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Cost Optimization of Formwork Using Value Engineering Techniques in Building Projects

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Abstract

Formwork is a temporary mold for concrete that shapes the concrete during the casting process until it reaches the desired strength according to standards. In addition to considering strength and ease of use, it is also important to consider the cost of formwork to make it more economical. This study analyzes costs using value engineering techniques, where traditional formwork methods are often inefficient due to the use of heavy materials and time-consuming installation processes, which lead to high labor costs and extended project duration. Based on these issues, this study highlights the problem of high formwork costs in building construction projects and seeks to find and recommend more cost-efficient methods without compromising the quality or functionality of the building structure. The results of the structural analysis comparison between conventional formwork and the full system, initially using conventional formwork, are processed using a full system alternative. This alternative was tested on column, beam, and floor slab formwork. Therefore, it is recommended for this project to replace column, beam, and floor slab formwork due to the high costs. In this analysis, savings were achieved by using the full system formwork, which saved 72% on beam formwork, 64% on column formwork, and 73% on floor slab formwork per square meter.

1. Introduction

Construction management is essential in ensuring that building projects are completed efficiently, on time, and within budget [1]. Effective project management requires careful planning and scheduling, both of which are critical to overcoming challenges in the construction industry, such as rising competition and the demand for faster, more cost-effective building methods [2,3]. As globalization advances, the construction industry must continuously evolve, adopting innovative practices to meet increasing demands for quality and efficiency [4,5].

One of the major challenges in modern construction, particularly in concrete work, is the effective use of formwork [6'7]. Formwork is a temporary structure that supports wet concrete until it hardens and can support itself [8]. This component is crucial, yet it accounts for a significant portion of construction costs—approximately 20-25% of the total cost [9,10]. Traditional formwork methods, often involving materials like wood, steel, and aluminum, are labor-intensive and time-consuming [11]. These methods can lead to inefficiencies in both time and cost, especially in large-scale projects where the repetition of formwork tasks is frequent[12,13].

In response to these challenges, new formwork systems have been developed, offering improved efficiency and cost-effectiveness [14,15]. Modern formwork systems, such as prefabricated and reusable forms, allow for faster assembly and disassembly, reducing labor costs and construction time [16]. However, despite these advancements, many projects continue to struggle with high costs due to inadequate planning and inefficient use of resources [17,18].

The research focuses on the structural work of a specific case study—the construction of the Psychology Building. This project is chosen due to its potential for cost optimization through VE techniques. By applying these methods, the study will demonstrate how careful selection and management of formwork can lead to significant cost savings without compromising the quality or functionality of the structure. The ultimate goal is to provide insights and recommendations that can be applied to future construction projects, particularly in Indonesia, where knowledge and implementation of VE are still limited. This research will contribute to improving the efficiency and effectiveness of construction management practices, particularly in the use of formwork in concrete structures.

2. Method

This research adopts a qualitative research methodology with a focus on building structures. The post-positivist observation method used falls into the category of qualitative methods [19]. Qualitative observation aims to recognize and respond to quality aspects that cannot be measured, such as feelings, ideas, experiences, and other factors [20]. In this method, the observer acts as the primary instrument in observing the natural conditions of the objects. Characteristics of qualitative research include data triangulation (a mix of various sources), inductive data analysis, intentionally selected data sampling, and an emphasis on meaning rather than generalization.

After the information collection process, the data is compiled to determine which parts of the work incur the highest costs. Analysis using the Pareto diagram is performed to determine if value engineering can be applied, which is then used to address the cost model. The results of the Pareto analysis show that the majority of project costs are allocated to key tasks, accounting for more than 80% of the total effort; in this case, value engineering experts are asked to find solutions for these high-cost tasks. Specifically, replacing original materials with more economical and faster alternatives is done without compromising the strength or quality of the structure. The replacement selection process involves collaboration with field practitioners; once several alternatives are identified, the cost of the selected replacement will be determined. In this study, we will analyze value engineering in formwork jobs in multi-story building construction projects because the costs of structural work involved in formwork are significant and can be optimized to reduce overall project costs. Below is the location map of the research object in Fig. 1.

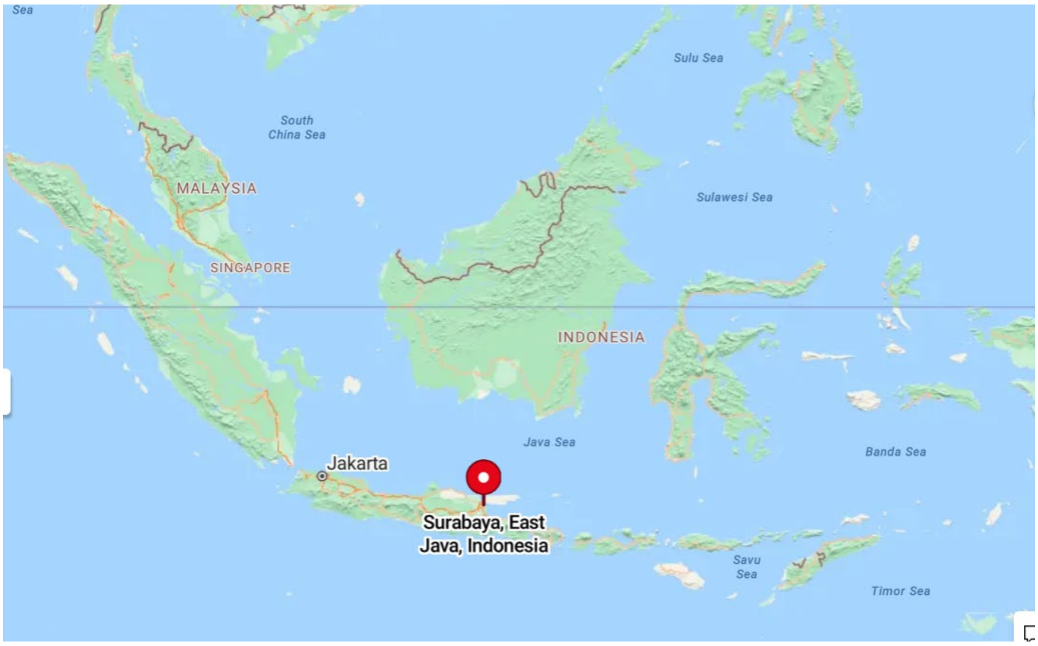

Fig. 1 *Research location*

3. Result and Discussion

In Surabaya, a building is currently under construction designed to meet students' classroom needs. The construction of this building involves the use of foundation piles or pillars, while its upper structure is made of solid concrete. The classroom bathroom design utilizes homogeneous tiles that can be customized to fit the room's size on each floor. For the interior walls, bright-colored bricks resistant to color changes are chosen. The doors used are products of engineering techniques, and the windows are equipped with aluminum frames and laminated glass. The contractor is responsible for various mechanical, electrical, architectural, and structural tasks. The total cost of this project is IDR 54,486,553,772.93. Table 1 displays the budget plan.

Table 1 *Recapitulation of the budget plan*

Works Description	Cost (IDR)
Structural Works	23,093,239,224.06
Architectural Works	18,891,521,349.99
Mechanical and Electrical Works	12,501,793,198.88
TOTAL	54,486,553,772.93

3.1 Eligibility Test for Value Engineering Implementation

Value engineering is used in building projects where there is a possibility of cost savings if the job is completedand has a significant financial contribution. After calculating and comparing the task cost weights, it was found that structural work carries the highest cost weight, accounting for 39.00%. A comprehensive breakdown of the cost weights assigned to each activity can be found in Table 2.

Table 2 *Cost weight summary*

Works Description	Weight (%)	Cost (IDR)
Structural Works	42%	23,093,239,224.06
Architectural Works	35%	18,891,521,349.99
Mechanical and Electrical Works	23%	12,501,793,198.88
TOTAL	100%	54,486,553,772.93

The next stage is to perform an eligibility test for value engineering applications, which include (1) Pareto diagram analysis and (2) cost resolution model, after recapitulating the job cost weight. Out of all the work, structural work is the most expensive. The next step is to list structural work according to building costs, starting with the most expensive work in Table 3 and working down to the least expensive work.

Table 3 *Structural work recapitulation*

Works Item	Cost (IDR)	Total Cost Component Presentation
Slab	5,581,210,482.86	33%
Beam	3,602,154,123.46	22%
Column	3,231,396,623.27	19%
Foundation	1,901,627,839.47	11%
Hallway	1,172,358,013.96	7%
Stair	892,177,283.96	5%
Lift & Dog House	335,887,164.34	2%
Total	16,716,811,531.32	100%

Based on the preceding summary, the three biggest jobs will be taken on since they have the potential to result in savings, as shown by Fig. 2 Pareto model for structural work

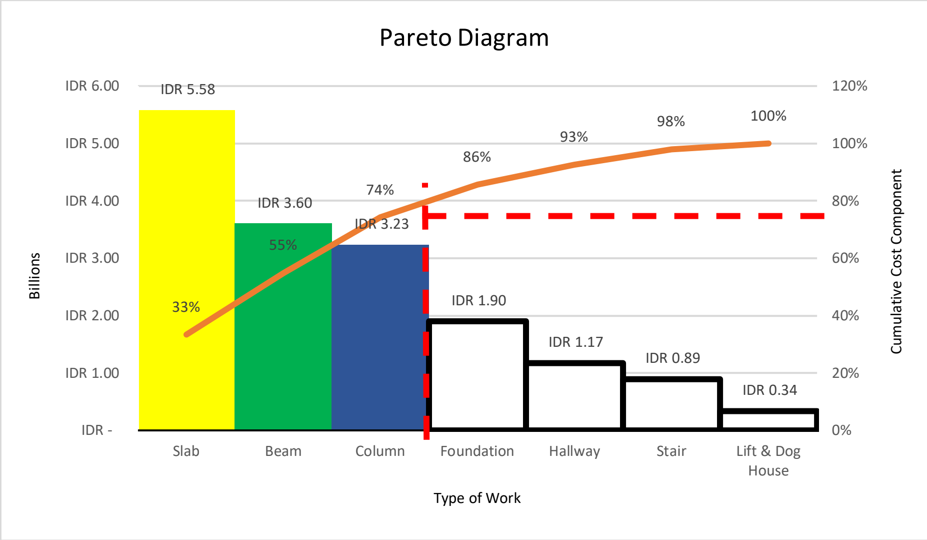

Fig. 2 *Pareto diagram*

In the diagram above, the x-axis represents the work items of the research project object, while the y-axis represents the amount of costs incurred for each work item. The work item to be examined is the work item that falls within the 20% of work items that contribute the largest costs to the total overall costs of the parabolic structure work. The Pareto line is this line; from this line, a straight line will be drawn based on the cumulative cost percentage of each work item, indicating which work items, when analyzed through value engineering, will yield the optimal percentage of savings.

The results of the Pareto diagram come from work on beams, floor slabs, and columns, which are costly tasks. Therefore, a material replacement is necessary to reduce costs. However, among these three tasks, the focus will be on the replacement of the column formwork method.

3.2 Conventional Column Formwork Analysis

The unit prices in Table 4 come from the initial price analysis used in the Psychology Building construction project. The analysis cost is IDR 180,140, and this formwork can be used twice.

Table 4 *Unit price of conventional column formwork*

Material	Koef	Unit	Unit Price (IDR)	Quantity (IDR)
Pinewood	0.045	m3	3,900,000	175,500
Nail	0.400	Kg	22,000	8,800
Formwork Oil	0.200	L	21,000	4,200
Plywood 9 Mm	0.035	Lbr	221,000	7,735
Volume Of Ingredients				196,235
For 2 X Used				98,117.50
Wages :				
The Workers	0.300	Oh	125,000	37,500
The Carpenters	0.150	Oh	135,000	20,250
The Captains	0.015	Oh	140,000	2,100
The Men	0.015	Oh	145,000	2,175
Number Of Workers				62,025
Tools :				
Scafollding	1.000	Ls	20,000	20,000
Quantity Of Equipment				20,000
Quantity Of Material + Workers+Tools				180,142.50
Rounded				180,140

3.3 Full System Column Formwork Analysis

In the full system formwork Table 5, only the material from the conventional formwork, which initially used plywood and nails, was replaced with peri lico, resulting in an analysis cost of IDR 65,340, and this formwork can be used 10 times. From the above analysis, the percentage savings obtained are shown in Fig. 3.

Table 5 *Unit price of full system column formwork*

Material	Koef	Unit	Unit Price (IDR)	Quantity (IDR)
Formwork Oil	0.2000	ltr	15,000	3,000
Volume Of Ingredients				**3,000**
Wages :				
The Workers	0.0070	Oh	125,000	875
The Carpenters	0.0760	Oh	135,000	10,260
The Captains	0.0080	Oh	140,000	1,120
The Men	0.0010	Oh	145,000	145
Number Of Workers	**0.0070**			**12,400**
Tools :				
PERI Lico	1.0000	m2	499,486	499,486
For 10 X Used				49,949
Quantity Of Equipment				**49,949**
Quantity Of Material + Workers+Tools				**65,349**
Rounded				**65,340**

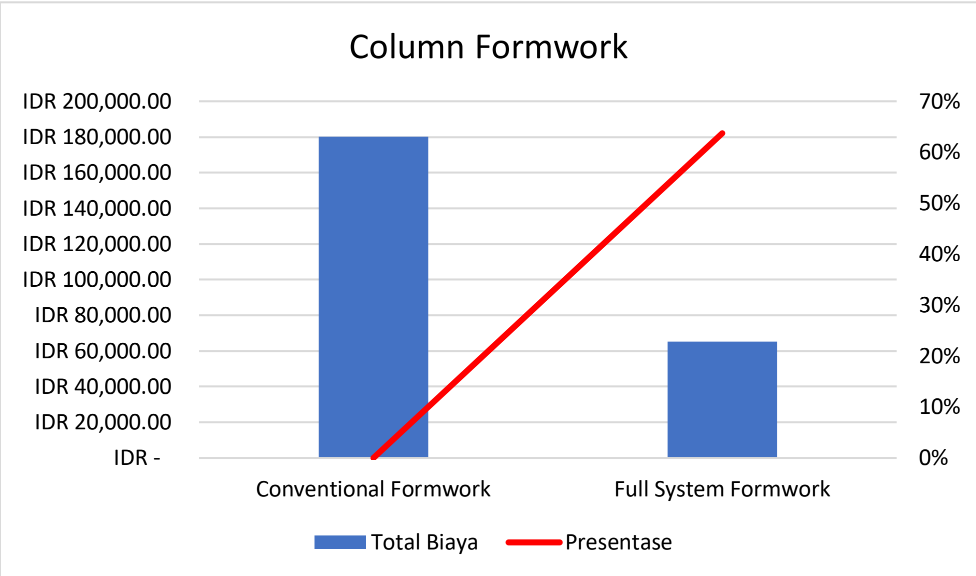

Fig. 3 *Column formwork savings percentage*

From the analysis above, the percentage of savings shown in Fig. 3 is 64%, amounting to IDR 114,800. These savings are primarily due to lower analysis costs for Peri Lico formwork and its longer lifespan, which reduces the need for regular analysis and replacement of new formwork. Although there may be higher initial costs for Peri Lico, long-term savings are achieved through reduced recurring analysis costs and less frequent formwork replacement.

3.4 Conventional Beam Formwork Analysis

The unit prices in Table 6 come from the initial price analysis conducted for the Psychology Building project, which cost IDR 220,800, and this formwork can be used twice.

Table 6 *Unit price of conventional beam formwork*

Material	Koef	Unit	Unit Price (IDR)	Quantity (IDR)
Pinewood	0.048	m3	3,900,000	187,200
Nail	0.400	Kg	22,000	8,800
Formwork Oil	0.200	L	21,000	4,200
Plywood 9 Mm	0.350	Lbr	221,000	77,350
Volume Of Ingredients	**0.998**			**277,550**
For 2 X Used				**138,775**
Wages :				
The Workers	0.300	Oh	125,000	37,500
The Carpenters	0.150	Oh	135,000	20,250
The Captains	0.015	Oh	140,000	2,100
The Men	0.015	Oh	145,000	2,175
Number Of Workers	**0.300**			62,025
Tools :				
Scafollding	1.000	Ls	20,000	20,000
Quantity Of Equipment				20,000
Quantity Of Material + Workers+Tools				**220,800**
Rounded				**220,800**

3.5 Full System Beam Formwork Analysis

The full system formwork in Table 7 only changes the material from the conventional formwork, which initially used nails and plywood. This material is replaced with peri lico, resulting in an analysis cost of IDR 62,770, and this formwork can be used 10 times. The percentage savings obtained from the above analysis are shown in Fig. 4.

Table 7 *Unit price of full system beam formwork*

Material	Koef	Unit	Unit Price (IDR)	Quantity (IDR)
Formwork Oil	0.2000	ltr	21,000	4,200
Volume Of Ingredients				**4,200**
For 10 X Used				**420**
Wages :				
The Workers	0.0070	Oh	125,000	875
The Carpenters	0.0760	Oh	135,000	10,260
The Captains	0.0080	Oh	140,000	1,120
The Men	0.0010	Oh	145,000	145
Number Of Workers	**0.0070**			**12,400**
Tools :				
PERI Lico	1.0000	m2	499,486	499,486
For 10 X Used				49,949
Quantity Of Equipment				**49,949**
Quantity Of Material + Workers+Tools				**62,769**
Rounded				**62,770**

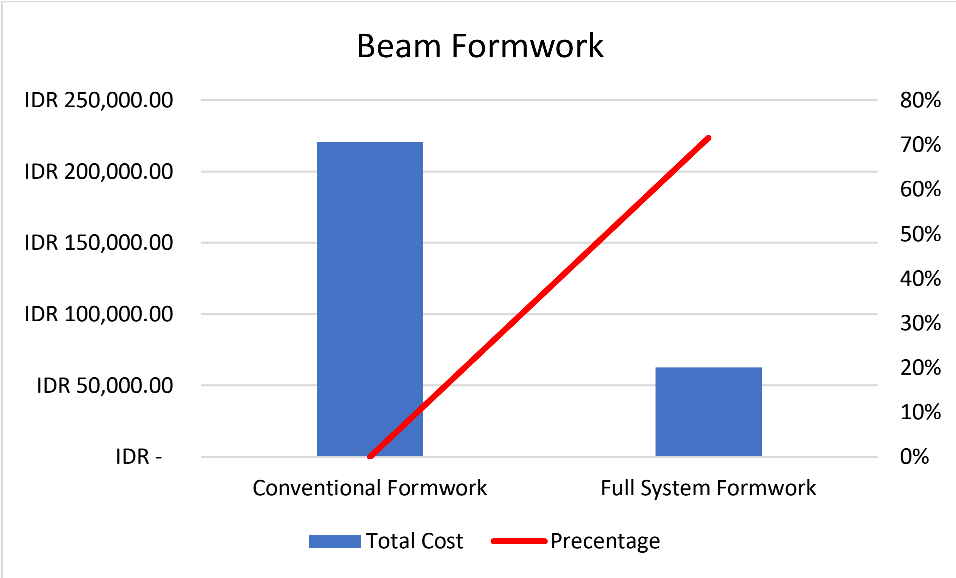

Fig. 4 *Beam formwork savings percentage*

From the analysis above, the percentage of savings shown in Fig. 4 is 72%, amounting to IDR 158,030. These savings are mostly attributable to Peri Lico formwork's longer lifespan and lower analysis expenses, which lessen the requirement for routine analysis and the replacement of new formwork. Long-term savings are realized by lower recurrent analytical costs and less frequent formwork repair, even if Peri Lico may have greater startup expenses.

3.6 Conventional Slab Formwork Analysis

The unit prices in Table 8 come from the initial price analysis conducted for the Psychology Building project, which cost Rp. 234,950, and this formwork can be used twice.

Table 8 *Unit price of conventional slab formwork*

Material	Koef	Unit	Unit Price (IDR)	Quantity (IDR)
Pinewood	0.045	m3	3,900,000	175,500
Nail	0.400	Kg	22,000	8,800
Formwork Oil	0.200	L	21,000	4,200
Plywood 9 Mm	0.350	Lbr	221,000	77,350
Volume Of Ingredients				**265,850**
For 2 X Used				**132,925**
Wages :				
The Workers	0.300	Oh	125,000	37,500
The Carpenters	0.150	Oh	135,000	20,250
The Captains	0.015	Oh	140,000	2,100
The Men	0.015	Oh	145,000	2,175
Number Of Workers	**0.300**			62,025
Tools :				
Scafollding	1.000	Ls	40,000	40,000
Quantity Of Equipment				**40,000**
Quantity Of Material + Workers+Tools				**234,950**
Rounded				**234,950**

3.7 Full System Beam Formwork Analysis

The full system formwork in Table 9 only changes the material from the conventional formwork, which initially used nails and plywood. This material is replaced with peri lico, resulting in an analysis cost of Rp. 62,760, and this formwork can be used 10 times. The percentage savings obtained from the above analysis are shown in Fig. 5.

Table 9 *Unit price of full system slab formwork*

Material	Koef	Unit	Unit Price (IDR)	Quantity (IDR)
Formwork Oil	0.2	ltr	21,000	4,200
Volume Of Ingredients				**4,200**
For 10 X Used				**420**
Wages :				
The Workers	0.0070	Oh	125,000	875
The Carpenters	0.0760	Oh	135,000	10,260
The Captains	0.0080	Oh	140,000	1,120
The Men	0.0010	Oh	145,000	145
Number Of Workers	**0.0070**			**12,400**
Tools :				
PERI Lico	1.0000	m2	499,486	499,486
For 10 X Used				49,949
Quantity Of Equipment				**49,949**
Quantity Of Material + Workers+Tools				**62,769**
Rounded				**62,760**

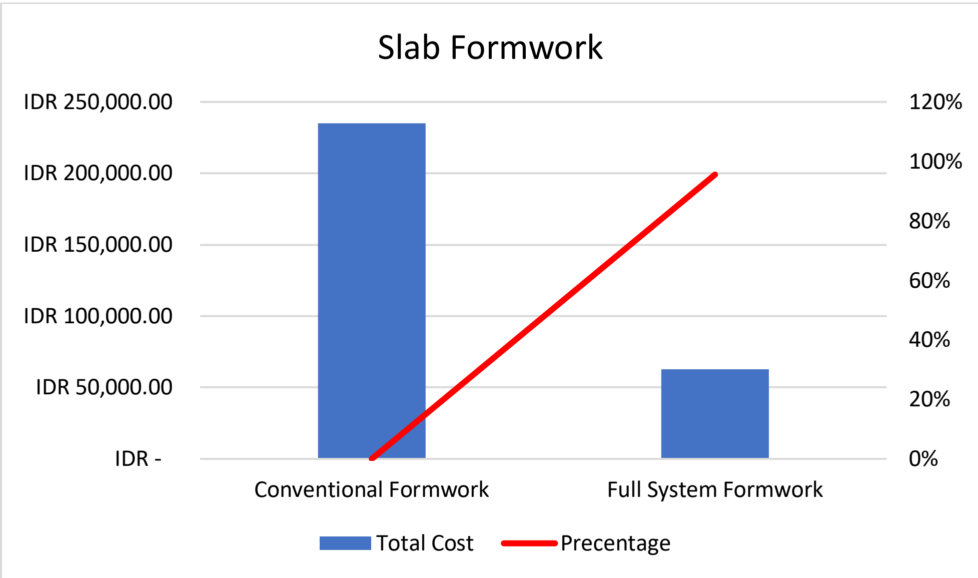

Fig. 5 *Slab formwork savings percentage*

Based on the preceding research, Fig. 5 displays a 96% savings percentage, or IDR 172,190. The main cause of these savings is the longer lifespan and lower analysis costs of Peri Lico formwork, which lessens the requirement for routine analysis and the replacement of new formwork. Peri Lico may have greater upfront expenses, but over time benefits are realized by lower recurring analytical costs and less frequent formwork repair.

4. Conclusion

The conclusion from the analysis above is that full system formwork provides significant cost savings compared to conventional formwork across all types of formwork, namely columns, beams, and slabs. In column formwork, the use of full system formwork reduces costs by 64%, from Rp. 180,140/m^2 to Rp. 65,340/m^2. Meanwhile, in beam formwork, the savings reach 72%, lowering costs from Rp. 220,800/m^2 to Rp. 62,770/m^2. The largest savings are observed in slab formwork, where full system formwork can reduce costs by up to 73%, from Rp. 234,950/m^2 to Rp. 62,760/m^2. Although there may be higher initial investment costs for full system formwork, the significant cost savings in the long run, especially for large construction projects, make it an attractive option.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper and confirm that there are no personal, financial, or professional interests that could influence or bias the research results or conclusions presented in this paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Muhammad Lawdy D.V.;* ***Data collection:*** *Sekar Ayu K., Dayat Indri Yuliastuti;* ***Analysis and interpretation of results:*** *Muhammad Lawdy D.V., Wisnu Abiarto N.;* ***Draft manuscript preparation:*** *Sekar Ayu K., Maulidya Octaviani B., Dayat Indri Yuliastuti. All authors reviewed the results and approved the final version of the manuscript.*

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