2020c). Specifically, this research's goal is to expedite and develop multi-objective optimization between ship resistance and building costs by minimizing ship resistance to reduce fuel consumption, which affects operating expenses (OPEX). Furthermore, this research aims to minimize hull materials to decrease investment costs and combine value engineering and multiobjective optimization to obtain cost reductions in the operation of ships.

In this case study, there were two stages of optimization. In the first stage, a ship design concept was developed using the value engineering method to obtain cost reductions (Dahooie et al., 2020). In the second stage, the results of the design concept were developed using ship-shape optimization. We combined these two methodologies because cost reductions must be done from the conceptual to the detailed design stages. Value analysis contributes to optimization at the conceptual stages, and multiobjective optimization contributes to the detailed design stages. With the double-staged optimization process, the result can be expected to have a greater impact on investment and operation cost reductions than a single-staged optimization process. Equation 1 describes the general function of value, which is the function of the object divided by its cost. In the first stage of optimization, the calculation is at the stage of the holistic design concept. The optimization concept was based on a literature review of existing research. All relevant information was collected to design a concept for the SSLNGC. The optimization equation is described below.

For value engineering optimization

$$value = \frac{cost\ of\ the\ component}{function\ of\ the\ component} \tag{1}$$

For multi-objective optimization

$$minimize\ or\ maximize\ f_i(x)\ \ i = 1, \ldots . N_{obj} \tag{2}$$

$$subject\ to{:}\ G_k(x) = 0, k = 1, \ldots\ldots, K \tag{3}$$

$$subject\ to{:}\ h_l(x) = 0, l = 1, \ldots\ldots, L \tag{4}$$

2.1. Value Engineering

The method of making an optimization design concept with a value engineering approach was carried out using value standards and a body of knowledge. Before value engineering, all information and data from the original or initial design concepts were gathered for cost calculations. Value engineering is currently the most effective technique for identifying and eliminating costs that are not important when designing a product. Value engineering can be applied to transportation projects and can have a cost-effective impact. The methodology used when conducting a value engineering study is a systematic process used by a project team to increase the value of the project by analyzing the functions. In general, value engineering is carried out with a sequential approach, using several stages to focus the project team so that they can think innovatively in a collaborative manner rather than an uncoordinated manner. There are three main stages: pre-study preparation, value workshop, and post-study documentation and implementation. In value engineering, we focused only on investment cost efficiency to minimize the hull component, especially hull shell material, by decreasing the hull area for both watertight integrity and non-watertight hull parts. For the calculations, we needed to know the variables of hull shell components and hull areas in meters squared, hull thickness, and marine steel plate pricing. The plate cost may vary depending on the region, market, and year of manufacturing. However, we considered assuming a constant price (for instance, 655.17 USD/ton) per total hull area. The value methodology is a systematic process that follows the job plan. A multidisciplinary team applied a value methodology to improve the value of a project through the analysis of functions. Value engineering is a procedure enabling one to exercise underutilized human creative potential to solve problems. This is accomplished through adherence to a precise sequence of steps, known as the job plan. In value engineering, as in other problem-solving methods, a systematic approach produces better results than undisciplined ingenuity. Identification of what is poor value must be recognized to know what makes up unnecessary components, wrong beliefs, habitual thinking, reluctance to seek advice, or changing technology that contributes to a design's poor value. Furthermore, during normal cost reductions, one is inclined to analyze an item from the standpoint of how to reduce the cost of the elements that make up the item. One "cheapens" the parts until quality and performance are sacrificed.

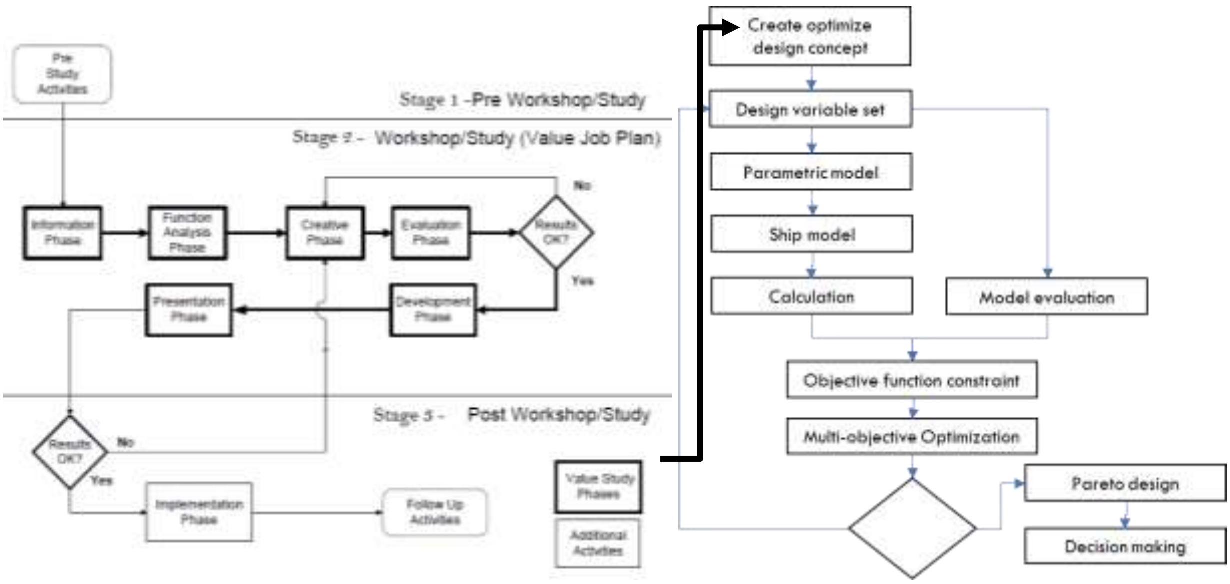

Figure 2 Value study process flow diagram (SAVE International, 2007) combined with multi-objective optimization

We considered the hull appendages to contribute less to hull integrity, so they could be removed. For instance, a bow thruster is not needed because navigation in the port must be assisted with a tug. Therefore, the presence of a bow thruster is not necessary. Other parts, such as pipe fenders, are also unnecessary because ships load and unload in port conditions that comply with safe berthing with dolphin and fender protection that does not harm the shipside. As a final result, hull shell component pipe fenders and bow thrusters could eliminate costs from hull construction materials. We also changed parallel middle body parameters in the main hull to reduce costs.

2.2. Multi-Objective Optimization

Multi-objective optimization/Pareto optimization is a form of multiple criteria decision-making that focuses on solving mathematical optimization problems with more than one objective function that must be optimized simultaneously. For example, in optimization, there are two objectives: maximizing quality by minimizing the investment costs of building a ship. In nontrivial optimization problems, no singular solution that simultaneously affects the other objectives is obtained; in such cases, the objective functions can conflict with each other. The solution is called nondominated if none of the objective functions can be improved in value without degrading some of the other objective values. In the second stage, multi-objective shape optimization was carried out using simulation methods using computer-aided engineering by MAXSURF (Version 20, Bentley System Inc. Exton, USA) and will be executed in future research using CAESES (Priftis et al., 2020). The design concept that was optimized in the early stages consisted of ship hull modeling so that it could be processed in software. Based on the reference design concept, a baseline model was created for an initial reference, which was used for the optimization process in the next stage. With the help of optimization applications, simulations were made to modify the shape of the ship's hull according to the optimization algorithm, in which the process will be carried out repeatedly and generate multiple hull model iterations. To obtain the Pareto design, the evaluation of the model was calculated repeatedly to obtain the most optimal ship size ratio. Optimization of the shape of the hull was done by making an initial model of the hull using MAXSURF; the baseline model itself was a ship model that was being developed in the feasibility study process and FEED for SSLNGC operations in Indonesia. In the process of drafting the ship design concept, optimization was carried out with a value engineering approach, where the ship design considered the needs and minimum operational requirements to increase the value/price with the same investment value.

The baseline model was optimized again using MAXSURF, and multi-objective optimization variables, parameter constraints, and objectives were defined in the simulation software along with the hull model. MAXSURF was used to simulate the shape optimization of the ship's hull by performing several iterations and automatic parametric shape transformations. In this earlier experiment, the optimization process used multi-objective optimization as a basic principle and was developed using genetic algorithms in future research with the help of CAESES software, which provides features of the multi-objective optimization algorithm (NSGA-II, MOGA, and others). Information on design variables, constraints, and objectives was set and input into the simulation. The results of the multiobjective optimization determined the Pareto frontier of the design. After the optimization simulation of the hull was completed, the Pareto diagram was obtained from the simulation results and algorithms (Ŝcap et al., 2013). In addition to calculating the optimization, the hull shape was also improved, so the optimal objective value was obtained from the improved model.

3. Results and Discussion

3.1. Design Concept and Base Model

The base model was based on the LIQUEFIED GAS CARRIER 5000 LNG STANDARD design standard as the initial reference for the design concept, which was optimized using value engineering. The initial design model used was chosen not only because the design concept was already in the research stage for FEED but also because several base models to improve the carrying capacity of 5000 CBM have been studied for SSLNGC and might be the standard market size. A such, the size of the 5000 CBM is most suitable for the needs of the FEED study and the retrofitted dual-fuel engine conversion is visible using boil-off gas (Pamitran et al, 2019). The specifications and general arrangements of the developed ship show the components of the location of the LNG tank, machinery, and equipment of the ship, following the needs of the study.

Figure 3 Base model hull geometry

Table 1 Base model ship's particulars

Dimension and Specification	Amount	Unit
Length overall	99.90	m
Beam molded	15.9	m
Depth	10.8	m
Draught	5.65	m
Cargo payload	5000	CBM
Speed	13	Knot
Thruster	400	kW
Estimated total resistance	317.9	kN
Hull shell area	3195.988	m^2

3.2. Combined Optimization

3.2.1. Stage 1. LNG carrier design optimization concept: Function analysis stage in value engineering

In the early stages of value engineering analysis, the experiment focused on optimizing the hull. Specifically, value engineering optimization focuses on minimizing fewer essential components. At the initial stage, the value engineering approach was carried out by estimating the construction cost of the hull shell in the initial design, so the construction costs were obtained before optimization. The initial hull model line had already been rendered (Figure 4) according to the initial hull model. The numerical calculation of the initial total resistance at speed 13 knots and the calculation of the total area of the outer hull shell were made. As a result, the exact calculation by MAXSURF for total resistance was approximately 317.9 kN, and the hull area was 3195,988 m^2.

In the initial process of value engineering, it is necessary to estimate the construction cost model or the material of the hull. Figure 4 is a cost model that explains the details of the costs of hull shell construction materials for each component (Fikri et al., 2020). The financial model representation of the costs is shown in Figure 4 and also describes a Pareto chart of the total construction costs of hull materials. Efforts to minimize costs and optimize the value of the external hull shell will contribute to most of the overall cost. After identifying the costs, it is necessary to analyze the function of each component, as described in Table 3. By using Equation 1, the cost per function was quantified as the value of a hull component. It is also important for a value study to have certain data, such as scope, list of constraints, risk management, design criteria, and various plans (as-built/detailed design/general plan), available before commencement of the study.

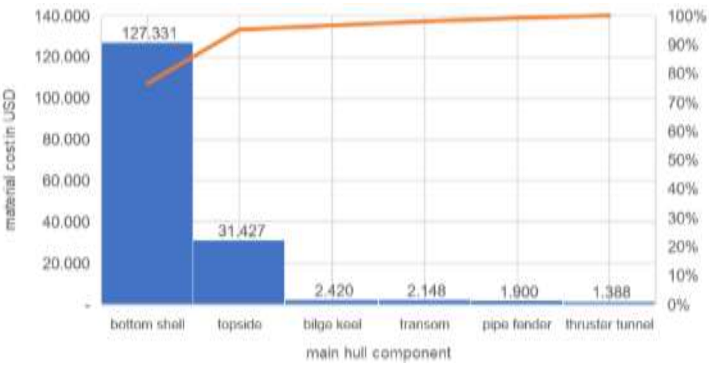

Figure 4 Pareto chart of hull shell material costs

Table 2 Estimated hull material costs

Item	Estimate cost (USD)	% of project cost
Outer hull shell	127.331	76.42
Hull topside	31.427	18.86
Hull transom stern	2.148	1.29
Appendages- bilge keel	2.420	1.45
Appendages- pipe fender	1.900	1.14
Bow thruster tunnel shell	1.388	0.83

To evaluate function analysis, we defined performance attributes to describe characteristics that can possess a range of values and to know what function the project must perform. In function analysis, some components that have the "BASIC" type are the most essential components of the hull skin structure and cannot be removed because of their function as the main watertight structure, but they can be modified to lower costs. However, components categorized as other than "BASIC" (required/secondary/etc.) can be eliminated or minimized depending on the defined essential level. Based on Table 3, each function can determine the components that can be eliminated for efficiency based on its classification. Efficiency can be achieved at the next stage of the creative phase.

Table 3 Cost per function analysis

Kinds: (B) Basic, (S) Secondary, (R) Required, (S) Secondary, (U) Unwanted
Worth: The higher score is worthier

function	kind	cost / % of total (USD)	worth / % of total	cost per function
outer hull shell below waterline	B (basic)	127.331	4	31.833
outer hull shell above waterline	B (basic)	31.427	4	7.857
transom area of hull	B (basic)	2.148	4	537
outer shell of thruster tunnel	S (secondary)	2.420	2	1.210
pipe fender in topside	R (required)	1.900	3	633
bilge keel	R (required)	1.388	3	463

The next stage is the creative stage. In this stage, all ideas and proposals related to cost efficiency are explained. Proposals are obtained from discussions and joint brainstorming sessions (Table 3) which are then evaluated quantitatively to see whether the idea or proposal has a Pareto function. Each idea and proposal also includes information on its advantages and disadvantages. The proposals and ideas that have been launched are then calculated for the estimated potential costs that can be reduced. Table 4 indicates the estimated deductible costs contributed by brainstorming ideas and recommendations for cost reduction. The analysis is continued by estimating the life-cycle costs. However, the life cycle cost analysis in this experiment will focus more on the value of the investment/one-time expenditure. Related operational/maintenance costs are assumed to not affect life-cycle costs. After value analysis, the evaluation phase is conducted on the number of creative ideas to get a shortlist of ideas with the greatest potential to improve the project and achieve the cost-reduction goal. A conscious effort was made to prohibit any judicial thinking to avoid inhibiting the creative process. In the evaluation phase, the ideas produced are critically appraised. The ideas for acceptance are based on performance information from the Information Phase and functional requirements determined in the Function Analysis Phase. The sum of all development acquisition, production or construction, operation, maintenance, use, and disposal costs for a product or project over a specified period are calculated. The ranking technique allows evaluators to assign numerical ratings to the alternatives. This process might start by judging an excellent idea to be worth four points; a fair idea, three points; a poor idea, two points; a very poor idea, one point. Next, all 4-point ideas are grouped and further evaluated. Paired comparison analysis is a good way to weigh the relative importance of different courses of action. It is useful when priorities are not clear or competing in importance. The tool provides a framework for comparing each course of action against the others and helps show the difference in importance between factors. Life cycle cost is conducted when project alternatives that fulfill the same performance requirements but differ from initial costs and operating costs have to be compared to select the one that maximizes net savings.

Table 4 Cost avoidance estimates after innovative brainstorming

Idea/ recommendation	Element			Original design		Proposed design	
	Item	units	unit cost (USD)	# unit	Total (USD)	# unit	Total (USD)
Remove thruster tunnel	Bow thruster tunnel shell	1	- 1.388	1	1.388	1	-
Parallel middle body in midship	Outer hull shell	1	- 4.404	1	127.331	1	122.927
	Hull topside			1	31.427	1	31.427
	Hull transom stern			1	2.148	1	2.148
	Appendages—bilge keel			1	2.420	1	2.420
	Appendages—pipe fender			1	1.900	1	1.900
				total	166.613	total	160.821
						cost avoidance	5.792

The selected ideas are developed into recommendations that are written so that the owner and other project stakeholders understand the intent of the recommendation and how it benefits the project. Write-ups also identify any potential negative factors associated with the recommendations. The recommendation should include text, sketches, diagrams, assumptions, supporting calculations, vendor information, cost comparison worksheets and other information that may be necessary to convey the intent of the recommendation. The text should also identify other alternatives that may be enhanced or complemented by the acceptance of a recommendation. The last stage is the implementation phase to execute any changes from the value engineering study. The objective of the implementation activities of the job plan is to ensure that accepted value alternatives are implemented and that the benefits projected by the value study can be realized. Following the delivery of the value study preliminary report, management and the project team should consider and agree upon the value alternatives to be implemented, and then how and when the implementation will occur. In some instances, additional studies and information may be required. The implementation of alternatives is the responsibility of management, with assistance from the project and value teams.

To summarize all the results of the value engineering that were carried out, Table 4 shows the cost engineering proposal and the cost differences between the original design and the proposed design. Value engineering efforts can contribute to cost optimization by 3.5%. The creative phase is the fun part of the job plan, as it involves gathering ideas and bringing up as many ideas as possible.

After obtaining the results of optimization using value engineering, we made a hull model according to the results of the study.

3.2.2. Multi-objective optimization

The 3D hull modeling was made using MAXSURF according to the design optimized in Stage One. The model was made starting from the main hull and appendages and did not include the rudder and propellor. In the hull shape validation stage, a simulation model was created to see whether the estimated ship resistance followed the estimated propulsion engine power. Then, another test was carried out to estimate the weight of the ship's steel as the initial value of the optimization objective. Figure 3 shows the rendered model of the base model, which was modified for optimization. After making the hull model, the parameters that will be used as input in the optimization process, objective functions, variables, and constraints were defined in advance, according to Table 5 below.

In this experiment, following the objectives, the objective of optimization was to minimize costs and ship resistance. These two objectives are represented by optimizing the shape of the ship to obtain the smallest possible hull surface area with the smallest possible total ship resistance prediction. To obtain this value, a simulation was carried out by modifying the length/beam (L/B) ratio of the ship. Based on the design variables and constraints that were determined, it was necessary to identify the initial variables in the original design, as shown in Table 5.

Table 5 Model parameter, objective, and objective set for optimization

Optimization Constraints	Value
Maximum ship draught (m)	5.65 meters
Displacement (ton)	6224 tons
Speed (knot)	13 knots

Optimization Variables	Min. value	Max. value
Dimension ratio L/B	5.24	6.24

Objective Values	Base Model
Total resistance	326.1 kN
Hull shell area	3174.127 m^2

In the initial stage in evaluating and estimating ship resistance, which was carried out using MAXSURF, slender body analysis was chosen as the resistance calculation method because it was suitable following the calculated ship type (displacement ship) and could be used as an estimation method because in this experiment, it was still in the early stages of estimation. The calculation of the hull area was also obtained using MAXSURF®. The variation that was simulated in the model was to modify the length and width of the ship as independent variables. The initial stage was to determine the variation in the length of the ship because practical variations can be modified more easily. After all, the length of the ship can be added/reduced according to the distance of the construction frame. In this experiment, it was assumed that the length variation in the hull model was every 500 mm. The width of the ship was calculated based on a fixed variable/constraint (ship width, displacement, and block coefficient), so that the width of the ship and the L/B ratio of each modification of the hull were obtained. Figure 5 is the resulting Pareto chart for multi-objective optimization between ship resistance and hull shell area.

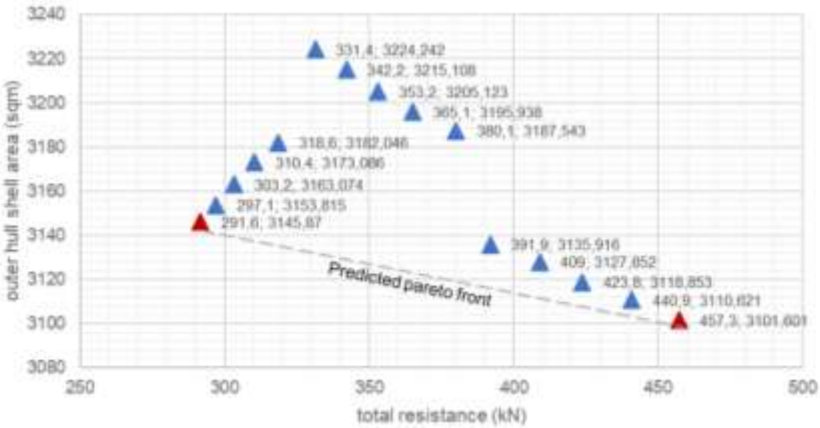

Figure 5 Estimated Pareto optimal front between resistance and hull area

After summarizing the two optimization processes, the results show that by using the two-stage optimization process, each stage contributed to reducing the construction costs of the ship. In the engineering stage, the optimization value was obtained by eliminating components that were less or not essential. Then, multi-objective optimization was carried out by simulating the calculation of the hull area and estimating ship resistance. The simulation was carried out with repeated iterations, and a calculation of the hull area and resistance for each iteration was carried out. All of these results were mapped into a Pareto diagram so that the most appropriate iteration number was obtained, and the minimum resistance value and surface area were obtained. Figure 6a and 6b describe the relationship between the L/B modification effect on total hull resistance and hull shell area.

Table 6 Comparison between base model and improved model after the two-stage optimization process

Objective values	Base model	Value optimization model	Non-dominated solution 1 (model 10)	Non-dominated solution 2 (model 15)
Total resistance	317.9 kN	326.1 kN	291.6 kN	457.3 kN
	relative efficiency	-2.6%	8.3%	-43.9%
Hull Shell area	3195.988 m^2	3174.127 m^2	3145.87 m^2	3101.601 m^2
	relative efficiency	0.68%	1.57%	2.95%

In the initial identification of iterations, 6^{th} to 10^{th} tended to have a smaller value of ship resistance to form its cluster compared to other iterations. The difference is due to the form factor (1+k) in the calculation of the Holtrop method (Birk, 2019) because the difference in the ratio will affect the provisions of the form factor calculation. Based on the results of optimization in Table 6, it was found that iteration model number 10 had the most optimal design. Number 10 was chosen as the first optimal option because it has the smallest ship resistance. However, model number 10 was not the model that had the smallest hull shell area. Meanwhile, model number 15 had the smallest hull area but the largest resistance value and a significantly larger difference than the base model, so model 15 was not an optimal alternative design option. Those model iterations, 10th and 15th, were concluded as non-dominated solutions. Non-dominated solution model number 10 was the best solution because both total resistance and hull shell area were more efficient.

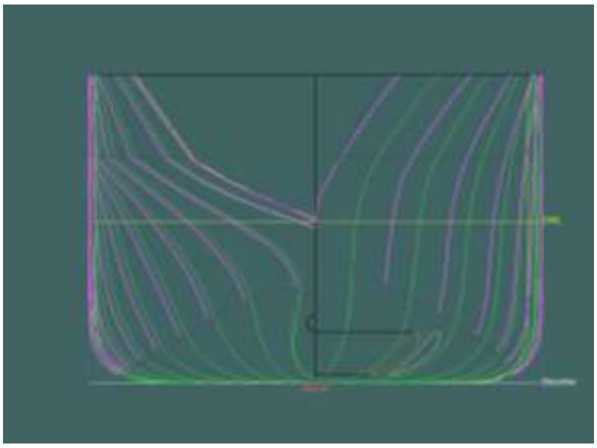

Figure 6 Final optimized hull model (magenta line) compared to the base model (green line)

The smaller the L/B ratio, the smaller the hull area, and the lower the cost of ship construction. This is due to a very significant change in the length of the ship, but the change in the width of the ship is very small, with an average decrease of 500 mm in ship length, which is equivalent to a 100 mm increase in the width of the ship. This phenomenon can be simplified by imagining a block that has the same volume but a different length and width; of course, the surface area of the block will be different. Overall, the engineering design concepts and details were optimized. Global optimization, with a review of literature studies, resulted in the optimization of construction material costs. Table 6 shows the results after optimization of shape and value. Each final solution was a non-dominated solution model. The two models have significantly different ship lengths but still have the same volume and displacement, which, of course, become a constraint in the optimization objective function.

4. Conclusions

The experiment showed that the size ratio significantly affected ship resistance. This could also be proved by a common ship resistance empirical calculation. With a combination of shape optimization and value engineering, the methodology can optimize SSLNGC design to the optimal level from the conceptual design to the detail process. This optimization study can be applied commercially because this methodology only uses commercial software without advanced research tools. As a result of the improved design, the propulsion efficiency improved as total resistance was decreased by 8.3% and hull surface area was reduced by 1.57%. An economic study of the optimized design (estimated reduction in investment costs and propulsion costs) was conducted in this experiment.

Combining value engineering and optimization can be practically done, and the combination of the two processes has an impact on the efficiency of ship production costs and total ship resistance. Both the combination and each optimization process contributed to increased efficiency. By modifying the ship's L/B ratio, the total ship resistance was reduced. In line with this, the optimal hull shell area was also obtained.

The research process is still in its early stages. In future research, we will continue to integrate the results of total resistance using CFD software to get a more precise estimate of ship resistance and to validate empirical calculations. In addition, to sharpen the results of the optimization of the shape of the hull ratio in the future, more comprehensive methods such as MOGA/NSGA II can be used as optimization algorithms, and the optimization will use CAESES® for numerical computations. This combination can not only be used for construction and transportation projects, but for marine and offshore projects, as has been done in this study. In the future, this research will be developed not only from the ship's hull components but also holistically from the entire system and machinery in the ship (cargo tanks, fuel selection, boil-of-gas treatment plant, etc.).

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