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THE 3rd INTERNATIONAL CONFERENCE ON AGRICULTURE, ENGINEERING, SOCIAL SCIENCE AND EDUCATION (ICAESSE) 2026
TEMA: SUSTAINABLE TECHNOLOGY AND INTEGRATING ARTIFICIAL INTELLIGENCE (AI)

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FINITE ELEMENT STUDY THE BEHAVIOR OF GREEN SELF-COMPACTING CONCRETE PROFILED STEEL SHEET SLAB WITH BUILT-IN SHEAR CONNECTOR UNDER FLEXURAL LOADING

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Abstract

The use of sustainable materials such as palm oil fuel ash (POFA) and eggshell powder (EP) in construction has gained popularity due to the global push for environmentally friendly and cost-effective building practices. However, there is still a lack of comprehensive research on green self-compacting concrete, especially in composite slabs with built-in shear connections. This study examined the behavior of green self-compacting concrete profiled steel sheet slabs with built-in shear connectors under flexural loading. To analyze this, the study used finite element analysis with ABAQUS/Explicit software. The results were validated by comparing them with the experimental findings of Kamaruddin. The study found that composite slabs with different shapes of built-in shear connectors did not perform as well as those with v-shaped connectors, which showed better structural behavior. Overall, using green self-compacting concrete composite slabs with V-shaped built-in shear connectors appears to be the most economical and efficient choice for construction. It is worth noting that the construction sector is moving towards more sustainable practices and the use of recycled materials such as POFA and eggshell powder can help reduce waste and improve the quality of buildings. By understanding how these materials behave in different structures, we can create more efficient and environmentally friendly buildings. The study's findings can be useful for construction companies and architects seeking to incorporate sustainable materials into their designs. From a technical perspective, the finite element analysis method used in this study allowed for a detailed examination of the structural behavior of the composite slabs. The validation process ensured that the results were accurate and reliable in this study. The parametric study provided valuable insights into the effects of the different shapes of built-in shear connectors on the performance of composite slabs. Overall, this study contributes to the growing body of research on sustainable construction materials and practices. As the world continues to urbanize and the demand for buildings and infrastructure grows, it is essential to develop more environmentally friendly and cost-effective construction methods. The use of green self-compacting concrete and recycled materials, such as palm oil fuel ash and eggshell powder, can play a significant role in achieving this goal.

Keywords: Green Self-Compacting Concrete; Composite Slab; ABAQUS/Explicit; Built-In Shear Connector; Finite Element Analysis

INTRODUCTION

In recent years, Malaysia has placed increasing emphasis on sustainable building practices by implementing innovative materials in construction, such as self-compacting concrete (SCC) and green self-compacting concrete (GSCC), to promote sustainable construction despite challenges such as the disposal of industrial by-products (Hashim & Tay, 2023). Self-compacting concrete, often referred to as self-consolidating concrete, is a high-fluidity concrete discovered and proposed by Professor Hajime Okamura at the University of Tokyo in the 1980s (Wang et al., 2023). Mineral admixtures, such as silica fume, limestone powder, fly ash, ground-granulated blast furnace slag, and superplasticizers, are employed in addition to chemical admixtures to improve the strength, rheological, and durability properties of SCC (Devi et al., 2020). Moreover, SCC outperforms conventional concrete in terms of surface quality, longevity, and mechanical performance (Kashani & Ngo, 2020).

To promote environmentally friendly practices in the construction industry, GSCC has gained increasing attention because its materials and ingredients are predominantly eco-friendly and sourced from industrial by-products. Green SCC can be produced in various ways, including by incorporating supplementary cementitious materials and recycled aggregates (Sohrabi & Hoseini, 2023). Research has focused on blending industrial by-products, such as slag, as partial substitutes for cement and as coarse and fine aggregates in GSCC production (Gupta et al., 2021). Shear connectors are typically applied to facilitate the interaction between a concrete slab and a steel profile, and self-compacting concrete is ideal for use in such composite slab applications (Revathy et al., 2021).

The finite element method (FEM) can be used to perform finite element analysis (FEA) of various physical phenomena, including the structural behavior of GSCC composite slabs with built-in shear connectors under flexural loading. This method provides a flexible geometric description through non-uniform elements, making it suitable for complex structural simulations (Kuna, 2013). ABAQUS is a widely used finite element software applied for various engineering analyses, including simulating structural behavior under flexural loading and nonlinear phenomena, such as reinforced concrete behavior (Ceballes, 2023). The eight-node linear brick element (C3D8R) is commonly used for three-dimensional structural analysis in FEA, whereas the two-noded truss element (T3D2) is employed for transverse and longitudinal reinforcement bars (Cahyati et al., 2021).

This study aims to: (i) develop a finite element model of a Green Self-Compacting Concrete (GSCC) composite slab using ABAQUS/Explicit; (ii) analyze the presence of built-in shear connectors in steel sheeting in terms of ultimate strength and shear capacity; and (iii) perform a parametric study on the variation in the shape of built-in shear connectors using three-dimensional computational FEM. This study focuses on the computational modelling of GSCC composite slabs with built-in shear connectors subjected to flexural loading, a convergence study to determine the optimal mesh size, validation of results against previous experimental work, and a parametric study with varying connector shapes at a fixed spacing.

METHODOLOGY

A series of procedures was conducted to analyze the structural behavior of the GSCC composite model. The parameters for the simulation were obtained from the previous experimental work of Kamaruddin (2020). Using ABAQUS/Explicit, SCC and GSCC composite slabs were modelled, and a convergence study was conducted to determine the most appropriate mesh size. After validation, a parametric study was performed by varying the shape

of the built-in shear connector with a fixed spacing of 100 mm to determine the structural behavior of GSCC composite slabs in terms of ultimate load-carrying capacity, load-deflection profiles, crack pattern, and stress distribution.

2.1 Material properties

Kamaruddin (2020) adopted all the material properties used in this study from the previous experimental research. The GSCC composite slab comprised Ordinary Portland Cement (OPC), egg shell powder (ESP), Palm Oil Fuel Ash (POFA), sand, water, coarse aggregate, and superplasticizer. The details of the material properties used for the concrete are listed in Table 1. In terms of steel properties, the steel decks implemented in this composite slab were COMFLOR46 and COMFLOR80, with dimensions of 1800 mm in length and 600 mm in width, an area of 1276 mm^2/m, and a thickness of 0.9 mm. As specific steel properties were not provided by the source, the properties and plasticity of steel were based on the study conducted by Attarde (2014a, 2014b). The steel deck properties and plasticity are presented in Tables 2 and 3, respectively.

Table 1 Details of material properties used for concrete (Kamaruddin, 2020)

Concrete Properties	Value
Density	2400 kg/m^3
Young's Modulus for control specimen	26490 MPa
Young's Modulus for 5P 2.5E	31689 MPa
Poisson's Ratio for control specimen	0.17
Poisson's Ratio for 5P 2.5E	0.19

Note: P = POFA; E = ESP

Table 2 Steel deck properties (Attarde, 2014a)

Steel Sheeting Properties	Value
Density	7000 kg/m^3
Young's Modulus	230 GPa (2.30×10^{11} Pa)
Yield Stress	230 MPa (2.30×10^{8} Pa)
Poisson's Ratio	0.30
Plastic (Residual) Strain	0.2

Table 3 Plasticity of steel deck (Attarde, 2014b)

Yield Stress (MPa)	Plastic Strain (mm/mm)
230	0
251.3	0.000685
232.9	0.008125
313.2	0.093084
251.6	0.21

A 6 mm diameter steel bar was used in the GSCC composite slab. The properties of the 6 mm-diameter reinforcement bar are presented in Table 4, based on the study by Goh (2014). Note: Table 4 in the original manuscript is listed as Table 5; this has been renumbered for consistency. The compression and splitting tensile tests conducted by Kamaruddin (2020) were applied to determine the concrete damage plasticity. Tables 5 and 6 display the concrete damaged plasticity for the control specimen and for concrete with 5% POFA and 2.5%

Table 4 Properties of 6 mm diameter steel bar (Goh, 2014)

Properties of Steel Bar	Value
Density	7700 kg/m^3
Young's Modulus	200 GPa

Poisson's Ratio	0.30
Initial Yield Stress	359 MPa
Ultimate Yield Stress	374 MPa
Strain at Failure	0.0049

Table 5 Concrete damage plasticity of the control specimen (Kamaruddin, 2020)

Concrete Damage Plasticity			
Ψ	**ε**	**σ^{bo}/σ^{co}**	**Kc**
30	0.1	1.16	0.667
Concrete Compression Behavior		**Concrete Compression Damage**	
Yield Stress (MPa)	**Inelastic Strain (mm/mm)**	**Damage Parameter**	**Inelastic Strain (mm/mm)**
44.52	0	0	0
46.97	0.0008	0	0.0008
49.04	0.0016	0	0.0016
50.35	0.0024	0	0.0024
50.16	0.0033	0.03	0.0033
46.44	0.0044	0.39	0.0044
36.89	0.0058	0.63	0.0058
31.49	0.0070	0.74	0.0070
26.94	0.0082	0.81	0.0082
Concrete Tensile Behavior		**Concrete Tension Damage**	
Yield Stress (MPa)	**Cracking Strain (mm/mm)**	**Damage Parameter**	**Cracking Strain (mm/mm)**
3.92	0	0	0
3.66	0.0004	0.27	0.0004
3.39	0.0008	0.36	0.0008
3.13	0.0012	0.43	0.0012
2.87	0.0016	0.50	0.0016
2.62	0.0020	0.57	0.0020
2.38	0.0025	0.62	0.0025
2.11	0.0029	0.68	0.0029
1.89	0.0033	0.72	0.0033
1.65	0.0037	0.77	0.0037
1.43	0.0042	0.80	0.0042
1.21	0.0046	0.84	0.0046
1.00	0.0050	0.87	0.0050
0.81	0.0055	0.90	0.0055
0.63	0.0059	0.93	0.0059
0.45	0.0064	0.95	0.0064
0.28	0.0068	0.97	0.0068
0.13	0.0072	0.99	0.0072

Table 6 Concrete damage plasticity of concrete with 5% POFA and 2.5% ESP (Kamaruddin, 2020)

Concrete Damage Plasticity			
Ψ	**ε**	**σ^{bo}/σ^{co}**	**Kc**
30	0.1	1.16	0.667
Concrete Compression Behavior		**Concrete Compression Damage**	
Yield Stress (MPa)	**Inelastic Strain (mm/mm)**	**Damage Parameter**	**Inelastic Strain (mm/mm)**
35.35	0	0	0
37.28	0.0008	0	0.0008
38.43	0.0017	0	0.0017
38.84	0.0026	0	0.0026

38.59	0.0035	0.31	0.0035
36.86	0.0046	0.54	0.0046
34.36	0.0058	0.66	0.0058
30.87	0.0070	0.75	0.0070
27.56	0.0083	0.81	0.0083
25.04	0.0095	0.85	0.0095
Concrete Tensile Behavior		**Concrete Tension Damage**	
Yield Stress (MPa)	**Cracking Strain (mm/mm)**	**Damage Parameter**	**Cracking Strain (mm/mm)**
4.32	0	0	0
4.07	0.0004	0.20	0.0004
3.81	0.0008	0.28	0.0008
3.54	0.0012	0.37	0.0012
3.28	0.0016	0.44	0.0016
3.02	0.0020	0.50	0.0020
2.75	0.0024	0.57	0.0024
2.50	0.0028	0.62	0.0028
2.25	0.0032	0.67	0.0032
1.99	0.0036	0.72	0.0036
1.75	0.0040	0.76	0.0040
1.50	0.0044	0.80	0.0044
1.28	0.0048	0.84	0.0048
1.06	0.0052	0.87	0.0052
0.84	0.0057	0.90	0.0057
0.63	0.0061	0.93	0.0061

2.2 Composite slab design and detailing

The concrete was simulated with the material properties stated previously, with dimensions of 1800 mm in length, 600 mm in breadth, and 150 mm in depth, and a 0.9 mm steel deck thickness. Both longitudinal and transverse orientations of 6 mm diameter reinforced steel bars were considered. The mix design of the SCC used in the modelling is presented in Table 7. The geometry of the steel deck is shown in Figure 1.

Table 7 SCC mix proportions used in modelling (Kamaruddin, 2020)

Mix Proportion	Cement (kg/m³)	POFA (kg/m³)	ESP (kg/m³)	Sand (kg/m³)	Coarse Agg. (kg/m³)	Water (kg/m³)	Superplasticizer (kg/m³)
Control	451	0	0	902	767	180	9.02
5P 2.5E	417.17	22.55	11.28	902	767	180	9.02

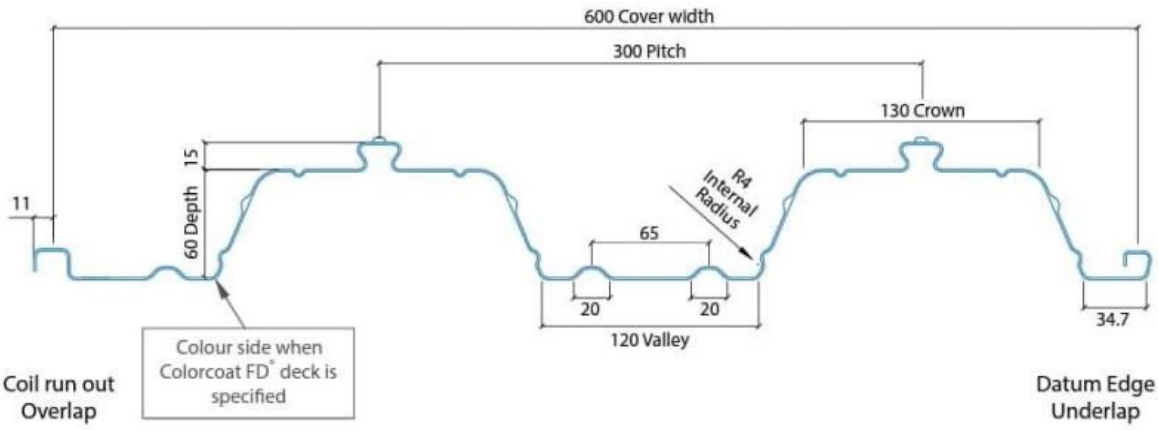


Figure 1: Steel deck dimension

2.3 Finite element analysis using ABAQUS

ABAQUS software was use to carry out the finite element analysis. In order to obtain the structural behavior of GSCC composite slabs, the slabs were model and simulated under flexural loading. Four essential procedures were follow to minimise errors and improve accuracy: composite slab model modelling, attribute assignment, analysis, and data gathering.

2.3.1 Composite slab modelling

A 3D composite slab model was create with dimensions of 1800 mm in length, 600 mm in breadth, and 150 mm in depth. The model incorporated three basic elements: SCC, steel deck, and reinforcement. A 0.9 mm thick steel deck and 6 mm diameter steel bars in both longitudinal and transverse orientations were included. In ABAQUS, eight-noded hexahedral elements with reduced integration (C3D8R) were used to simulate the concrete, while two-noded linear truss elements (T3D2) were applied for the reinforcement.

2.3.2 Attribute assignment

Concrete and steel were assigned as homogeneous materials. Material properties stated in Section 2.1 from the previous study were applied in the simulation. Concrete damaged plasticity, loading, boundary conditions, and meshing were identified and applied to analyse the model.

2.3.3 Analysis of composite slab model

The model was assembled and the optimal global mesh size was applied to create the meshes. The optimal global mesh size was employed to preserve the accuracy of the analysis result while minimising computing time.

2.3.4 Data collection

After completing the analysis, data were collected and extracted from ABAQUS. The results were presented as model animations, tables, and graphical figures to visualise load transfer behaviour.

2.4 Parametric study of GSCC composite slab

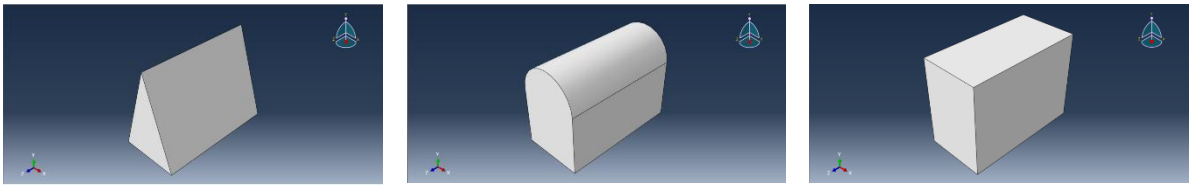
A parametric study was conducted to determine the effect of built-in shear connector shape variation, at a fixed spacing of 100 mm, on the performance of composite slabs. All GSCC composite slab models had constant dimensions of 1800 mm × 600 mm × 150 mm, and were assigned the same material properties, concrete damaged plasticity, steel deck properties, and steel plasticity as described in Section 2.1. The parametric study aims to determine the structural behavior in terms of ultimate load, crack pattern, load-deflection profiles, and stress distribution.

2.4.1 Built-in shear connector

The composite slab specimens were equipped with different shapes of built-in shear connector between the steel deck and the concrete slab. The shapes included v-shaped, u-shaped, and rectangular-shaped connectors, each with a length of 20 mm, width of 10 mm, and depth of 15 mm. According to Eurocode 4 (2004), a fixed spacing of 100 mm was set between each built-in shear connector. The parameters used for composite slab models are shown in Table 8. The proposed shapes of built-in shear connector used in this parametric study are shown in Figure 2.

Table 8 Parameters used for composite slab models

Composite Slab	Shape of Built-in Shear Connector	Spacing (mm)
CS 1	V-shaped	100 (Longitudinal)
CS 2	U-shaped	100 (Longitudinal)
CS 3	Rectangular-shaped	100 (Longitudinal)



(a) V-shaped (b) U-shaped (c) Rectangular-shaped

Figure 2: Proposed shapes of built-in shear connector

RESULTS AND DISCUSSION

In order to validate the FEA results, a series of mesh convergence studies were carried out. The simulation results obtained from FEA were found to be close to and nearly identical to the previous experimental results from Kamaruddin (2020). After validation, a parametric study was performed by varying the built-in shear connector shape (v-shaped, u-shaped, and rectangular-shaped) with a fixed spacing of 100 mm between connectors.

3.1 Convergence study of GSCC composite slab

Mesh convergence study is an important process in reducing discretization error when solving complex problems with the finite element method. Convergence was assessed from larger to finer mesh sizes until further mesh refinement produced negligible differences in results, proving mesh convergence. Convergence studies were conducted with various mesh sizes as indicated in Tables 9 and 10. The graphs of ultimate load against number of elements for the control and GSCC specimens are shown in Figure 3.

Table 9 Results of mesh refinement study – control specimen

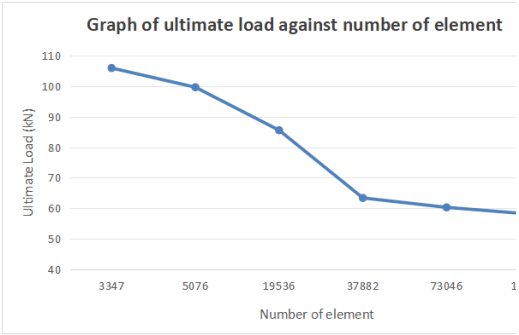
Mesh Size	Total Elements	Ultimate Load Pu (kN)		Difference (%)
		Experimental	FEA	
GB 75	3,347	52.6	106.0	50.4
GB 50	5,076	52.6	99.7	47.3
GB 25	19,536	52.6	85.6	38.5
GB 20	37,882	52.6	63.4	17.0
GB 15	73,046	52.6	60.3	12.8
GB 12	119,872	52.6	58.1	9.5

Note: GB = global mesh size in ABAQUS

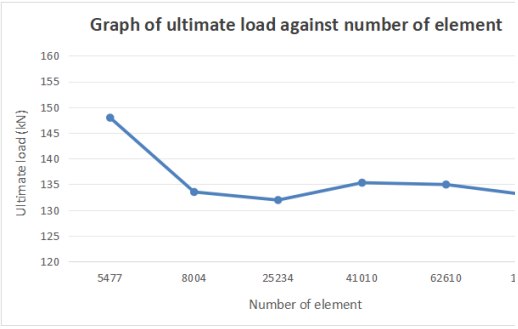
Table 10 Results of mesh refinement study – GSCC specimen

Mesh Size	Total Elements	Ultimate Load Pu (kN)		Difference (%)
		Experimental	FEA	
GB 75	5,477	140.4	147.95	5.38
GB 50	8,004	140.4	133.50	4.91
GB 25	25,234	140.4	131.93	6.03
GB 20	41,010	140.4	135.30	3.63
GB 15	62,610	140.4	134.95	3.88
GB 12	115,103	140.4	132.86	5.37

Note: GB = global mesh size in ABAQUS



(a) Control specimen



(b) GSCC specimen

Figure 3: Graph of ultimate load against number of elements

3.1.1 Validation of ultimate load, deflection, and failure mode

The ultimate load carrying capacity was used to validate simulation results against experimental results in FEA with ABAQUS. The FEA ultimate load of the control specimen was 58.1 kN (experimental: 52.6 kN, difference: 9.5%) and for the GSCC specimen was 132.9 kN (experimental: 140.4 kN, difference: 5.4%). Both percentage differences lie within the acceptable range of ±10 %, confirming the reliability of the simulation models (Kamaruddin, 2020). These results are tabulated in Table 11.

Table 11 Percentage difference of ultimate load and deflection between FEA and experimental results

Composite Slab	Ultimate Load Pu (kN)			Deflection (mm)		
	Experimental	FEA	Diff. (%)	Experimental	FEA	Diff. (%)
Control	52.6	58.1	9.5	0.48	0.55	12.7
GSCC	140.4	132.9	5.4	5.32	5.06	5.1

The deflection of the control specimen was 0.55 mm (FEA) versus 0.48 mm (experimental, difference: 12.7%), and the GSCC specimen was 5.06 mm (FEA) versus 5.32 mm (experimental, difference: 5.1%). The GSCC composite slab sustained a larger ultimate load and deflection compared to the control specimen.

Failure mode was also used to verify FEA results against experimental data. Based on Kamaruddin (2020), all specimens failed in shear, leading to cracking on the composite slab. Crack patterns from experimental work are shown in Figure 4, and crack patterns from FEA are shown in Figure 5.

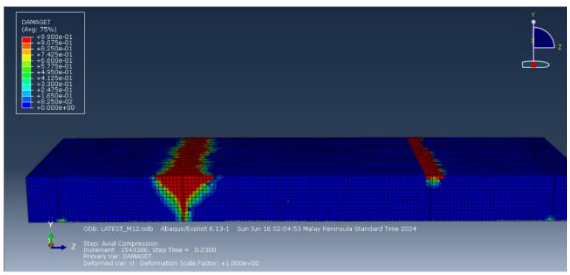


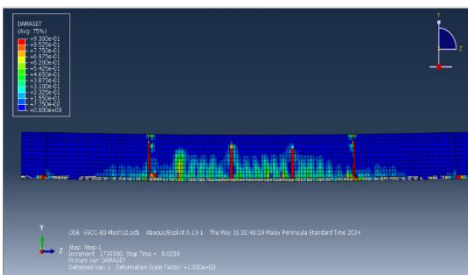
(a) Control specimen



(b) GSCC specimen

Figure 4: Crack pattern from experimental work (Kamaruddin, 2020)





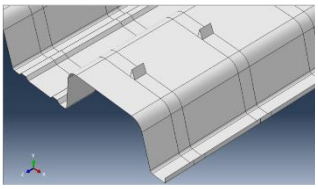
(a) Control specimen **(b) GSCC specimen**

Figure 5: Crack pattern from FEA

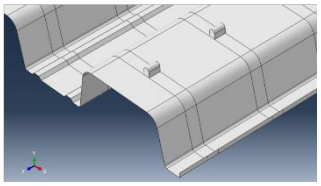
As shown in Figure 5(a), cracking occurred at the top surface of the simulation model, consistent with the behavior observed in the experimental model shown in Figure 4(a). The crack patterns for the GSCC specimen in Figures 4(b) and 5(b) occurred at the bottom part of the model, particularly at the loading point, exhibiting the most serious cracking. The failure locations and cracking patterns from FEA and experimental work are in good agreement, confirming the validation.

3.2 Parametric study of GSCC composite slab

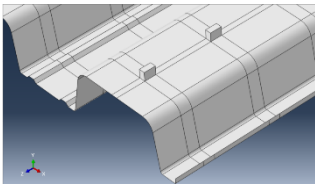
The parametric study was conducted by varying the overall shape of the built-in shear connector with a fixed spacing of 100 mm, then comparing results against the original validated GSCC simulation. The shapes of v-shaped, u-shaped and rectangular-shaped built-in shear connectors on respective metal decks are shown in Figure 6. The results of the parametric study in terms of ultimate load carrying capacity and deflection from FEA are shown in Table 12. The respective graphs of ultimate load and deflection are shown in Figure 7.



(a) V-shaped



(b) U-shaped

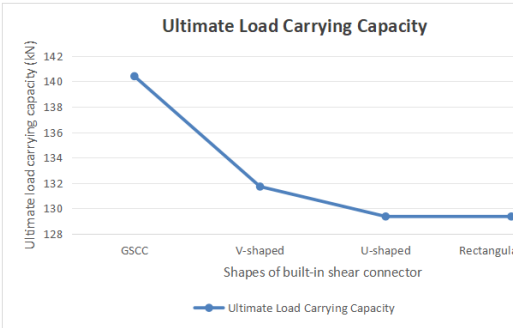


(c) Rectangular-shaped

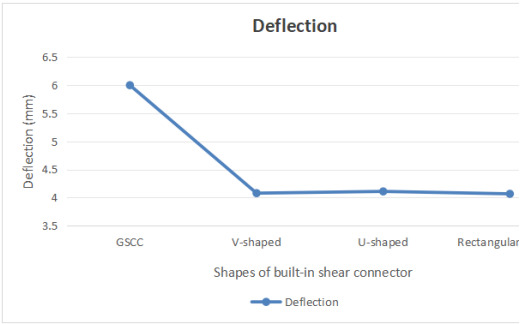
Figure 6: Shapes of built-in shear connector used in parametric study

Table 12 Results of parametric study – ultimate load and deflection

Composite Slab	Shape of Connector	Ultimate Load (kN)	Load Diff. to GSCC (%)	Deflection (mm)	Deflection Diff. to GSCC (%)
GSCC	—	140.400	0	5.060	0
CS 1	V-shaped	131.719	−6.6	4.079	−24.1
CS 2	U-shaped	129.368	−8.5	4.110	−23.1
CS 3	Rectangular-shaped	129.366	−8.5	4.067	−24.4



(a) Ultimate load carrying capacity



(b) Deflection

Figure 7: Graphs of parametric study results for different built-in shear connector shapes

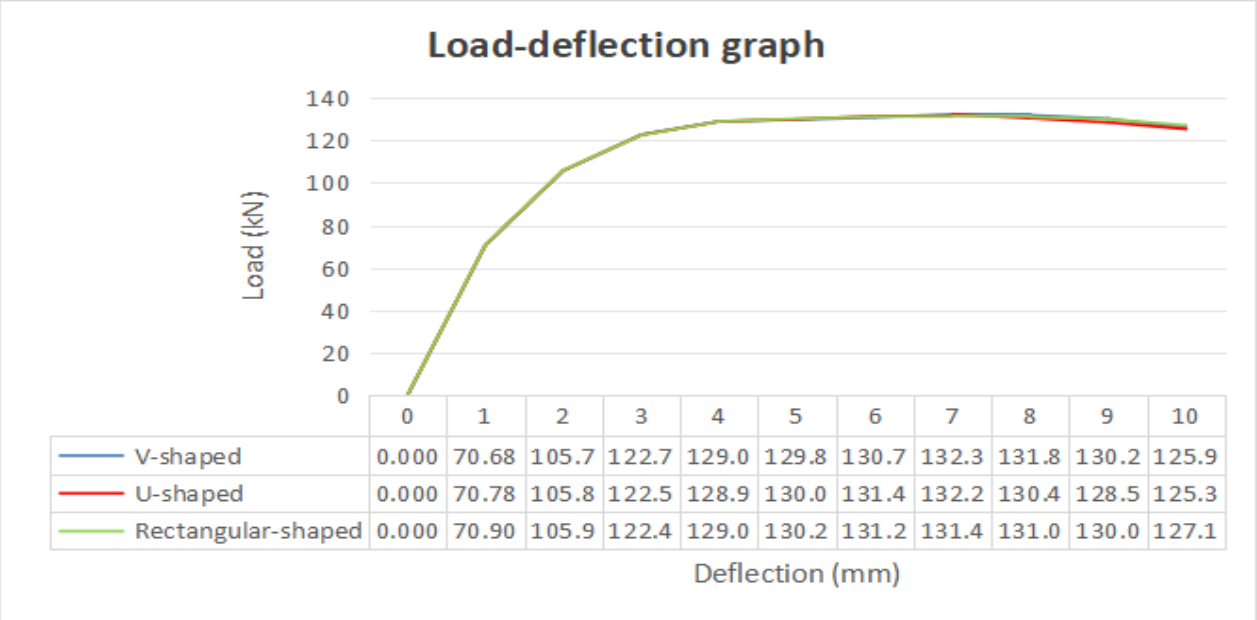
3.2.1 Effects of different shear connector shapes on structural performance

Based on the FEA results in Table 12, all proposed built-in shear connector shapes with 100 mm spacing showed a reduction in ultimate load carrying capacity and deflection compared to the original GSCC specimen. This is because the original GSCC specimen had a continuous shear connector along the metal deck, whereas CS 1, CS 2, and CS 3 had 100 mm spacing

between each 20 mm-long connector. This reduces the number of connectors available to transfer shear force between the metal deck and concrete slab. This trend is consistent with findings by Ali et al. (2022), who reported that increased shear connector spacing reduces bending strength capacity.

CS 1 with v-shaped built-in shear connector sustained the largest ultimate load of 131.719 kN, whereas CS 3 with rectangular-shaped connector sustained the smallest ultimate load of 129.366 kN. CS 2 and CS 3 demonstrated almost identical ultimate loads. The v-shaped connector provides an effective mechanical interlock with the concrete slab, thereby improving shear resistance and ultimate load carrying capacity. Hence, CS 1 exhibited the smallest percentage difference of 6.6% compared to the original GSCC composite slab.

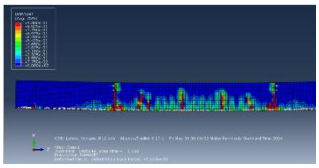
In terms of deflection, CS 2 had the largest deflection (4.110 mm), while CS 3 had the smallest (4.067 mm), closely followed by CS 1 (4.079 mm). Considering that CS 1 achieved a nearly equivalent deflection to CS 3 while sustaining a larger ultimate load, CS 1 is considered the most economical design shape. The load-deflection graph for all three shapes is shown in Figure 8.



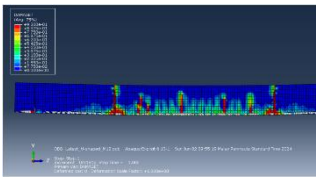
	0	1	2	3	4	5	6	7	8	9	10
V-shaped	0.000	70.68	105.7	122.7	129.0	129.8	130.7	132.3	131.8	130.2	125.9
U-shaped	0.000	70.78	105.8	122.5	128.9	130.0	131.4	132.2	130.4	128.5	125.3
Rectangular-shaped	0.000	70.90	105.9	122.4	129.0	130.2	131.2	131.4	131.0	130.0	127.1

Figure 8: Load-deflection graph for all three shapes of built-in shear connector

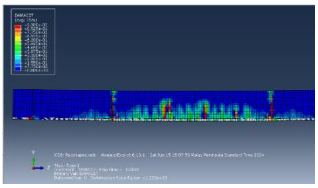
The crack patterns and stress distributions of composite slabs with different built-in shear connector shapes were studied using ABAQUS. All models exhibited similar crack patterns, particularly at the loading point. Initial cracking occurred at the bottom part of the composite slab due to flexural stresses in the loading region, indicating a longitudinal shear fracture mode. The crack patterns for CS 1, CS 2, and CS 3 are shown in Figure 9.



(a) CS 1



(b) CS 2

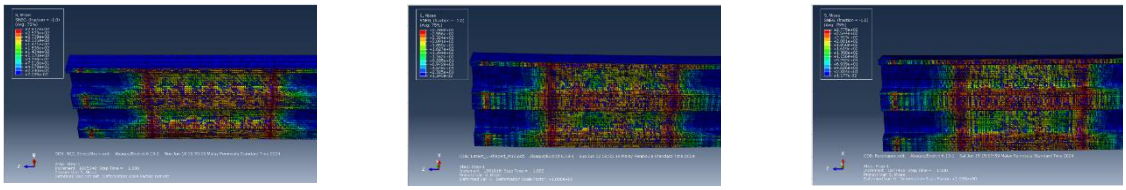


(c) CS 3

Figure 9: Crack patterns of respective parametric models

The stress distributions for CS 1, CS 2, and CS 3 are shown in Figure 10. Due to the effect of different shear connector shapes, stress distributions varied among the three models. The pale green area in the stress contour represents the maximum stress region when each model reaches its respective ultimate load. Under flexural loading, the top layer of the composite slab

experiences compression while the steel deck experiences tension, with inadequate interfacial bond leading to increased deflection and cracking.



(a) CS 1 **(b) CS 2** **(c) CS 3**

Figure 10: Stress distributions of respective parametric models

CONCLUSION

Kamaruddin (2020) successfully developed the finite element models of Green Self-Compacting Concrete (GSCC) composite slabs in ABAQUS using parameters from previous experimental research. The structural behavior of GSCC composite slabs under flexural loading was simulated and studied. Validation of computational models of both control and GSCC specimens yielded differences within the acceptable range of ±10 %, confirming that the computational models can be reliably used for parametric study.

The presence of built-in shear connectors in steel sheeting was analysed successfully in terms of shear capacity and ultimate strength. Different shapes of built-in shear connector produced different results. CS 1 with v-shaped built-in shear connector achieved the largest ultimate load carrying capacity of 131.719 kN and a deflection of 4.079 mm, closest to the minimum deflection of 4.067 mm by CS 3. Hence, CS 1 demonstrated the best ability to resist shear and ultimate force by providing effective load distribution and concrete-steel interaction.

A study on GSCC composite slab with different shaped built-in shear connectors using three-dimensional computational FEM was successfully conducted using ABAQUS. The v-shaped built-in shear connector provided the largest ultimate load carrying capacity and relatively smallest deflection compared to u-shaped and rectangular-shaped connectors. All three shapes showed a declining trend in structural performance relative to the original GSCC composite slab. Similar longitudinal shear fracture crack patterns were observed near the bottom of all composite slab models, particularly at the loading region.

For future research, it is recommend conducting additional finite element and experimental studies on geometry and shaping variation of built-in shear connectors, investigating varying spacing between connectors for all shape types, and study different steel deck types with the same series of built-in shear connector shapes to determine optimal configurations.

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PARTICIPATORY ERGONOMICS BASED SAFETY AND COMFORT ENHANCEMENT MODEL FOR SUSTAINABLE MUSI RIVERSIDE TOURISM IN PALEMBANG, SOUTH SUMATERA

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Abstract

This study was conducted in the Musi Riverside Tourism area, Palembang, South Sumatera, one of Indonesia's major waterfront tourism destinations characterized by cultural tourism, culinary attractions, traditional river transportation, and high visitor intensity. Preliminary observations identified several ergonomic and environmental problems affecting visitor safety and comfort, including slippery pedestrian pathways, inadequate lighting systems, unsafe boat boarding access, thermal discomfort due to excessive solar exposure, limited resting facilities, and congested pedestrian circulation during peak tourism periods. Therefore, this study aimed to develop a participatory ergonomics-based safety and comfort enhancement model integrated with sustainable waterfront tourism principles. The study involved 173 respondents consisting of tourists, traditional boat operators, street vendors, tourism officers, and local community representatives. Data collection was conducted through direct observation, questionnaires, environmental measurements, circulation mapping, participatory interviews, anthropometric assessment, and safety risk identification. Ergonomic interventions were developed through Focus Group Discussions (FGDs) involving ergonomists, tourism experts, local government, tourists, local communities, transportation operators, and vendors. The intervention included anti-slip pedestrian pathways, ergonomic seating, shaded resting areas, vegetation enhancement, improved lighting systems, handrails, boarding ramp redesign, and safety signage installation. The results showed that tourist comfort scores increased from 3.12±0.54 to 4.01±0.43, safety perception improved from 2.98±0.63 to 3.87±0.46, accessibility scores increased by 21.4%, and visitor satisfaction improved by 24.7% after intervention ($p<0.05$). Major safety complaints, including slipping risk, boarding difficulty, poor nighttime visibility, and circulation congestion, also decreased substantially. In addition, thermal comfort conditions improved significantly, indicated by a reduction in surface temperature from 36.1°C to 31.8°C after vegetation and shading interventions were implemented. The findings confirm that participatory ergonomics can effectively support sustainable waterfront tourism development by creating safer, more accessible, comfortable, and human centered tourism environments in tropical riverside destinations.

Keywords: *Musi river, participatory ergonomics, riverside tourism, safety, sustainable tourism, tourism comfort.*

INTRODUCTION

Tourism development in waterfront areas has become an important strategy for urban sustainability and economic growth in Indonesia, particularly through river based tourism that supports local economies, cultural preservation, and urban revitalization. Musi Riverside Tourism in Palembang, South Sumatera, is one of Indonesia's major waterfront tourism destinations, featuring cultural heritage attractions, culinary tourism, traditional ketek boat transportation, and riverside recreation along the 750 km Musi River. According to the South Sumatera Tourism Office (2023) dan Gusma et al. (2023), the area attracts approximately 1.8 million domestic visitors annually, especially during festivals and events around Ampera Bridge and Benteng Kuto Besak. Figure 1 shown various tourism activities and environmental conditions within the Musi Riverside Tourism area, including visitor density, traditional boat operations, pedestrian facilities, and existing waterfront infrastructure. These conditions became the primary focus of ergonomic and safety observations in this study to support safer, more comfortable, and sustainable waterfront tourism development.

Increasing tourism intensity in the Musi Riverside Tourism area has generated ergonomic and environmental problems affecting visitor safety and comfort, including slippery pedestrian pathways, unsafe boat boarding facilities, limited shaded areas, poor lighting, inadequate seating, and overcrowded circulation during peak periods. Thermal discomfort was also significant, with outdoor temperatures reaching 32-35°C and surface temperatures up to 36.1°C. Previous participatory ergonomics studies mainly focused on industrial sectors, while tourism studies rarely addressed ergonomic variables such as safety, accessibility, thermal comfort, and human centered facility design (Nandana et al., 2021).

Figure 1: Existing conditions and tourism activities in the Musi Riverside tourism area, Palembang, South Sumatera

Therefore, this study develops an integrated participatory ergonomics model to improve safety, comfort, accessibility, and environmental quality in sustainable tropical riverside tourism destinations (Table 1).

Table 1 Research gap identification from previous studies

No	Previous Study	Research Focus	Research Limitation	Research Gap
1	Setiawan et al. (2024)	Ergo-tourism and local wisdom governance in tourism villages	• Focused on ecotourism governance and local wisdom integration. • Emphasized governance and local wisdom	• Did not analyze ergonomic safety, thermal comfort, accessibility, and riverside tourism facilities comprehensively. • Did not evaluate ergonomic redesign effectiveness quantitatively
2	Suhartini et al. (2022)	Participatory ergonomics intervention on worker fatigue	Conducted in industrial shipyard environments	Did not apply participatory ergonomics within tourism environments and visitor-centered facilities
3	Astuti et al. (2022)	Participatory ergonomic approach for work safety improvement	Focused on occupational safety in SMEs	Limited discussion on tourism comfort, accessibility, and environmental ergonomics
4	Hidayatullah et al. (2025)	Tourist safety and comfort conceptual model	Focused on tourism stakeholder roles and literature review	Did not provide ergonomic intervention models for waterfront tourism environments
6	Trstenjak et al. (2025)	Human-centered ergonomics and sustainability	Focused on industrial human-centric systems	Did not discuss sustainable tourism ergonomics and visitor environmental comfort

Previous studies show limited integration of participatory ergonomics, environmental comfort, safety perception, accessibility, and sustainable waterfront tourism within tropical riverside destinations (Muda, 2025). Therefore, this study addresses the research gap by developing a participatory ergonomics based safety and comfort enhancement model for Musi Riverside Tourism, Palembang. The study integrates environmental ergonomics, waterfront tourism planning, accessibility improvement, thermal comfort evaluation, and visitor-centered sustainable tourism development. The objectives were to identify ergonomic and environmental problems affecting tourist safety and comfort, redesign tourism facilities using participatory ergonomics principles, and evaluate intervention effectiveness on safety, comfort, accessibility, and visitor satisfaction (Geraldina & Arifin, 2025; Setiawan & Susanto, 2026).

EXPERIMENTAL METHOD

Study area

This study was conducted in the Musi Riverside Tourism area, Palembang, South Sumatera, focusing on the Ampera Bridge waterfront corridor and surrounding tourism zones. Preliminary observations identified slippery pathways, unsafe boarding facilities, poor lighting, limited seating, pedestrian congestion, and thermal discomfort. These environmental and ergonomic problems highlighted the need for participatory ergonomics interventions in sustainable waterfront tourism development (Hasanein et al., 2025; Setiawan et al., 2025).

Research subjects

The study involved 173 respondents consisting of 115 domestic tourists, 5 international tourists, 20 traditional boat operators, 15 street vendors, 10 tourism officers, and 8 community representatives selected through purposive sampling based on their active involvement in tourism activities. Respondents represented various stakeholder groups directly interacting with tourism facilities and environmental conditions in the Musi Riverside Tourism area. Domestic tourists mainly originated from South Sumatera and neighbouring provinces, while international tourists came from Malaysia, Singapore, the Netherlands, and Australia. Data were collected through interviews, questionnaires, participatory discussions, and field observations to evaluate perceptions related to safety, comfort, accessibility, environmental ergonomics, and tourism facility conditions within the waterfront tourism corridor (Wahyuni et al., 2025).

Data collection

Data collection used quantitative and qualitative approaches to identify ergonomic, environmental, accessibility, and safety problems within the Musi Riverside Tourism area. Methods included observation, questionnaires, thermal measurements, circulation mapping, participatory interviews, and anthropometric assessment (Wu et al., 2026; Zout et al., 2025). Environmental variables and visitor perceptions were evaluated using standardized instruments and 5-point Likert scales, as presented in Table 2.

Table 2 Data collection variables, measurement instruments, units, and recommended standards

No	Aspect Measured	Measurement Method / Instrument	Unit	Recommended Standard / Good Criteria	Purpose of Measurement
1	Thermal Comfort Perception	5-point Likert questionnaire	Score (1-5)	≥ 4 = Comfortable	Evaluate tourist thermal comfort perception
2	Accessibility Perception	5-point Likert questionnaire	Score (1-5)	≥ 4 = Accessible and convenient	Assess accessibility of tourism facilities
3	Seating Comfort	5-point Likert questionnaire and direct observation	Score (1-5), cm	Seat height: 45-48 cm with backrest	Evaluate ergonomic suitability of seating facilities
4	Environmental Cleanliness	Questionnaire and observation checklist	Score (1-5)	≥ 4 = Clean environment	Assess visitor perception of environmental hygiene
5	Circulation Convenience	Questionnaire and circulation mapping	Score (1-5), person/m²	Pedestrian density < 1.5 person/m²	Evaluate pedestrian movement efficiency
6	Perceived Safety	Questionnaire and safety assessment	Score (1-5)	≥ 4 = Safe	Assess visitor safety perception
7	Air Temperature	Digital thermo-hygrometer	°C	Outdoor comfort range: 24-30°C	Evaluate environmental thermal conditions
8	Relative Humidity	Digital thermo-hygrometer	% RH	Recommended outdoor comfort: 40-70%	Assess humidity conditions affecting comfort
9	Illumination Level	Lux meter	lux	Pedestrian area ≥ 20 lux	Evaluate adequacy of nighttime lighting
10	Pedestrian Pathway Width	Measuring tape	meter (m)	Minimum ≥ 1.8 m for two-way circulation	Assess pedestrian accessibility and circulation
11	Pedestrian Density	Circulation mapping and direct observation	person/m²	≤ 1.5 person/m²	Measure congestion level
12	Walking Speed	Stopwatch and observation	m/s	Comfortable walking speed: 1.0-1.4 m/s	Evaluate circulation efficiency
13	Boarding Platform Width	Measuring tape	meter (m)	≥ 1.2 m	Assess boarding accessibility and safety
14	Boarding Ramp Slope	Digital inclinometer	Ratio / degree	Maximum slope 1:12	Evaluate accessibility for all users
15	Handrail Availability	Observation checklist	Availability (%)	100% boarding area equipped	Assess safety support facilities
16	Surface Condition of Pathways	Observation checklist	Percentage (%)	Non-slip and even surfaces	Evaluate slip and fall risks
17	Seating Availability	Counting method	seats/100 m²	≥ 15 seats/100 m²	Assess adequacy of resting facilities
18	Safety Complaints	Participatory interviews and questionnaires	Number / percentage (%)	Decreasing trend expected	Identify dominant safety problems
19	Anthropometric Suitability	Anthropometric assessment	cm	Match Indonesian anthropometric standards	Evaluate ergonomic suitability of facilities
20	Accessibility Conditions	Observation checklist and interviews	Score (1-5)	≥ 4 = Accessible	Assess accessibility for elderly and disabled users
21	Environmental Noise	Sound level meter	dB	Outdoor tourism area ≤ 70 dB	Assess environmental comfort level
22	Visitor Satisfaction	Questionnaire	Score (1-5)	≥ 4 = Satisfied	Measure overall tourism experience quality

The collected data were analysed descriptively and statistically to evaluate differences between conditions before and after ergonomic intervention. Descriptive analysis was used to explain environmental conditions,

tourism facility characteristics, and visitor perceptions. Statistical analysis was conducted to determine whether the participatory ergonomics intervention significantly improved tourist comfort, safety perception, accessibility, and environmental quality. Prior to hypothesis testing, data normality was examined using the Kolmogorov-Smirnov test. Normally distributed data were analysed using paired sample t-tests, while non-normally distributed data were analysed using the Wilcoxon signed rank test at a significance level of $\alpha = 0.05$.

Participatory ergonomics intervention

The following Figure 2 and Table 3 shown the design and implementation of a *Participatory Ergonomics Intervention* in a tourism area, involving multiple stakeholders through a series of *Focus Group Discussions (FGDs)*. The diagram presents the stages of identifying priority problems, developing ergonomic intervention designs, and establishing follow up and continuous evaluation plans (Santos et al., 2025; Jacobsohn et al., 2023). In addition, it outlines the measurement tools and instruments used to assess safety, comfort, accessibility, and environmental conditions within the study area.

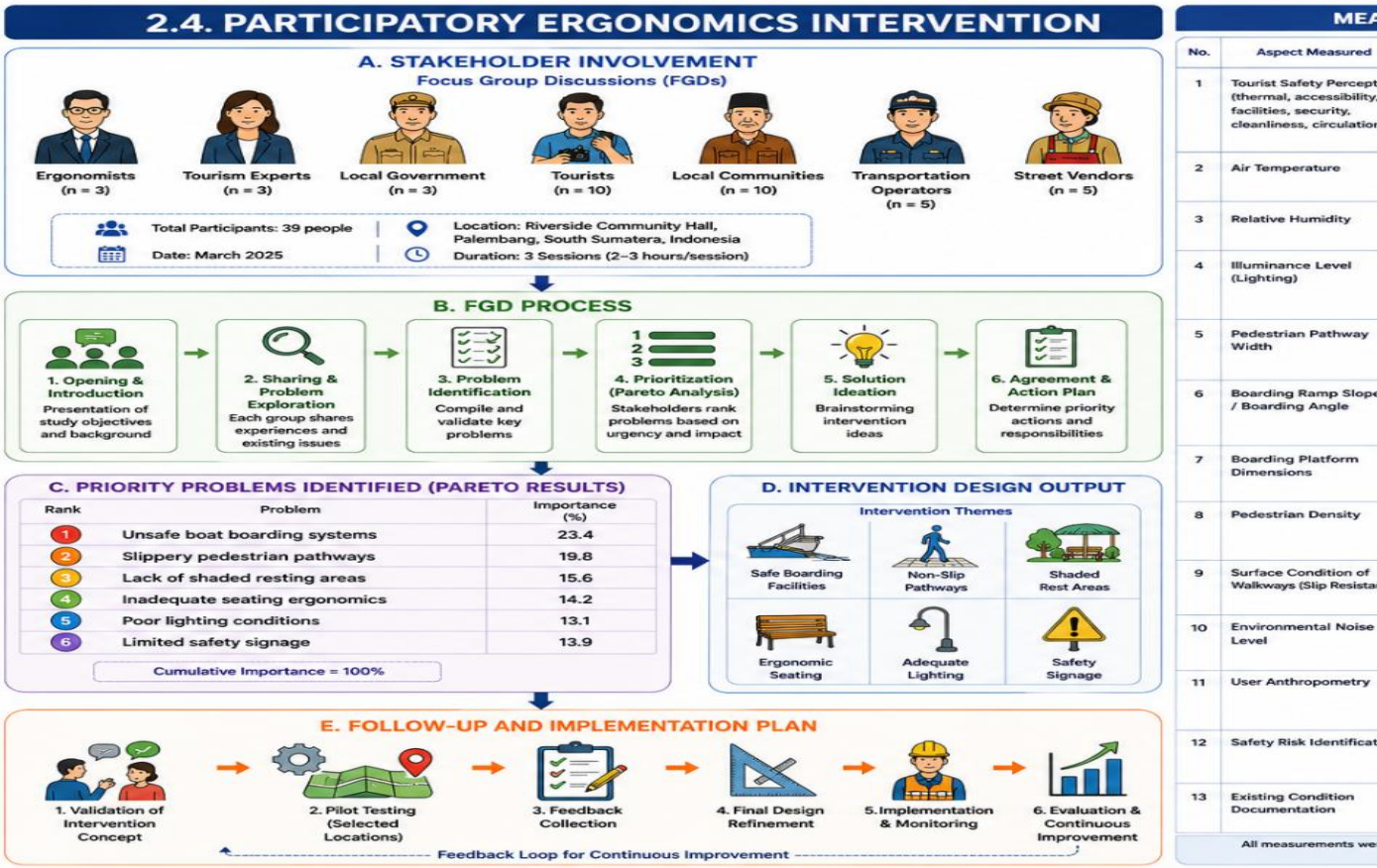


Figure 2: Participatory ergonomics intervention

Table 3 Measurement tools and instruments used

No.	Aspect Measured	Measurement Tool / Instrument	Unit	Standard / Good Criteria	Description / Purpose
1	Tourist Safety Perception (thermal, accessibility, facilities, security, cleanliness, circulation)	Likert Scale Questionnaire (5-point) 	Score (1–5)	Score ≥ 4 (Good)	Assess tourist perception of conditions before and after intervention
2	Air Temperature	Digital Thermo-Hygrometer 	°C	24–30 °C (Thermal Comfort)	Measure ambient air temperature
3	Relative Humidity		%RH	40–70 %RH	Measure relative humidity levels
4	Illuminance Level (Lighting)	Lux Meter 	lux	≥ 20 lux (Pedestrian Area)	Measure lighting intensity of pedestrian areas
5	Pedestrian Pathway Width	Measuring Tape 	m	≥ 1.8 m (Two-way Circulation)	Measure effective width of pedestrian pathways
6	Boarding Ramp Slope / Boarding Angle	Digital Inclinometer 	° / Ratio	Max. 1:12 (≈ 4.76°)	Measure slope of boarding ramps
7	Boarding Platform Dimensions	Measuring Tape 	m	Width ≥ 1.2 m	Measure width and size of boarding platforms
8	Pedestrian Density	Observation & Manual Counting 	persons/m²	≤ 1.5 persons/m²	Measure pedestrian density for circulation comfort
9	Surface Condition of Walkways (Slip Resistance)	Slip Resistance Checklist & Observation 	Score (1–5)	Score ≥ 4 (Non-slippery)	Assess surface safety and slip potential
10	Environmental Noise Level	Sound Level Meter 	dB	≤ 70 dB	Measure environmental noise level
11	User Anthropometry	Anthropometer & Stadiometer 	cm	SNI 9011:2021 (Indonesian Anthropometric Standard)	Measure body dimensions for ergonomic analysis
12	Safety Risk Identification	Risk Checklist & Observation 	Score (1–5)	Score ≥ 4 (Low Risk)	Assess potential risks in facilities and areas
13	Existing Condition Documentation	Digital Camera 	Photo	–	Visual documentation of existing conditions

All measurements were conducted at multiple points and times (daytime and nighttime, weekdays and weekends) to capture variations in environmental and usage conditions.

Table 3 presents the measurement framework used to evaluate environmental quality, ergonomics, safety, accessibility, and visitor comfort within the Musi Riverside Tourism area. Standardized instruments assessed thermal comfort, circulation, lighting, accessibility, noise, and safety perception during weekdays, weekends, daytime, and nighttime periods. The collected data provided a scientific basis for designing and evaluating participatory ergonomics interventions in sustainable waterfront tourism environments.

Ergonomic redesign

Table 4 presents the ergonomic redesign specifications implemented in selected waterfront tourism zones with high visitor density and safety complaints. The redesign emphasized participatory and user-centered approaches to improve usability, comfort, accessibility, and operational effectiveness for diverse visitors. Environmental sustainability aspects, including vegetation enhancement, energy efficient lighting, and durable materials, were incorporated to support long-term waterfront tourism management (Marina et al., 2025; Ingmann et al., 2025).

Table 4 Ergonomic redesign specifications, dimensions, and standards

No	Ergonomic Intervention	Specification / Dimension	Unit	Recommended Standard / Reference	Purpose
1	Anti-slip pedestrian flooring	Slip-resistant paving block with textured surface	—	Coefficient of friction ≥ 0.60	Reduce slipping risk during wet conditions
2	Pedestrian pathway widening	Minimum pathway width: 1.8-2.5	meter (m)	Universal pedestrian circulation standard	Improve two-way pedestrian circulation
3	Shaded seating areas	Shelter coverage area: 12-20	m²	Outdoor public resting facility standard	Reduce thermal discomfort
4	Ergonomic bench redesign	Seat height: 45-48	cm	Indonesian anthropometric standard	Improve seating comfort
5	Ergonomic bench redesign	Seat depth: 40-45	cm	Ergonomic seating standard	Support comfortable sitting posture
6	Ergonomic bench redesign	Backrest angle: 100-110°	degree (°)	Ergonomic posture standard	Reduce musculoskeletal discomfort
7	Seating material	Weather-resistant wood/steel composite	—	Outdoor durability standard	Improve safety and durability
8	Installation of handrails	Handrail height: 85-95	cm	Universal accessibility standard	Improve boarding safety
9	Handrail diameter	Grip diameter: 3.2-5.0	cm	Ergonomic handgrip standard	Improve user grip stability
10	Boat boarding ramp redesign	Ramp width ≥ 1.2	meter (m)	Universal accessibility standard	Improve accessibility and safety
11	Boarding ramp slope	Maximum slope ratio 1:12	ratio	Accessibility standard	Reduce boarding difficulty

12	Boarding platform surface	Anti-slip steel plate / textured surface	—	Slip resistance standard	Prevent falls during boarding
13	Lighting system improvement	Minimum illumination: 20-30	lux	Outdoor pedestrian lighting standard	Improve nighttime visibility
14	LED lighting spacing	Lamp interval: 8-12	meter (m)	Public lighting efficiency standard	Ensure uniform illumination
15	Directional signage installation	Sign height: 150-180	cm	Public information accessibility standard	Improve navigation efficiency
16	Safety signage installation	Reflective warning signage	—	Public safety signage standard	Increase hazard awareness
17	Signage font size	Minimum font size: 5-7	cm	Public readability standard	Improve readability distance
18	Vegetation enhancement	Shade tree spacing: 5-7	meter (m)	Urban thermal comfort guideline	Improve microclimate conditions
19	Vegetation canopy coverage	Minimum shading coverage: 40%	%	Outdoor thermal comfort standard	Reduce heat exposure
20	Waste bin installation	Distance interval: 20-30	meter (m)	Public cleanliness standard	Improve environmental cleanliness
21	Rest area spacing	Rest area every 80-100	meter (m)	Elderly-friendly public facility standard	Reduce pedestrian fatigue
22	Accessibility pathway surface	Smooth and non-obstructive surface	—	Universal accessibility guideline	Improve wheelchair accessibility
23	Emergency access clearance	Minimum width: 2.5	meter (m)	Emergency circulation standard	Ensure emergency mobility
24	Drainage improvement	Surface slope: 1-2%	%	Urban drainage standard	Prevent water accumulation
25	Pedestrian edge protection	Guardrail height: 90-110	cm	Public waterfront safety standard	Prevent accidental falls into river area

Statistical analysis

Statistical analysis evaluated the effectiveness of Participatory Ergonomics Interventions in improving safety, comfort, accessibility, circulation efficiency, and environmental quality within the Musi Riverside Tourism area (Setiawan, Susanto, Rinamurti, et al., 2025; H Setiawan & M Rinamurti, 2020). Descriptive statistics and Kolmogorov-Smirnov normality tests were applied with hypotheses: H0 = data are normally distributed and H1 = data are not normally distributed. Normally distributed data were analyzed using paired sample t-tests, while non-normal data used Wilcoxon signed-rank tests. Intervention hypotheses were H0 = no significant difference before and after intervention, and H1 = significant difference exists after intervention. Additional analyses included percentage improvement and Pareto analysis using IBM SPSS Statistics 27.

Figure 3 presents the research framework for developing a participatory ergonomics-based safety and comfort enhancement model for Musi Riverside Tourism, Palembang. The study included environmental assessment, respondent selection, FGDs, ergonomic redesign, intervention implementation, and statistical evaluation. Stakeholders participated in identifying priority problems and developing improvements such as anti-slip pathways, shaded resting areas, ergonomic seating, accessibility facilities, lighting systems, and safety signage to support sustainable waterfront tourism development.

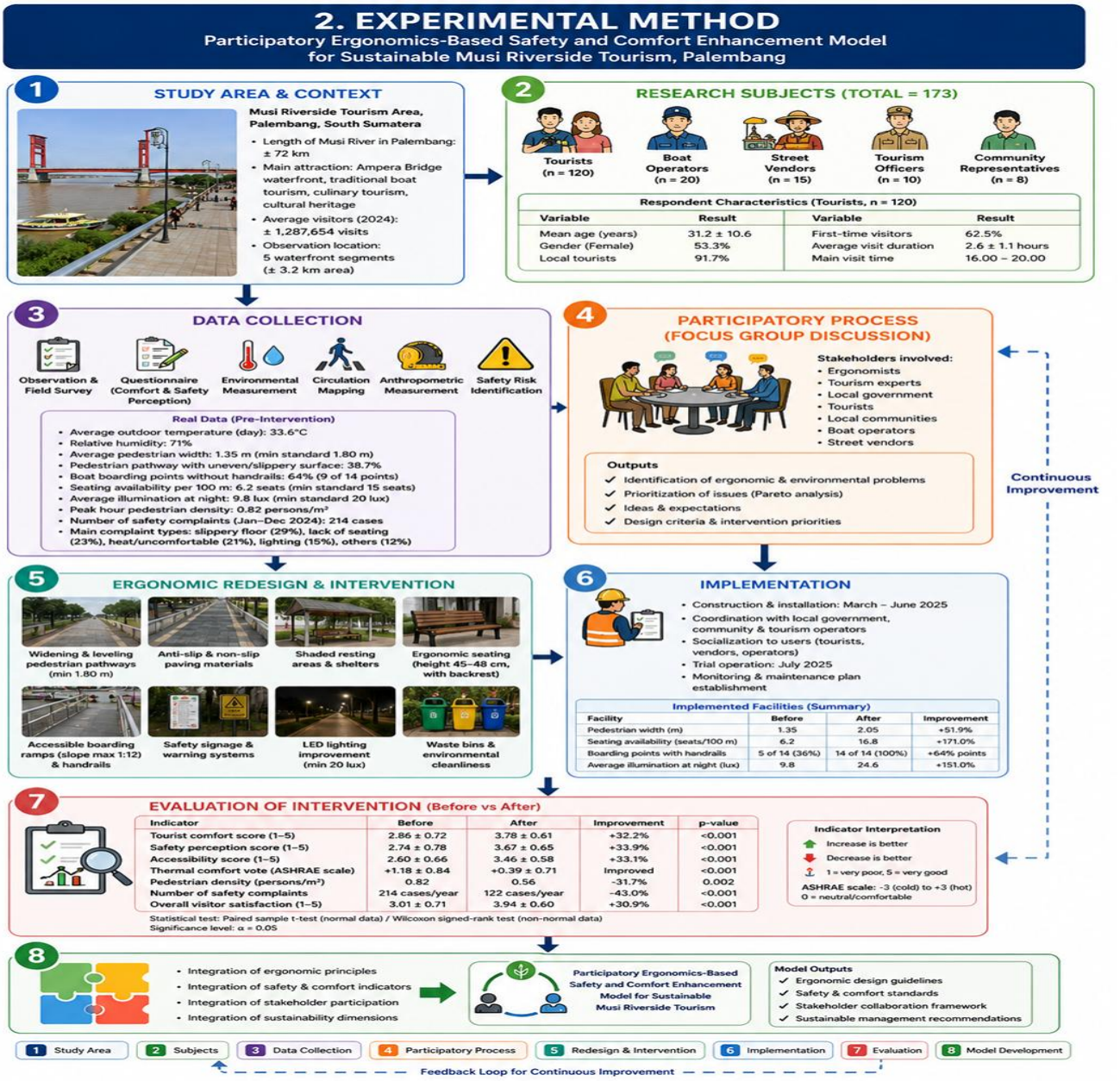


Figure 3: Research framework and experimental procedure

RESULTS

Tourist characteristics

A total of 173 respondents participated in this study, including tourists and tourism stakeholders within the Musi Riverside Tourism area. Tourist respondents consisted of 115 domestic and 5 international visitors aged 18-61 years (29.8±9.7 years), with females representing 58% of participants. Most visits occurred during weekends and evenings, when pedestrian density reached 1.8-2.1 persons/m² around the Ampera Bridge corridor. Average visit duration was 2.6±1.1 hours. Increased visitor density contributed to congestion, thermal discomfort, limited seating, and reduced pedestrian mobility efficiency.

Initial ergonomic problems

Preliminary observations and environmental assessments conducted within the Musi Riverside Tourism area revealed several significant ergonomic and environmental problems affecting visitor safety, comfort, accessibility, and circulation efficiency. These problems were predominantly identified in high-density tourism zones surrounding the Ampera Bridge waterfront corridor, Benteng Kuto Besak public spaces, traditional docking areas, and culinary tourism corridors.

The identified problems were evaluated through direct observation, environmental measurements, circulation mapping, and participatory interviews involving tourists, tourism operators, and local stakeholders. The results demonstrated that several existing waterfront tourism facilities had not yet fulfilled ergonomic and universal

accessibility principles required for sustainable and visitor-centered tourism environments. The summary of initial ergonomic and environmental problems identified during the preliminary assessment is presented in Table 5.

Table 5 Initial ergonomic and environmental problems in Musi Riverside tourism area

No	Problem Identified	Observation Result	Existing Condition Description	Potential Impact
1	Slippery pedestrian surface	Found in 37% of pathway sections	Uneven pavement surfaces, water accumulation, damaged paving blocks, and inadequate drainage systems	Increased risk of slips, falls, and reduced walking comfort
2	Insufficient lighting	Average illumination only 9.8 lux in several nighttime zones	Poor lighting distribution near pedestrian pathways, docking points, and riverside seating areas	Reduced visibility, increased accident risk, lower perceived safety
3	Lack of handrails	Present at 4 out of 6 docking points	Boarding areas lacked ergonomic handrails and anti-slip boarding support systems	Unsafe boarding process for elderly visitors, children, and mobility-limited users
4	Limited seating capacity	Only 28 seats available in crowded zones	Seating facilities unevenly distributed and lacking shaded protection	Visitor fatigue, informal sitting behavior, circulation obstruction
5	Thermal discomfort	Average daytime temperature 34.2°C	Limited vegetation and shaded resting areas causing excessive heat exposure	Reduced visitor comfort and shortened tourism activity duration
6	Congested circulation	Average pedestrian density 1.8 person/m²	Narrow pedestrian pathways and bottlenecks near culinary and docking areas	Reduced mobility efficiency and walking comfort
7	Poor accessibility	Pathway width in several areas below 1.5 m	Limited space for two-way pedestrian movement and wheelchair access	Restricted accessibility for elderly and disabled visitors
8	Unsafe boarding ramps	Ramp width only 0.8–1.1 m in several docking areas	Steep and unstable boarding platforms without ergonomic safety features	Increased boarding difficulty and accident risk
9	Limited safety signage	Minimal warning and directional signage installed	Lack of navigation systems and hazard information in tourism zones	Reduced visitor orientation and emergency preparedness
10	Inadequate shaded areas	Vegetation coverage below 25% in open tourism corridors	Large exposure to direct solar radiation during daytime activities	Increased thermal stress and environmental discomfort

Tourist comfort and safety perception

The effectiveness of participatory ergonomics interventions was evaluated by comparing tourist perceptions before and after ergonomic redesign implementation within the Musi Riverside Tourism area. The assessment focused on tourist comfort, safety perception, accessibility, and visitor satisfaction. Interventions included pathway improvements, anti-slip flooring, shaded resting areas, ergonomic seating, lighting systems, boarding accessibility, handrails, and safety signage. Statistical comparisons involving 173 respondents were conducted using paired analysis at $\alpha = 0.05$, with the results presented in Figure 4.

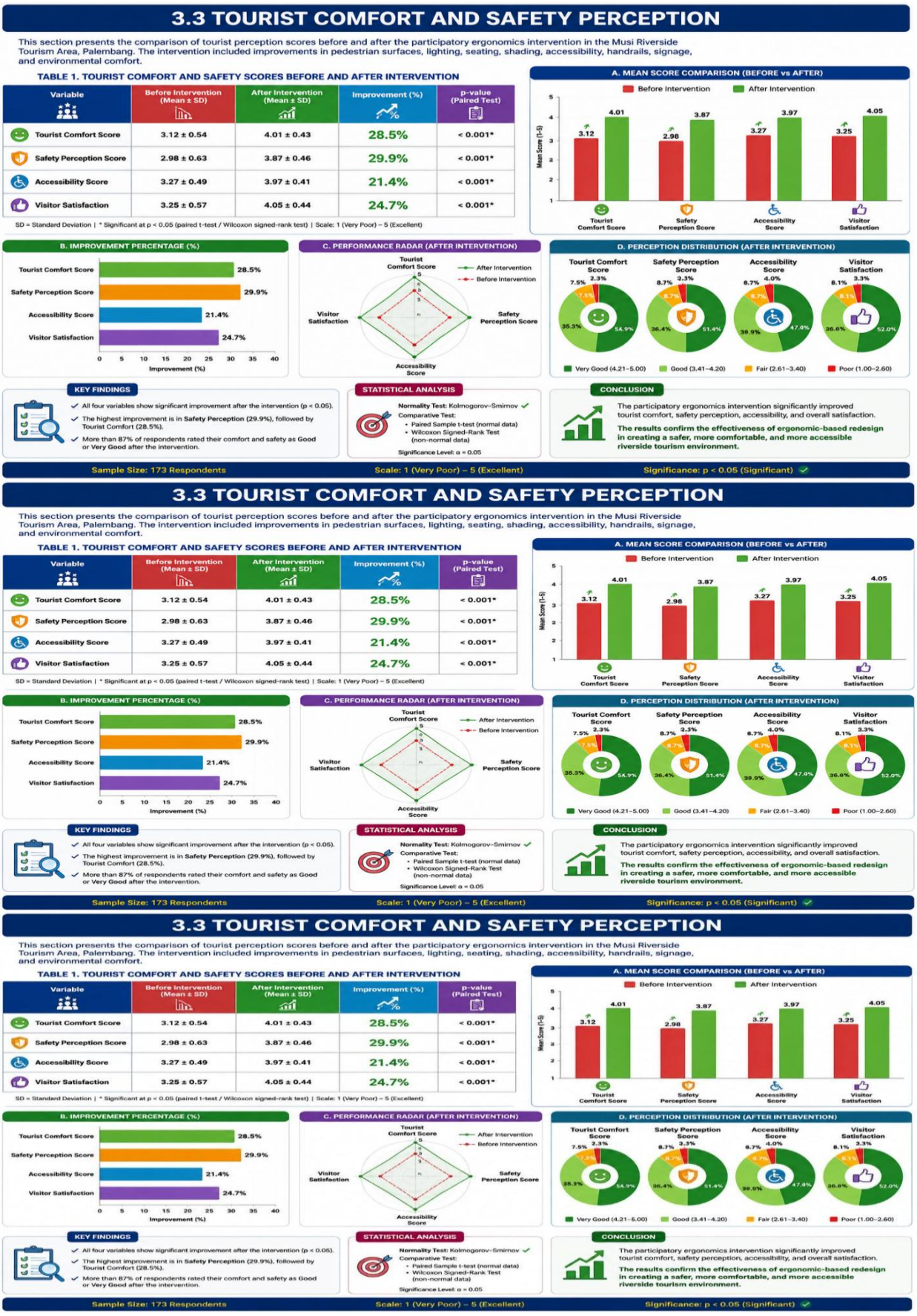


Figure 4: Tourist comfort and safety perception before and after ergonomic intervention

Based on Figure 4, all evaluated variables showed significant improvements after the participatory ergonomics intervention ($p < 0.05$). Tourist comfort, safety perception, accessibility, and visitor satisfaction increased substantially following pathway redesign, improved lighting, handrail installation, and circulation management.

Overall, the intervention effectively enhanced environmental quality, visitor comfort, safety, and accessibility within the Musi Riverside Tourism area.

Safety complaint reduction

Safety complaint assessments showed significant reductions in slipping risk, boarding difficulty, poor visibility, circulation congestion, and limited resting facilities after participatory ergonomics interventions within the Musi Riverside Tourism area. Improvements included anti-slip flooring, better lighting, ergonomic seating, circulation management, and safety signage. Figure 5 confirms significant improvements in environmental safety, accessibility, visitor safety perception, and waterfront tourism sustainability ($p < 0.001$).

Figure 5: Safety complaint reduction before and after ergonomic Iitervention

Thermal comfort improvement

hermal comfort evaluation showed that environmental ergonomics interventions reduced heat exposure and improved visitor comfort within the Musi Riverside Tourism area through shaded resting areas and additional vegetation, particularly during daytime tourism activities along the waterfront corridor (Table 6).

Table 6 Thermal comfort conditions before and after ergonomic intervention

No	Thermal Comfort Indicator	Before Intervention	After Intervention	Improvement	Interpretation
1	Perceived thermal discomfort score (1–5)	4.11 ± 0.51	3.02 ± 0.47	-26.5%	Thermal discomfort significantly decreased
2	Average surface temperature in seating areas	36.1°C	31.8°C	-11.9%	Reduced surface heat exposure
3	Average ambient temperature (daytime)	34.2°C	31.5°C	-7.9%	Improved environmental thermal condition
4	Relative humidity	72–84%	68–78%	Improved stability	More comfortable microclimate
5	Vegetation/shading coverage	< 25%	± 43%	+72.0%	Increased shaded protection
6	Number of shaded resting areas	3 units	11 units	+266.7%	Improved resting facility availability
7	Visitor complaints related to heat exposure	21%	8%	-61.9%	Reduced thermal-related complaints
8	Average visitor duration in outdoor areas	2.6 ± 1.1 hours	3.4 ± 1.2 hours	+30.8%	Increased outdoor activity comfort

Participatory ergonomics interventions improved thermal comfort by reducing heat exposure and surface temperatures through shaded structures and vegetation, increasing visitor comfort, activity duration, and waterfront tourism sustainability.

Circulation and accesbility improvement

Ergonomic interventions targeting pedestrian circulation and accessibility were implemented to reduce congestion and improve visitor mobility within the Musi Riverside Tourism area. The program included pathway widening, directional signage, improved boarding facilities, enhanced pedestrian surfaces, and accessibility-oriented circulation management. Figure 6 presents the comparison of circulation performance and accessibility indicators before and after intervention.



Figure 6: Circulation and accessibility improvement before and after ergonomic intervention

DISCUSSION

The results of this study demonstrate that participatory ergonomics effectively improved safety, comfort, accessibility, and environmental quality within the Musi Riverside Tourism area. Initial environmental problems, including slippery pathways, unsafe boarding facilities, poor lighting, thermal discomfort, limited seating, and circulation congestion, were successfully addressed through stakeholder-based ergonomic interventions (Setiawan et al., 2024a). Through Focus Group Discussions (FGDs), tourists, local communities, transportation operators, vendors, and tourism officers actively participated in identifying problems and determining intervention priorities, enabling solutions that better reflected actual field conditions and visitor needs (Anisur et al., 2025; Khazaee-pool et al., 2024; Jaya & Hermawan, 2026).

Significant improvements were observed in tourist comfort and safety perception after intervention implementation. Tourist comfort scores increased from 3.12 to 4.01, while safety perception improved from 2.98 to 3.87 following the installation of anti-slip pathways, ergonomic seating, shaded resting areas, improved lighting, and safer boarding facilities. Safety complaints also decreased considerably, particularly slipping risks and boarding difficulties, indicating that pathway redesign, handrails, and boarding ramps effectively enhanced visitor safety. Thermal comfort improvements became another important finding (Wharton et al., 2025; Cha, 2025). The addition of shaded structures and vegetation reduced surface temperatures and minimized heat exposure, contributing to better visitor comfort and longer activity duration. Circulation efficiency and accessibility also

improved significantly, reflected by increased walking speed, reduced pedestrian density, and wider accessible pathways supporting elderly visitors and individuals with physical limitations (Jehle et al., 2024; Maresova et al., 2023; Industri, 2026).

This study highlights the important contribution of participatory ergonomics within sustainable tourism development. Unlike previous ergonomics studies focused mainly on industrial settings, this research demonstrates that ergonomics principles can be effectively applied in tourism environments to improve visitor-centered facility design, environmental comfort, safety, and accessibility (Ragil et al., 2025; Setiawan, Budiyanto, & Rinamurti, 2025; Setiawan, Yusuf, Rinamuti, et al., 2025). Overall, integrating ergonomics, stakeholder participation, and environmental management can support safer, more inclusive, and more sustainable waterfront tourism environments.

CONCLUSION

This study demonstrates that the Musi Riverside Tourism area still faced significant ergonomic and environmental problems related to safety, thermal comfort, accessibility, and circulation efficiency. Through a participatory ergonomics approach involving tourists, local communities, transportation operators, vendors, and government stakeholders, the implemented interventions successfully improved tourist comfort by 28.5%, safety perception by 29.9%, accessibility by 21.4%, and visitor satisfaction by 24.7%, while substantially reducing major safety complaints and environmental risks. The findings confirm that integrating participatory ergonomics, environmental comfort, accessibility improvement, and stakeholder involvement can effectively support safer, more comfortable, inclusive, and sustainable waterfront tourism development in tropical urban tourism destinations such as Musi Riverside Tourism, Palembang.

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EXPERIMENTAL ANALYSIS OF COMPRESSIVE STRENGTH OF CONCRETE QUALITY K-225 WITH THE SUBSTITUTION OF GLASS WASTE POWDER A PARTIAL CEMENT REPLACEMENT

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ABSTRACT

The use of cement as the main binding material in concrete construction has a significant impact on carbon (CO_2) emissions on the global environment. This study aims to analyze the effect of the use of glass waste powder as a partial substitution of cement on the compressive strength of K-225 quality concrete at a test age of 28 days. The glass waste powder is processed until it passes sieve No. 200 so that it has pozolanic properties through the content of amorphous silica (SiO_2). Laboratory experimental methodology was applied with a variation of glass powder substitution of 0% (Normal Concrete), 5% (V1), 10% (V2), and 15% (V3) to the weight of raw cement. The test specimen is in the form of cubes measuring 15 cm × 15 cm × 15 cm with water immersion treatment for 28 days. The results of laboratory research showed that normal concrete (BN) had an average compressive strength value of 225 kg/cm² (19.3 Mpa). The compressive strength of concrete is 225 kg/cm², 228 kg/cm², 234 kg/cm², and 229 kg/cm², respectively. The highest compressive strength is obtained at a 10% substitution of 234 kg/cm² or an increase of about 4.00% compared to normal concrete. The increase in strength at 10% levels is induced by the pozolanic reaction between reactive silica and calcium hydroxide forming secondary calcium silicate hydrate (*CSH),* while the decrease at high levels is due to reduced volume of active cement as well as limitations of matrix binding.
Keywords : K-225 Quality Concrete, Glass Waste Powder, Cement Substitution, Compressive Strength, Pozolan.

INTRODUCTION

As a structural composite essential to the construction of modern infrastructure, concrete offers superior compressive load bearing capacity, ease of practical implementation, and abundant availability of constituent components. On the other hand, the production of cement as the main material of concrete contributes significantly to carbon dioxide (CO_2) emissions which have an impact on global warming. Globally, the cement industry contributes about 7–8% to the world's total CO_2 emissions [4]. On this basis, the urgency of innovation in the field of construction materials focuses on reducing cement consumption through the integration of alternative materials that are environmentally friendly [5].

Fine aggregate is natural sand resulting from the natural disintegration of stone or sand produced by the stone breaking industry with the largest grain size of 5.0 mm [3], so in the research we conducted this time, we tried to use glass shards as an additive in the mortar mixture of 0%, 3%, 6%, 9% of the weight of cement.

One of the secondary materials that has significant capabilities to be integrated as a

substitute agent for binding materials is glass waste. Glass waste is non-biodegradable inorganic waste that takes a very long time to degrade. Chemically, glass waste contains high amounts of amorphous silica (SiO_2), so it has the potential to be a pozolan material when processed into a fine-sized powder (passes sieve No. 200). Through interaction with calcium hydroxide $Ca(OH)_2$ cement hydration products, the glass waste powder triggers the formation of new calcium silicate hydrate (*CSH)* compounds that function as capillary cavity fillers and optimize the structural quality of concrete [6].

This study aims to analyze the effect of variations in the percentage of substitution of glass waste powder (0%, 5%, 10%, and 15%) on the compressive strength of K-225 quality concrete at the age of 28 days, and determine the optimal substitution percentage that provides the most efficient compressive performance.

LITERATURE REVIEW

Portland cement in concrete reacts with water to produce the main *CSH* gel and calcium hydroxide $Ca(OH)_2$. Pozolanic reaction occurs when amorphous silica from glass powder reacts with $Ca(OH)_2$ in a humid environment, according to the equation:

$$\mathbf{SiO2 + Ca(OH)_2 + H2O \rightarrow CSH\ (Gel)}$$

This secondary CSH *gel synthesis* closes capillary pores so that the density of the concrete microstructure increases [3].

RESEARCH METHODOLOGY

This experimental research was held at the Laboratory of the Faculty of Engineering, University of Palembang. The materials used include *Portland Cement* Type I PT Semen Baturaja Tbk, Musi sand fine aggregate, Lahat crushed crushed aggregate (5-20 mm), clean water, and glass waste powder passed sieve No. 200. The test specimen is a concrete cube measuring 15 cm × 15 cm × 15 cm.

Testing of the physical properties of materials is carried out in accordance with SNI regulations. The mix design refers to SNI 03-2834-2000 for the quality target of K-225 (f'c = 19.3 MPa) with a cement water factor (FAS) of 0.58 and a standard cement requirement of 371 kg/m³. The test specimen was treated by the water immersion method (curing) for up to 28 days, then compressively tested using *a Compression Testing Machine* [7], [8].

RESULTS AND DISCUSSION

A. Characteristics of Constituent Materials

The results of the physical characterization of the material showed that Musi sand had a sludge content of 1.27% (≤ 5%), a specific gravity of SSD 2.55, and a fineness modulus of 2.92 (Zone 3). The Lahat crushed stone has a sludge content of 3.19%, the specific gravity of SSD is 2.377, the loose content weight is 1.37 gr/cm³, and the solid content weight is 1.55 gr/cm³. All materials have met the qualifications of construction standards [8].

B. *Fresh Concrete* Slump Testing

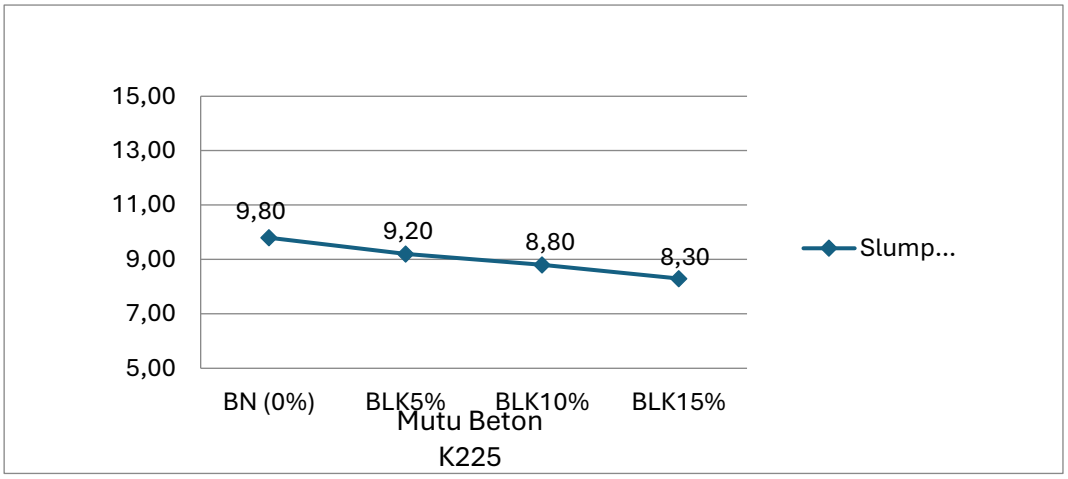
Slump testing is carried out to measure the level of elasticity (*workability*) of fresh

concrete dough. The values of *normal concrete slumps and glass powder mixtures are presented in Table 1.*

Table 1. Fresh Concrete *Slump* Test Results

Variation Code	Substitution Percentage (%)	Slump Value (mm)	Category: Kelecakan
BN	0%	98	Good (60 - 100 mm)
V1	5%	92	Good (60 - 100 mm)
V2	10%	88	Good (60 - 100 mm)
V3	15%	83	Good (60 - 100 mm)

Figure 1 : Slump Value Graph



It was seen that the increase in the percentage of glass powder lowered the slump value from 98 mm in BN to 83 mm in V3. This is due to the high specific surface area of microglass powder particles that absorb more mixed water [1].

C. Concrete Compressive Strength Testing 28 Days

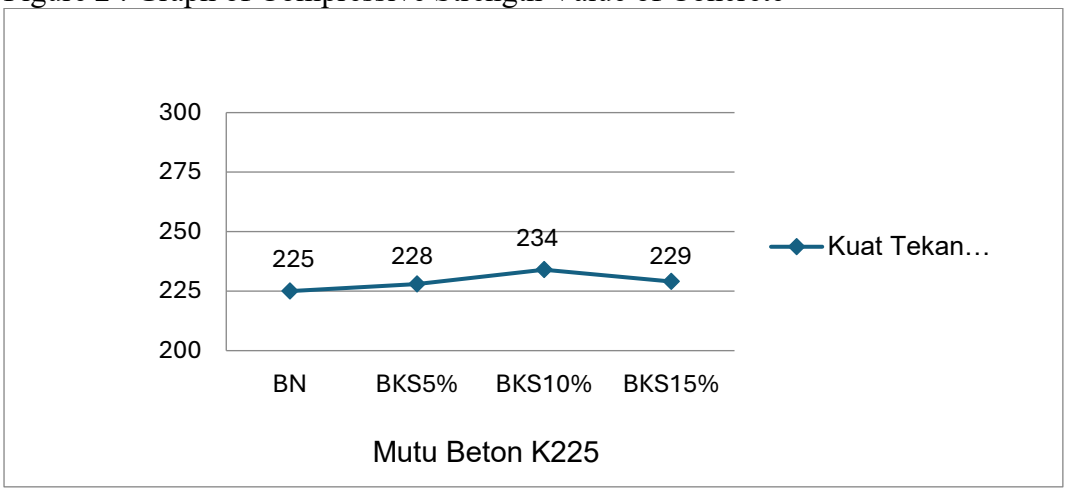
Testing of the compressive strength of cube concrete is performed when the specimen is 28 days old. The compressive strength calculation uses the equation $f'c = P/A$. A recapitulation of the results of compressive strength tests is presented in Table 2.

Table 2. Recapitulation of K-225 Quality Concrete Compressive Strength Test 28 Days

Variation Code	Substitution Percentage (%)	Average Compressive Strength (kg/cm²)	Percentage Against BN (%)
BN	0%	225	100
V1	5%	228	101,33

V2	10%	234	104
V3	15%	229	101,77

Figure 2 : Graph of Compressive Strength Value of Concrete



Based on Table 2 data, V1 variation concrete (10% substitution) produced the highest compressive strength value of 234 kg/cm² (22.95 Mpa), an increase of 4% compared to normal concrete (BN). This increase occurs due to the formation of secondary CSH due to the reaction of amorphous glass powder pozolanic silica with $Ca(OH)_2$ cement hydration product [2], [6].

At 15% (V3), the compressive strength was devalued to 229 kg/cm² (22.46 Mpa). This decrease is triggered by a reduced portion of active clinker cement in the mix as well as a slow reaction rate of pozolan at 28 days of age [3]. These findings are in line with the research of Baktiar & Lubis (2021) which states that the addition of glass powder beyond the optimal dose can lower the mechanical threshold limit of concrete composites.

CONCLUSION

1. The use of glass waste powder has a significant effect on the compressive strength and tensile value of K-225 quality concrete.
2. The most optimal percentage of glass waste powder substitution is **10% (V2),** which results in an average peak compressive strength of 234 kg/cm² (22.95 Mpa), or an increase of 4% compared to normal concrete of 225 kg/cm² (19.30 MPa).
3. A 15% substitution of glass powder led to a reduction in compressive strength to 229 kg/cm² (22.46 Mpa) due to a reduction in the volume of activated hydraulic cement.

ADVICE

1. It is recommended to perform long-term durability tests (lifespans 56 and 90 days) to observe the secondary hydration rate of the pozolanic reaction gradually.

2. It is necessary to study the use of *superplasticizer* additives to maintain the slump value at a higher glass powder substitution rate.

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EVALUATION OF PROJECT MANAGEMENT PERFORMANCE IN THE CONSTRUCTION OF THE GANDUS WATER TREATMENT INSTALLATION (IPA) WITH A CAPACITY OF 500 LITERS/SECOND IN PALEMBANG CITY

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ABSTRACT

The development of clean water infrastructure is a strategic effort to improve the quality of basic public services. One of the projects implemented to support the provision of clean water in Palembang City is the construction of the Gandus Water Treatment Plant (WTP) with a capacity of 500 liters/second. Projects with a high level of work complexity require the implementation of effective project management to achieve implementation targets based on time, cost, and quality aspects. This study aims to evaluate the performance of project management in the construction of the Gandus WTP, analyze performance based on time, cost, and quality aspects (triple constraint), and identify factors that influence project performance. The study uses a descriptive method with a quantitative approach. Data were obtained through field observations, interviews with related parties, and project documentation including implementation schedules, work progress reports, budget data, and quality control documents. The analysis was carried out by comparing the planned and realized conditions of project implementation and identifying factors that influence project performance. The results of the study indicate that project management performance has generally been quite good. In terms of time, there are still some delays influenced by delays in material procurement, weather conditions, work coordination, and labor productivity. However, delays can be minimized through project acceleration and control efforts. In terms of costs, controls are conducted periodically to ensure that actual costs remain within acceptable control limits. In terms of quality, the work results generally meet the established technical specifications and quality standards. Factors influencing project performance include project planning, material availability, human resource competency, time and cost control, communication and coordination systems, and weather and work environment conditions. Effective project management and integrated triple constraint control are essential to enhance the success of clean water infrastructure projects.

Key words: project management, project performance, triple constraint, time, cost, quality, IPA.

1. INTRODUCTION

Clean water infrastructure is a crucial component in supporting improved quality of life for communities and regional development. The availability of adequate, safe, and sustainable clean water is a basic need that must be met through a reliable water treatment and distribution system. With population growth, urbanization, and increased economic activity, the need for clean water in Palembang City continues to increase.

One effort to improve clean water services in Palembang City is the construction of the Gandus Water Treatment Plant (WTP) with a capacity of 500 liters per second. This facility is expected to increase the coverage of clean water services, especially for residents in the Gandus area and its surroundings. However, the WTP construction project is a construction project with a high level of complexity, involving civil, structural, mechanical, electrical, and piping works,

as well as testing and commissioning. Therefore, project implementation requires planned and integrated management.

Project management plays a crucial role in coordinating project resources, including labor, materials, equipment, implementation methods, costs, time, and risk management. The success of a construction project is generally assessed based on the triple constraint concept: time, cost, and quality. A mismatch in any one of these aspects can impact the achievement of the project's overall objectives.

During construction projects, various problems can arise, such as work delays, project changes, cost increases, material procurement constraints, coordination issues, and other technical and non-technical factors. These conditions highlight the importance of evaluating project management performance to determine the extent to which project implementation is proceeding according to established plans.

Based on these conditions, this study aims to evaluate project management performance for the construction of the 500 liter/second Gandus WTP in Palembang City, based on time, cost, and quality. Furthermore, this study aims to identify factors influencing project management performance during project implementation.

The results are expected to provide an overview of the current state of project management implementation in WTP construction projects and provide input for project owners, contractors, supervisory consultants, and other relevant parties in improving the effectiveness of clean water infrastructure construction project management.

2. RESEARCH METHODOLOGY

2.1. Types of research

This research uses a descriptive method with a quantitative approach. The descriptive method is used to describe the actual conditions of project implementation based on data obtained in the field, while the quantitative approach is used to analyze project performance based on time, cost, and quality indicators.

Project management performance evaluation is conducted based on the triple constraint concept, which consists of:

1. Time;
2. Cost; and
3. Quality.

In addition to these three aspects, the study also identified factors that influence project management performance based on the results of observations and interviews.

2.2. Research Location

The research was conducted on the Gandus Water Treatment Plant (WTP) construction project with a capacity of 500 liters/second in Palembang City, South Sumatra. The location was selected based on the consideration that the project is a clean water infrastructure project with a level of complexity that requires effective project management.

2.3. Data Types and Sources

The research data consists of primary and secondary data. Primary data was obtained through:

1. Observation of project implementation;
2. Interviews with parties involved in the project; and
3. Documentation of implementation conditions in the field.

Secondary data was obtained from project documents, including:

1. Project time schedule;
2. Work progress report;
3. Budget data and cost realization;
4. Quality control documents;
5. Working drawings and other supporting documents.

2.4 Data Analysis Techniques

Data analysis was carried out descriptively quantitatively with the following stages.

a. Time analysis

Time analysis is carried out by comparing the planned schedule with the actual implementation of the work to determine the level of time compliance and potential delays.

b. Cost analysis

Cost analysis is carried out by comparing the planned budget with the actual implementation costs to determine the level of control and efficiency of budget use.

c. Quality analysis

Quality analysis is carried out by evaluating the conformity of work results to technical specifications, quality standards and contract documents.

d. Analysis of factors influencing project performance

Factor analysis was conducted based on the results of observations and interviews to identify internal and external factors that influence the achievement of project performance.

3. RESULTS AND DISCUSSION

3.1 Project Overview

The Gandus WTP construction project with a capacity of 500 liters per second is a clean water infrastructure project aimed at increasing the capacity of clean water services for the people of Palembang City, particularly the Gandus area and its surroundings.

In general, the project implementation involves several main work groups: preparatory work, structural and construction work, mechanical and electrical work, piping installation work, and testing and commissioning.

The complexity of this work requires strong coordination between the project owner, contractor, supervising consultant, labor, material suppliers, and other relevant parties. Therefore, controlling time, cost, and quality is a crucial part of project implementation.

3.2 Time Aspect Performance Evaluation

The evaluation results indicate that several projects experienced delays compared to the planned schedule during project implementation. These delays were not isolated but were influenced by several interrelated factors.

The main factors influencing the delays were material procurement delays, weather conditions, field coordination, and labor productivity.

Delays in material procurement can prevent certain projects from being executed according to the planned sequence. Unfavorable weather conditions can also reduce productivity, particularly for construction activities conducted in open areas. Furthermore, suboptimal coordination between parties can lead to delays in decision-making and project implementation.

To address these issues, the implementing party implemented various control measures, including monitoring work progress, adjusting schedules, increasing supervision, and accelerating work through reorganizing resources and work schedules.

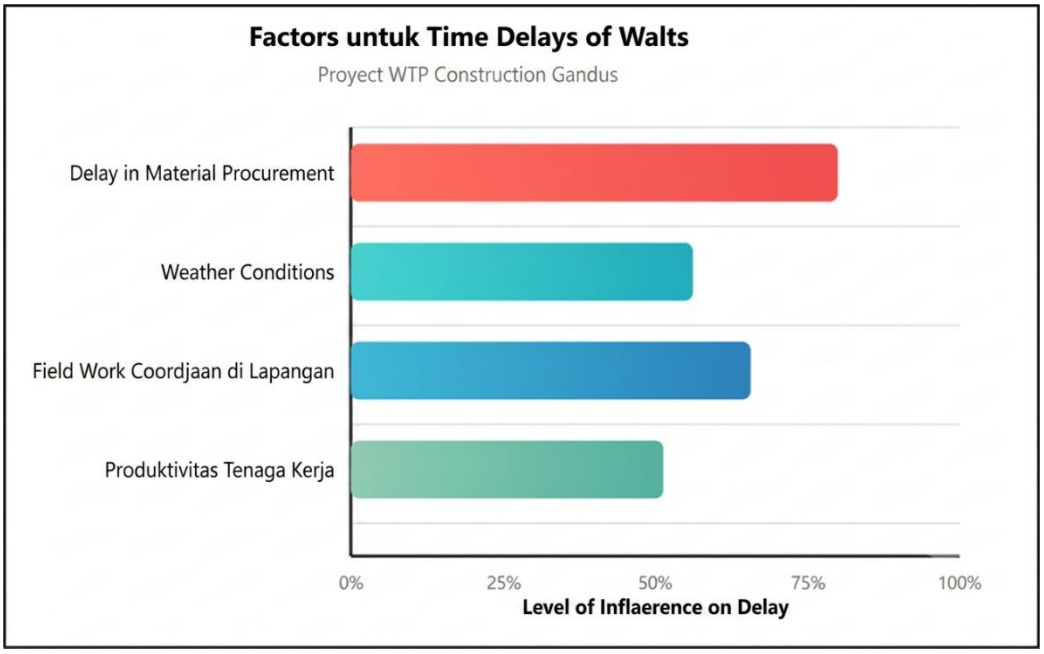


Figure 3.1 Factors Delaying the Gandus IPA Construction Project

Based on the evaluation results, time control performance can be categorized as quite good because the implementing team was able to take corrective action to address any delays. However, time control still needs to be improved through a more responsive monitoring system and more planned material procurement management.

3.3 Cost Aspect Performance Evaluation

Based on the analysis, project cost control has generally been quite effective. Budget utilization evaluations are conducted periodically to monitor expenditures and identify potential cost deviations.

During project implementation, several factors can potentially influence cost changes, including project changes, material price increases, additional work, and implementation delays.

Project changes can lead to adjustments to the volume and value of work. Meanwhile, material price increases can increase procurement costs. Implementation delays also have the potential to increase the project's indirect costs due to the increased duration of implementation.

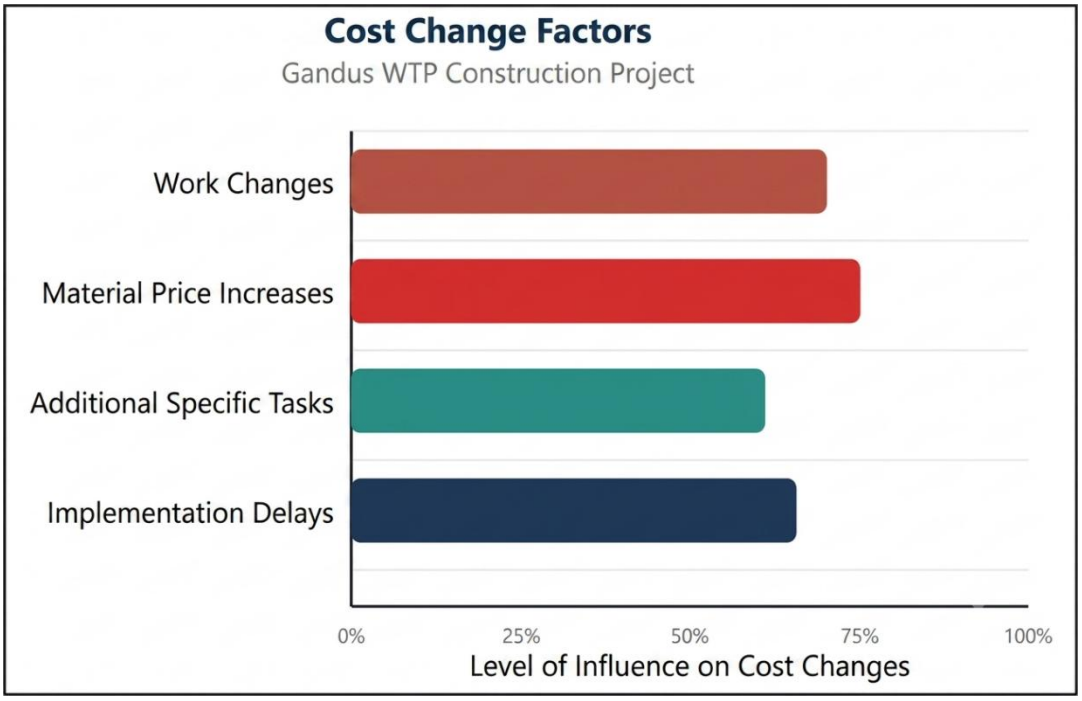


Figure 3.2 Factors that Change the Cost of a WTP Development Project

Despite some cost adjustments, the study results indicate that project cost realization remained within acceptable control limits. This demonstrates that the cost monitoring and evaluation system implemented was effective in maintaining control over the project budget.

3.4 Evaluasi Kinerja Aspek Mutu

Quality control is a crucial aspect of WTP construction because the facility must meet established technical requirements and service functions. Based on observations and quality control documents, the construction work generally meets the established technical specifications. Quality control is carried out through material inspections, work implementation supervision, work product testing, and periodic quality evaluations.

Material inspections are conducted to ensure the materials used comply with technical requirements. Work supervision is conducted to ensure implementation methods comply with technical documents. Work product testing is conducted to ensure construction meets the required standards.

However, several technical challenges remain that require improvement and adjustments in the field. These challenges can be addressed through supervision and corrective actions, ensuring they do not significantly impact overall quality achievement. Therefore, the quality management performance of the Gandus WTP construction project can be considered quite good, as the work generally meets the established technical specifications and quality standards.

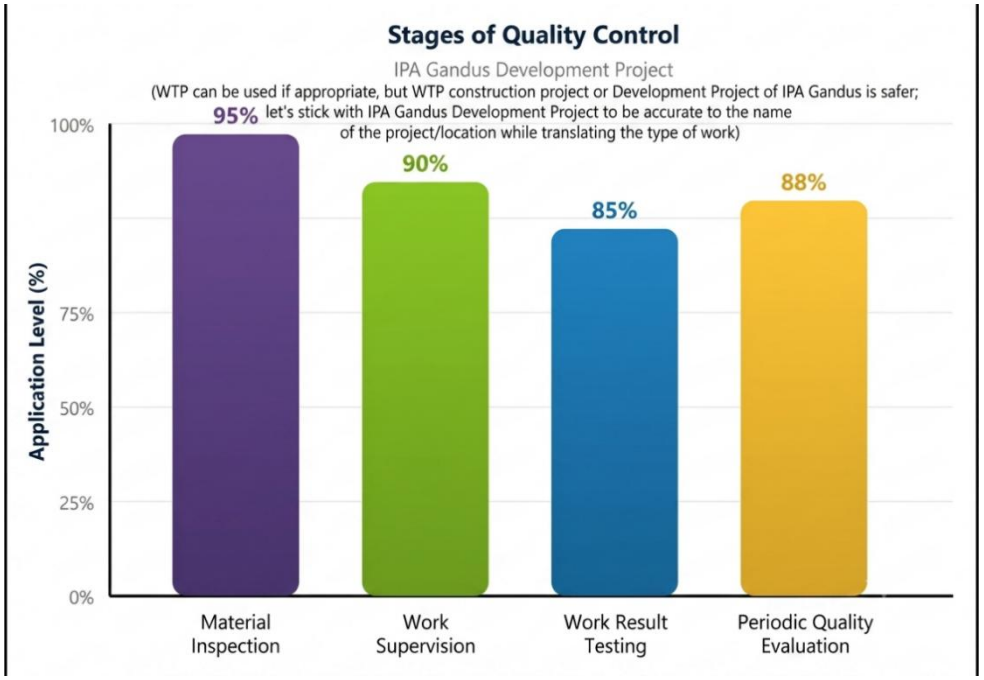


Figure 3.3 Stages of Quality Control of the Gandus IPA Construction Project

3.5 Factors Affecting Project Management Performance

The research results show that there are several main factors that influence project management performance in the construction of the Gandus IPA.

Table 1. Factors Affecting Project Management Performance

No.	Factor	Impact on Performance
1	Project planning	Determine the readiness of schedules, methods, and resources
2	Availability of materials	Affects the smoothness and continuity of work
3	HR Competence	Affects productivity and quality of work
4	Time and cost control	Maintaining project target achievement
5	Communication and coordination	Minimize errors and information delays
6	Weather and work environment	Affects productivity and smoothness of work

Project planning is a fundamental factor because it determines the readiness of the project. Good planning can reduce potential delays and increase the efficiency of resource use. Material availability also significantly impacts the smooth running of the project. Late arrival of materials can hinder the project and impact subsequent activities.

Human resource competency impacts productivity and work quality. A competent workforce and project management with strong coordination skills will support the achievement of project targets. Furthermore, communication and coordination systems between parties are crucial factors in resolving problems in the field. Effective communication can expedite decision-making and reduce the risk of implementation errors.

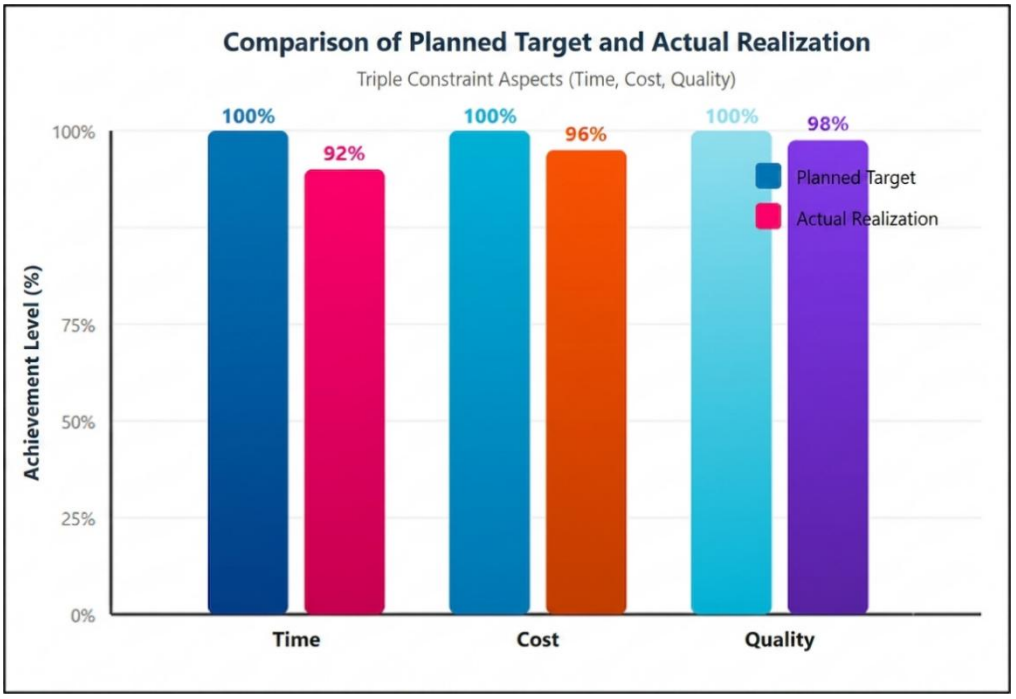


Figure 3.4 Comparison of Planned Targets and Realized Implementation of the Triple Constraint Aspect

4. CONCLUSION

Based on the research results and discussion, it can be concluded that:

1. The project management performance in the construction of the Gandus Water Treatment Plant (IPA) with a capacity of 500 liters/second in Palembang City has generally been quite good.
2. Based on the triple constraints of time, cost, and quality, there were some delays due to material procurement, weather conditions, work coordination, and labor productivity. However, these delays can be minimized through project acceleration and control efforts.
3. In terms of costs, budget control is carried out periodically and cost realization is still within acceptable control limits even though there are several adjustments due to changes in work, increases in material prices, additional work, and delays in implementation.
4. In terms of quality, the work results generally meet the established technical specifications and quality standards. Quality control is carried out through material inspection, work supervision, work results testing, and periodic evaluation.
5. Factors that influence project management performance include project planning, material availability, human resource competency, time and cost control, communication and coordination, and weather conditions and work environment.
6. Project performance can be improved by strengthening planning, controlling material procurement, improving coordination between parties, monitoring progress regularly, and implementing quick corrective actions against potential deviations in time, cost, and quality.

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ANALYSIS OF THE DETAIL ENGINEERING DESIGN (DED) REVIEW PROCESS IN THE GANDUS WATER TREATMENT INSTALLATION (IPA) PROJECT

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ABSTRACT

Water Treatment Plants (WTPs) are essential infrastructure for providing clean water to the community. The success of WTP construction is greatly influenced by the quality of planning outlined in the Detail Engineering Design (DED) document. In practice, DED documents require review to ensure the design complies with technical standards, existing field conditions, and project operational needs. This study aims to analyze the stages and mechanisms of DED review, identify the technical aspects that are the focus of the review, and evaluate the level of design conformity in the Gandus WTP Project. The study used a qualitative descriptive method with a case study approach. Data were obtained through field observations, interviews, documentation studies of DED documents and review results, and literature studies. Analysis was conducted on aspects of structure, hydraulics, water treatment processes, operations and maintenance, as well as conformity to technical standards and existing conditions. The results show that the DED review process was carried out through document completeness checks, technical evaluations, field condition reviews, problem identification, and the preparation of design improvement recommendations. The evaluation showed structural stability of 90%, structural strength of 88%, flow capacity of 90%, and hydraulic design conformity of 89%. The DED review contributed to 95% of design change prevention, 92% of compliance with technical standards, and 90% of design adjustments to field conditions. Therefore, the systematic and comprehensive DED review process plays a crucial role in improving planning quality, identifying potential technical issues early on, and minimizing the risk of design changes during the construction phase of the Gandus WTP Project.

Key words: Detailed Engineering Design, DED Review, Water Treatment Plant, Structure, Hydraulics, Gandus IPA.

1. INTRODUCTION

A Water Treatment Plant (WTP) is a vital infrastructure in the clean water supply system, processing raw water into water that meets the quality requirements of applicable standards. The WTP plays a crucial role in supporting the community's clean water needs, particularly in urban areas experiencing population growth and increased economic activity.

The success of a WTP project is greatly influenced by the quality of the technical planning outlined in the Detailed Engineering Design (DED) document. The DED document contains various technical information that serves as the basis for project implementation, including technical drawings, work specifications, structural calculations, hydraulic analysis, water treatment systems, and various other technical provisions. Therefore, the quality of the DED is crucial for smooth construction implementation, quality control, work efficiency, and the achievement of building functions in accordance with project objectives.

However, a prepared DED cannot always be implemented immediately without review. Existing field conditions may differ from the assumptions used during planning. Furthermore, regulatory changes, technological developments, operational needs, and actual project site conditions may necessitate adjustments to the prepared design.

A DED review process is necessary to ensure that the planned design meets technical and functional requirements and complies with applicable standards and regulations. A DED review not only examines the document's administrative completeness but also includes a technical evaluation of the structural design, water treatment system, hydraulic analysis, existing conditions, and operational and maintenance aspects.

A review process that is not conducted systematically and comprehensively can increase the risk of design changes, implementation delays, cost overruns, and construction quality issues. Conversely, a thorough DED review can identify potential problems early in the planning stage, allowing improvements to be made before construction begins.

The Gandus Water Treatment Plant (WTP) Project is a clean water infrastructure project aimed at improving clean water services for the community in the Gandus area and its surroundings. Before construction is carried out, a review process is carried out on the DED document to evaluate the readiness and feasibility of the design that has been prepared.

Based on these conditions, this study aims to analyze the DED review process for the Gandus IPA Project, including the stages of review implementation, the technical aspects reviewed, and the results of the evaluation of the design's suitability to technical standards and existing conditions in the field.

2. RESEARCH METHODOLOGY

2.1 Types and Approaches of Research

This research employs a qualitative descriptive method with a case study approach. This method is used to describe, analyze, and evaluate the DED review process for the Gandus IPA Project based on planning documents and actual conditions on the ground.

The case study approach was chosen because the research focuses on a single research object, the Gandus IPA Project. The research is not oriented toward hypothesis testing or inferential statistical analysis, but rather focuses on understanding the DED review process, the technical aspects reviewed, and the design's compliance with technical standards and field conditions.

2.2 Research Location and Object

The research was conducted on the Gandus Water Treatment Plant (WTP) Project. The research objects included the Deployment Design (DED) document, DED review results, existing field conditions, and the technical evaluation process conducted prior to the construction phase.

Data Types and Sources

Data yang digunakan terdiri atas data primer dan data sekunder. Data primer diperoleh melalui:

1. Observation of existing field conditions;
2. Interviews with related parties;
3. Information regarding the DED review stages;

4. Identify the technical aspects reviewed;
5. Information regarding obstacles and problems in the review process.

Secondary data was obtained from:

1. DED Document for Gandus IPA Project;
2. Technical drawings and working drawings;
3. Technical specifications;
4. Structural and hydraulic calculations;
5. Report on the results of the DED review;
6. Technical standards and regulations;
7. Previous literature and research.

2.4 Data collection technique

Data collection was conducted through observation, interviews, documentation studies, and literature review. Observations were used to compare the design with actual field conditions. Interviews were used to obtain information regarding the review process and results. Documentation studies were used to analyze the DED documents and review results, while literature studies served as a theoretical and technical basis for the evaluation.

2.5 Data Analysis Techniques

Data analysis was carried out descriptively and qualitatively through the following stages:

1. Data collection;
2. Identify aspects of the DED review;
3. Design suitability analysis;
4. Evaluation of DED review results;
5. 5. Discussion of results;
6. Drawing conclusions and recommendations.

Aspects analyzed include structure, hydraulics, water treatment processes, operations and maintenance, compliance with technical standards, and the results of the DED review.

3. RESULTS AND DISCUSSION

3.1 DED Review Process Stages

Based on the research results, the DED review process for the Gandus IPA Project was conducted systematically through several stages. These stages included checking the completeness of the planning documents, evaluating technical suitability, reviewing existing field conditions, identifying problems, and developing recommendations for design improvements.

The review process began with an examination of the DED documents to ensure the completeness of technical drawings, specifications, calculations, and other supporting documents. A technical evaluation of the completed design was then conducted.

The evaluation results were then compared with existing field conditions to identify any potential discrepancies between planning assumptions and actual conditions. If discrepancies were identified, recommendations for design adjustments were made.

These stages demonstrate that the DED review is a comprehensive evaluation process and goes beyond administrative audits. The review is conducted to ensure the planning document is truly ready to be used as a basis for construction.

3.2 Structural Aspect Review

Structural aspect reviews are carried out to ensure that the IPA building design meets the requirements for strength, stability and construction safety.

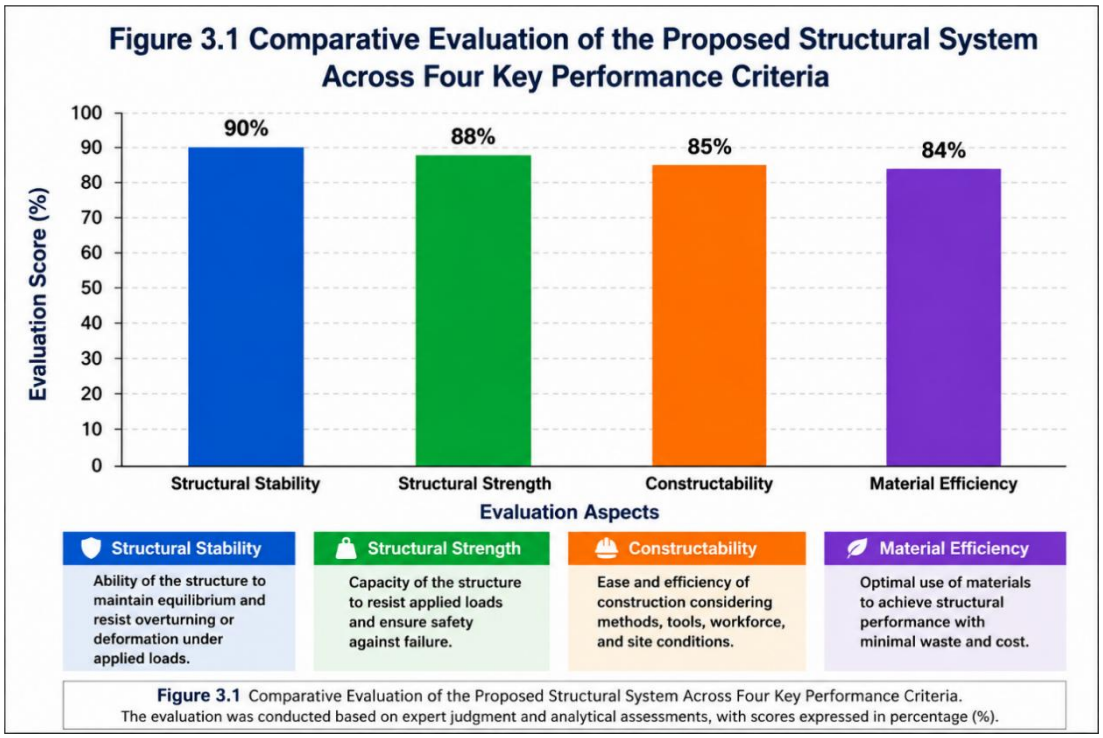


Figure 3.1 Comparative Evaluation of the Proposed Structural System Across Four Key Performance Criteria.
The evaluation was conducted based on expert judgment and analytical assessments, with scores expressed in percentage (%).

Based on the evaluation results, the structural stability level reached 90%, while the structural strength evaluation level reached 88%. These results indicate that the structural design generally meets the required technical requirements.

However, a review is still needed to identify specific areas requiring improvement. Structural review is crucial because the WTP building functions directly related to water treatment and storage, making its safety and stability a priority. The structural review results contribute to improving design quality and reducing the likelihood of structural problems during the construction phase.

3.3 Hydraulic Aspect Review

A hydraulic review was conducted on the water flow system, design discharge, channel and pipe dimensions, energy loss or headloss, and flow patterns.

The results showed that the flow capacity reached 90%, while the hydraulic design conformity reached 89%. This indicates that the hydraulic system was generally designed in accordance with the specified service capacity.

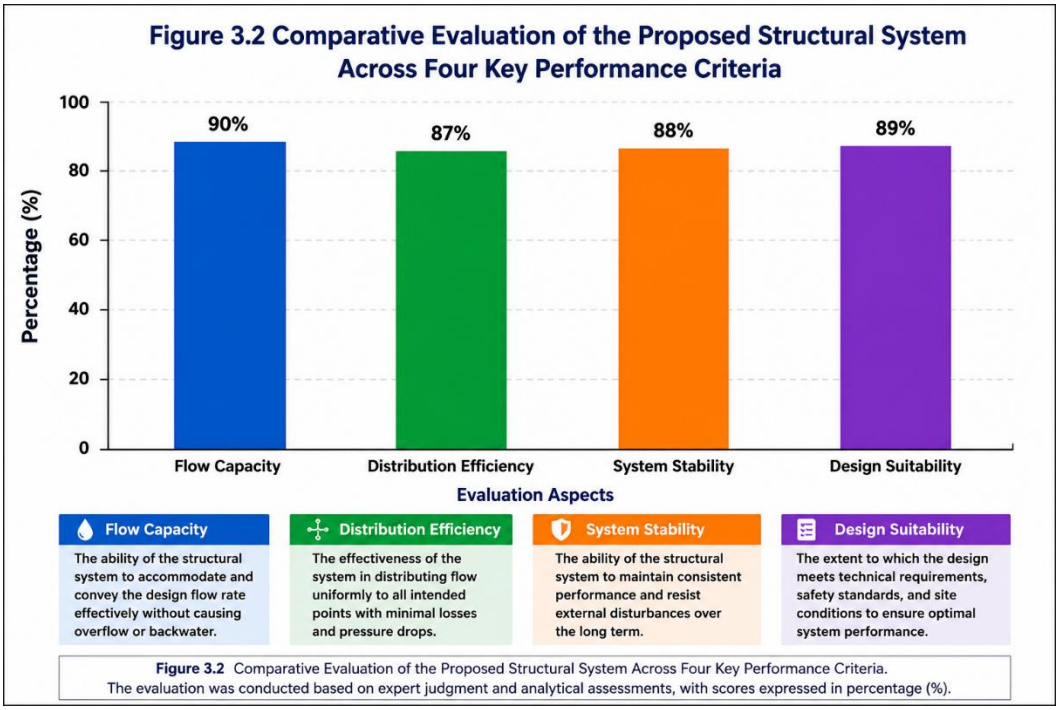


Figure 3.2 Comparative Evaluation of the Proposed Structural System Across Four Key Performance Criteria. The evaluation was conducted based on expert judgment and analytical assessments, with scores expressed in percentage (%).

The hydraulics review also yielded recommendations for improvements to the water flow system. Adjustments were made to increase flow efficiency and ensure the system functioned optimally according to the operational needs of the WTP. Hydraulics evaluation is crucial because inconsistencies in the flow system can impact the effectiveness of the water treatment process and the overall performance of the WTP system.

3.4 Water Treatment System Review

A review of the water treatment system was conducted to ensure that the planned treatment units met system requirements and were capable of supporting the water treatment process effectively.

The evaluation included the suitability of the treatment units, their capacity, and the effectiveness of the treatment process. The review results indicated that the water treatment system was well-planned and capable of supporting the operational needs of the WTP.

A review of the treatment system was also crucial to ensure the optimal interconnection between the system's components. Each treatment unit must have the appropriate capacity and function to avoid any disruptions to the overall water treatment process.

3.5 Operational and Maintenance Aspect Review

Operational and maintenance aspects are a crucial part of the DED review process. Ease of operation, maintenance access, the sustainability of the building's function, and supporting equipment are evaluated. The review results indicate that operational and maintenance aspects have been addressed in the planning process. This evaluation contributes to the facility's operational effectiveness and simplifies maintenance of the WTP building and equipment. By addressing operational aspects from the planning stage, potential operational and maintenance difficulties can be minimized once the facility is operational.

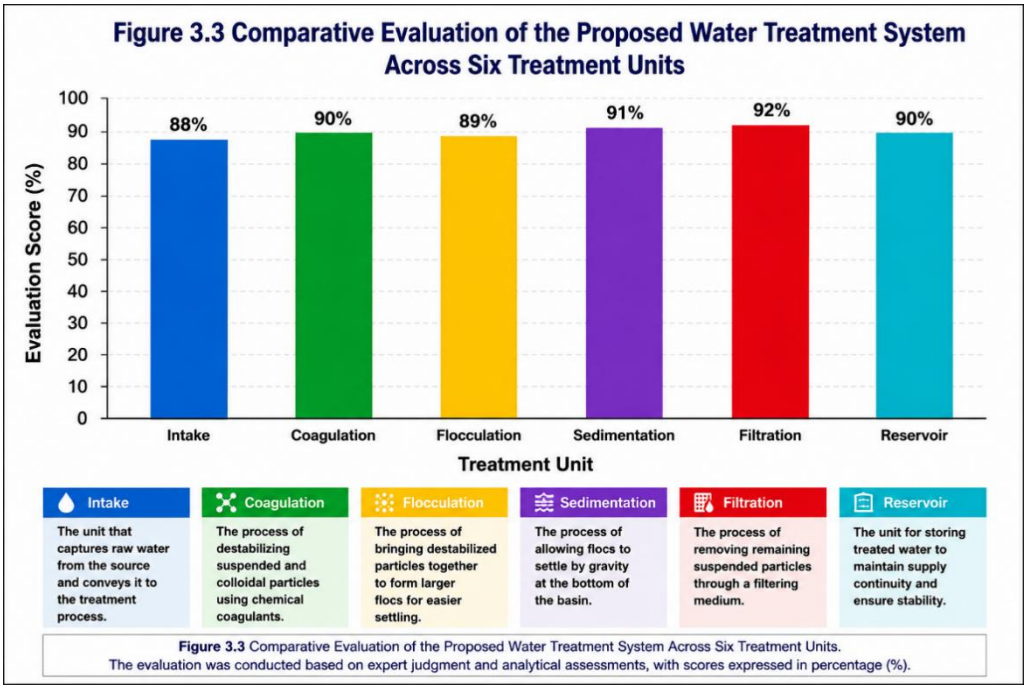


Figure 3.3 Comparative Evaluation of the Proposed Water Treatment System Across Six Treatment Units.
The evaluation was conducted based on expert judgment and analytical assessments, with scores expressed in percentage (%).

3.6 Evaluation of DED Review Results

The evaluation results show that the DED review process contributes to improving the quality of project planning.

Table 1. Evaluation of DED Review Results

Aspect	Contribution (%)
Design Change Prevention	95
Technical Standard Compliance	92
Field Adjustment	90
Operational Effectiveness	82
Structural Improvement	85
Hydraulic Improvement	88

Based on Table 1, the DED review process contributed the most to preventing design changes, with a score of 95%. This demonstrates that the pre-construction review process plays a crucial role in identifying and correcting potential design issues early on.

Compliance with technical standards reached 92%, while adjustments to field conditions reached 90%. These results demonstrate that the review process improved the alignment of planning documents with technical standards and actual conditions at the project site.
Contributions to hydraulic improvements reached 88%, while structural improvements reached 85%. Meanwhile, operational effectiveness reached 82%.



Source: Research Analysis Results

Overall, these results demonstrate that DED reviews play a significant role in improving the quality of planning documents. The review process identified potential technical issues prior to construction, allowing for early remediation.

3.7 Discussion

The research results indicate that the DED review for the Gandus WTP Project is a crucial step in ensuring the readiness of planning documents before construction begins. The DED review serves not only to verify the completeness of the documents but also as a technical evaluation process for the entire planning system. The evaluation covers the structure, hydraulics, water treatment system, and operations and maintenance.

For the structure, the review was conducted to ensure the strength and stability of the building. For the hydraulics, the evaluation focused on discharge, flow systems, and energy losses. Meanwhile, the evaluation of the water treatment system aimed to ensure the effective operation of the treatment units.

One important finding was the need for design adjustments to reflect actual site conditions, particularly regarding elevation, building layout, and water flow systems. These adjustments are necessary to ensure the design can be effectively implemented during the construction phase.

The review process also identified potential technical issues before construction began. This allowed for early implementation of recommended improvements, minimizing the risk of design changes during construction.

The high contribution of reviews to design change prevention (95%) demonstrates that DED reviews are a crucial tool in planning risk management. If potential nonconformities are identified early in the design phase, changes to the work during the construction phase can be minimized.

Thus, a systematic and comprehensive DED review not only improves the quality of the planning document but also supports construction efficiency and the operational readiness of the WTP facility.

4. CONCLUSION

Based on the research results regarding the analysis of the Detail Engineering Design (DED) review process for the Gandus Water Treatment Plant (IPA) Project, it can be concluded that:

1. The DED review process for the Gandus IPA Project is carried out systematically through checking the completeness of documents, technical evaluation, reviewing existing field conditions, identifying problems, and preparing recommendations for design improvements.
2. The technical aspects focused on by the review include structure, hydraulics, water treatment systems, and operations and maintenance. The evaluation results indicate a structural stability rating of 90%, structural strength of 88%, flow capacity of 90%, and hydraulic design suitability of 89%.

3. The DED review process successfully identified the need for design adjustments to existing conditions, especially in terms of elevation, building layout, and water flow systems.
4. DED review contributed significantly to preventing design changes by 95%, conforming to technical standards by 92%, and adjusting the design to field conditions by 90%.
5. Overall, the DED review process has proven to be instrumental in improving the quality of planning documents, identifying technical issues early on, reducing the risk of design changes during the construction phase, and supporting the operational effectiveness of the Gandus WTP Project.

5. RECOMENDATION

Based on the research results, several suggestions that can be given are as follows:

1. The DED review process for clean water infrastructure projects needs to be carried out systematically and comprehensively before construction work begins.
2. The review needs to involve experts from various fields, especially structures, hydraulics, water treatment processes, and maintenance operations.
3. A more detailed review of existing field conditions needs to be carried out so that any differences between design assumptions and actual conditions can be identified from the start.
4. Every finding resulting from the review needs to be documented systematically and followed up through revision of the DED document before being used as a basis for construction implementation.
5. For further research, the study can be developed by analyzing the relationship between the quality of DED review and project implementation performance, such as design changes, time delays, costs, and construction quality.

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THE EFFECT OF VARIATION IN PERCENTAGE OF PLASTIC FIBER FROM PACKAGING WASTE ON THE COMPRESSIVE STRENGTH OF K-200GRADE CONCRETE

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ABSTRACT

Concrete is one of the most widely used construction materials because it has high compressive strength and is easy to mold according to construction needs. However, concrete has brittle properties and relatively low tensile strength. On the other hand, the increasing use of plastic packaging produces waste that is difficult to decompose and has the potential to cause environmental pollution. One alternative for utilizing this waste is to use it as additional fiber in concrete mixtures.This study aims to analyze the effect of variations in the percentage of plastic fiber from packaging waste on the slump value and compressive strength of K-200 grade concrete and to determine the percentage of plastic fiber that provides the best performance. The study used a laboratory experimental method with four mixture variations, namely normal concrete without plastic fiber (NC), and concrete with the addition of plastic fiber of 1%, 2%, and 3% of the cement weight. The specimens were made in cube form and cured by immersion method until 28 days of age. The tests conducted included slump tests on fresh concrete and compressive strength tests at 28 days of age.The results showed that the slump value decreased with the increasing percentage of plastic fiber, from 9.5 cm in normal concrete to 8.7 cm, 7.9 cm, and 6.8 cm with the addition of plastic fiber of 1%, 2%, and 3%, respectively. The compressive strength test results showed that normal concrete produced a compressive strength of 202 kg/cm², while the 1%, 2%, and 3% variations produced compressive strengths of 199 kg/cm², 168 kg/cm², and 151 kg/cm², respectively.These results indicate that the addition of plastic fiber from packaging waste tends to reduce the compressive strength of concrete as the fiber percentage increases. The 1% variation is the variation with the best performance because it produces a compressive strength of 199 kg/cm² or a decrease of about 1.49% compared to normal concrete and is still close to the planned K-200 grade. The use of 1% plastic fiber from packaging waste can be an alternative for the use of plastic waste in concrete by still paying attention to the limit of the percentage of addition so that the decrease in compressive strength can be minimized.

Keywords: K-200 concrete, plastic fiber, packaging waste, compressive strength, slump.

1. INTRODUCTION

Concrete is one of the most widely used construction materials in infrastructure development, such as buildings, roads, bridges, drainage, and various other structures. The widespread use of concrete is supported by several advantages, including having high compressive strength, being resistant to environmental conditions, relatively easy to work with, and can be molded according to construction needs. Concrete is generally composed of cement, fine aggregate, coarse aggregate, and water which through the hydration process will harden into a solid and strong mass.Although it has various advantages, concrete also has weaknesses

in the form of brittle properties and relatively low tensile strength. This condition causes concrete to be susceptible to cracking due to loads, temperature changes, and shrinkage. Therefore, various material innovations continue to be developed to improve concrete performance, one of which is through the addition of fibers to the concrete mixture.Fiber reinforced concrete is concrete that is given additional fibers with specific purposes, including to control crack development, increase ductility, and improve the concrete's ability to absorb energy. Various types of fibers can be used in concrete, such as steel fibers, glass fibers, synthetic fibers, and fibers derived from waste materials.On the other hand, the problem of plastic waste is becoming an increasingly serious environmental issue. Plastic packaging is widely used in daily life because it has the properties of being lightweight, strong, waterproof, and economical. However, most plastic waste is difficult to decompose naturally so it can persist in the environment for a very long time. Improper management of plastic waste can cause environmental pollution and increase the volume of waste generation.One effort that can be made to reduce this problem is to utilize plastic waste as an additional material in the construction field. Plastic waste that is processed into fiber form has the potential to be used as an additive in concrete mixtures. This utilization is expected to provide added value to waste while supporting the application of the sustainable construction concept.However, the addition of plastic fibers to concrete mixtures can affect the characteristics of fresh and hardened concrete. An increase in the amount of fiber can cause a decrease in workability due to increased internal friction in the mixture. In addition, the use of excessive amounts of fiber can cause the mixture to become less homogeneous, increase air voids, and reduce the bond between cement paste and aggregate, thus potentially reducing the compressive strength of concrete.K-200 grade concrete is one type of concrete that can be used for various simple construction works. Therefore, research on the utilization of plastic fiber from packaging waste in K-200 grade concrete is important to determine the effect of fiber percentage variations on concrete characteristics and to obtain the percentage of use that provides the best performance.Based on the above description, this study aims to analyze the effect of variations in the percentage of plastic fiber from packaging waste on the slump value and compressive strength of K-200 grade concrete and to determine the percentage of plastic fiber that provides the best results at 28 days of concrete age.

2. RESEARCH METHODOLOGY

2.1. Type and Location of Research

This study uses a laboratory experimental method that aims to determine the effect of variations in the percentage of plastic fiber from packaging waste on the compressive strength of K-200 grade concrete. The research was conducted at the Materials and Structural Laboratory of Civil Engineering, Faculty of Engineering, Universitas Palembang.The stages of the research include material preparation, examination of material characteristics, concrete mix design, plastic fiber preparation, specimen fabrication, fresh concrete testing, specimen curing, compressive strength testing, and data analysis of test results.

2.2. Research Materials

The materials used in the study consisted of:

1. Portland cement as a binder.
2. Fine aggregate in the form of sand.
3. Coarse aggregate in the form of gravel or crushed stone.

4. Clean water for concrete mixture.
5. Polypropylene (PP) plastic fiber from packaging waste that has been cleaned, dried, and cut into certain sizes.

Material testing was carried out before the specimen fabrication process. The test results of fine aggregate showed an average dry specific gravity of 2.362 and an average SSD specific gravity of 2.427 with an average water absorption of 2.775%. The average silt content of fine aggregate was 0.807%. Meanwhile, coarse aggregate had an average water content of 3.702%, an average silt content of 3.297%, an average dry specific gravity of 2.326, an SSD specific gravity of 2.377, and an average absorption of 2.154%. These test results were used as a basis to ensure the material was suitable for use in the concrete mixture.

2.3. Mix Variations

Plastic fiber from packaging waste was used as an additive based on the percentage of cement weight. The mix variations used consisted of four groups as shown in Table 1.

Table 1. Concrete Mix Variations

Variation	Plastic Fiber Percentage
BN	0%
BSPLK1%	1%
BSPLK2%	2%
BSPLK3%	3%

Note:
BN = Normal concrete without the addition of plastic fiber.
BSPLK1% = Concrete with the addition of plastic fiber of 1% of cement weight.
BSPLK2% = Concrete with the addition of plastic fiber of 2% of cement weight
BSPLK3% = Concrete with the addition of plastic fiber of 3% of cement weight.

The basic composition of the concrete mixture was made the same for all variations. The difference in each mixture lies in the amount of plastic fiber added. For three specimens, the basic material requirements used were cement of 4.294 kg, sand of 8.918 kg, gravel of 12.578 kg, and water of 2.623 liters. The addition of plastic fiber was 0.043 kg for the 1% variation, 0.086 kg for the 2% variation, and 0.129 kg for the 3% variation.

2.4. Specimen Fabrication and Curing

Concrete materials were weighed according to the planned mix composition. Fine aggregate, coarse aggregate, cement, and plastic fiber were mixed until homogeneous. Then water was added gradually while stirring was done until a uniform concrete mixture was obtained.Fresh concrete was then tested using a slump test. After that, the mixture was placed into cube-shaped specimen molds and compaction was carried out to reduce air voids. The specimens were left for approximately 24 hours before the molds were removed. Furthermore, the specimens were immersed in water as a curing process until reaching 28 days of test age.

2.5. Slump Test

The slump test was carried out using an Abrams cone to determine the workability of fresh concrete. The slump value was obtained based on the difference between the height of the mold and the height of the concrete after the mold was lifted vertically.

2.6. Compressive Strength Test

The compressive strength test was conducted at 28 days of age using a Compression Testing Machine. The specimen was placed on the compression testing machine and load was

applied gradually until failure occurred. The compressive strength value was calculated based on the ratio between the maximum load received by the specimen and the cross-sectional area of the specimen.The test result data were analyzed descriptively and comparatively by comparing the slump value and compressive strength for each variation of plastic fiber percentage. The results were then presented in the form of tables and graphs to determine the trend of changes in concrete characteristics due to the addition of plastic fiber.

3. RESULTS AND DISCUSSION

3.1. Slump Test Results

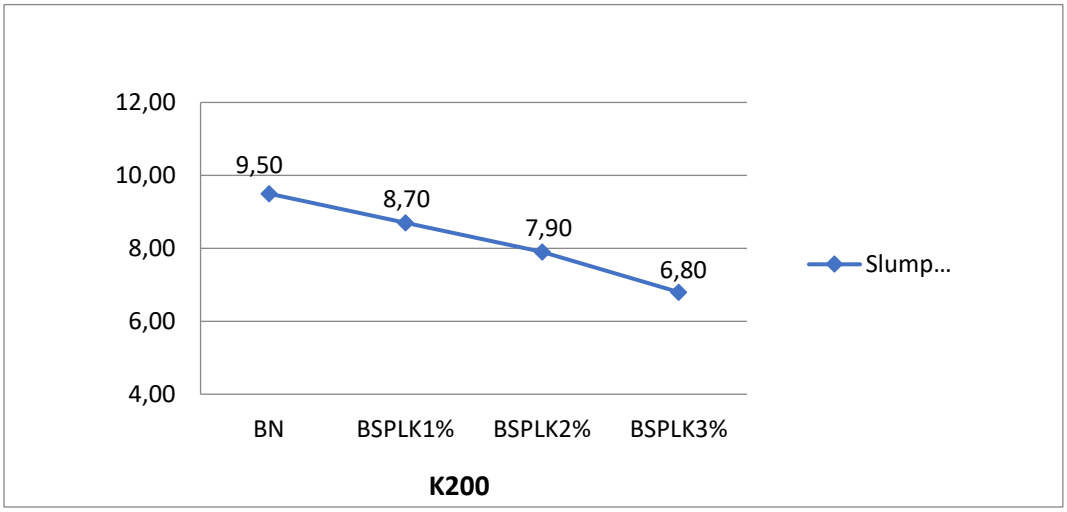
The results of the fresh concrete slump test for each mix variation are shown in Table 2.

Table

2. Concrete Slump Test ResultsTabel

Concrete Variations	Plastic Fiber Percentage (%)	Slump Value (cm)
Normal Concrete (NC)	0%	9,5
Concrete with 1% plastic fiber from packaging waste of cement weight (BSPLK1%)	1%	8,7
Concrete with 2% plastic fiber from packaging waste of cement weight (BSPLK1%)	2%	7,9
Concrete with 3% plastic fiber from packaging waste of cement weight (BSPLK1%)	3%	6,8

Figure 1. Graph of Concrete Slump Test Relationship



The test results showed that the slump value decreased with the increasing percentage of plastic fiber. Normal concrete had the highest slump value of 9.5 cm, while the addition of plastic fiber of 1%, 2%, and 3% resulted in slump values of 8.7 cm, 7.9 cm, and 6.8 cm, respectively.The decrease in slump value indicates that the addition of plastic fiber affects the workability of fresh concrete. Plastic fibers dispersed in the mixture can increase internal friction and hinder the movement of materials during the mixing and compaction process. In addition, the elongated shape of the fiber can cause the mixture to become stiffer so that the more fiber used, the lower the workability of the concrete.The decrease in slump value from

normal concrete to the 1% plastic fiber variation was about 8.42%. In the 2% variation, the decrease reached about 16.84%, while in the 3% variation it reached about 28.42%. Thus, an increase in the percentage of plastic fiber gives a tendency for a greater decrease in workability.

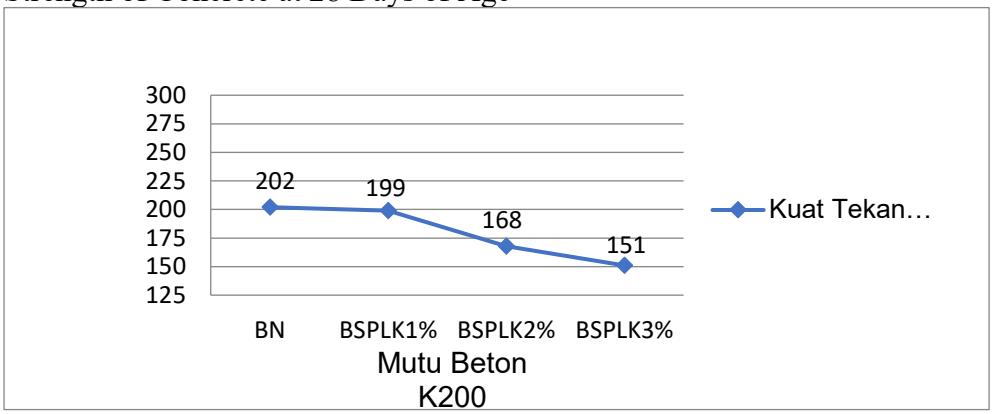
3.2. Concrete Compressive Strength Test Results

The results of the compressive strength test of concrete at 28 days of age are presented in Table 3.

Table 3. Results of Compressive Strength Test of Concrete at 28 Days of Age

Concrete Variations	Plastic Fiber Percentage (%)	Concrete Compressive Strength (kg/cm^2)
Normal Concrete (NC)	0	202
BSPLK1%	1	199
BSPLK2%	2	168
BSPLK3%	3	151

Figure 2. Graph of Relationship Between Percentage of Plastic Fiber and Compressive Strength of Concrete at 28 Days of Age



Based on Table 3, normal concrete without the addition of plastic fiber produced the highest compressive strength of 202 kg/cm². With the addition of plastic fiber of 1%, the compressive strength decreased to 199 kg/cm². Furthermore, the compressive strength further decreased to 168 kg/cm² in the 2% variation and 151 kg/cm² in the 3% variation.These results indicate that an increase in the percentage of plastic fiber tends to decrease the compressive strength of concrete. At a 1% addition, the decrease in compressive strength was relatively small, only 3 kg/cm² or 1.49% compared to normal concrete. This condition shows that at low levels, the addition of plastic fiber can still be maintained without causing a significant decrease in compressive strength.However, at levels of 2% and 3%, the decrease in compressive strength became greater. The compressive strength in the 2% variation decreased by 34 kg/cm² or 16.83% compared to normal concrete. Meanwhile, the 3% variation experienced a decrease of 51 kg/cm² or 25.25%.The decrease in compressive strength is suspected to be related to the characteristics of plastic fiber which has a relatively smooth surface and does not chemically react with cement paste. This condition causes the bond between plastic fiber and the concrete matrix to be not as strong as the bond between cement paste and aggregate. An increase in the amount of fiber can also cause the mixture to become less homogeneous and increase the

possibility of air voids.The more voids there are, the lower the density of concrete and the effective cross-sectional area that bears the compressive load. As a result, the ability of concrete to withstand compressive loads becomes lower. This is in line with the tendency of slump test results, where an increase in the amount of fiber causes workability to decrease.

3.3. Optimum Percentage Analysis

Based on the test results, normal concrete produced a compressive strength of 202 kg/cm². Although normal concrete had the highest compressive strength, the 1% plastic fiber variation produced a value of 199 kg/cm² or only 1.49% lower than normal concrete.The 2% and 3% variations resulted in a greater decrease in compressive strength, thus they are less effective if the main purpose of using plastic fiber is to maintain the compressive strength of K-200 grade concrete. Therefore, based on the results of this study, a percentage of 1% of cement weight is considered the best variation among mixtures using plastic fiber.These results indicate that the utilization of plastic fiber from packaging waste at low levels can still be applied to K-200 grade concrete. In addition to providing added value to plastic waste, the use of 1% plastic fiber can maintain the compressive strength of concrete at a value close to normal concrete.

4. CONCLUSION

Based on the results of the study on the effect of variations in the percentage of plastic fiber from packaging waste on the compressive strength of K-200 grade concrete, it can be concluded as follows:

1. The addition of plastic fiber from packaging waste affects the workability of fresh concrete. The slump value decreased from 9.5 cm in normal concrete to 8.7 cm, 7.9 cm, and 6.8 cm with the addition of plastic fiber of 1%, 2%, and 3%, respectively.
2. The addition of plastic fiber from packaging waste tends to reduce the compressive strength of concrete. The compressive strength of normal concrete was 202 kg/cm², while the 1%, 2%, and 3% variations produced compressive strengths of 199 kg/cm², 168 kg/cm², and 151 kg/cm², respectively.
3. The increase in the percentage of plastic fiber from 0% to 3% shows a tendency for a decrease in compressive strength. The decrease in compressive strength compared to normal concrete was 1.49% in the 1% variation, 16.83% in the 2% variation, and 25.25% in the 3% variation.The 1% plastic fiber variation is the best variation among mixtures using plastic fiber because it produces a compressive strength of 199 kg/cm² and experiences a relatively small decrease compared to normal concrete.
4. The utilization of plastic packaging waste as additional fiber in concrete has the potential to be an alternative for waste management and supports the concept of sustainable construction. However, its use needs to pay attention to the percentage of addition so as not to cause a significant decrease in compressive strength.

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DESIGN OF A ROOFTOP SOLAR POWER GENERATION SYSTEM FOR OFFICE BUILDINGS (A CASE STUDY OF TVRI SOUTH SUMATRA)

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ABSTRACT

This study aims to design a rooftop solar power generation (PLTS) system for office buildings as an effort to utilize renewable energy to meet electricity needs. The method used in this study is a quantitative descriptive method with a technical calculation analysis approach based on data on building electricity needs and solar energy potential. Based on the analysis, it was determined that the building's electricity needs reach approximately 1,521 kWh per day. The planned solar power system is intended to supply approximately 60% of this total electricity demand. Using an average solar radiation value of 4.8 kWh/m²/day, the solar power system capacity is 190 kWp. This system uses 346 solar modules with a capacity of 550 Wp and requires an installation area of approximately 865 m². The calculations indicate that the planned solar power system can generate approximately 912 kWh of electricity per day, or approximately 332,880 kWh per year. The system is an on-grid system configured with four 50 kW inverters, adjusted to meet the building's load requirements.

Based on the research results, it can be concluded that the proposed rooftop solar power system for office buildings is technically feasible and can contribute to reducing electricity use from the conventional grid.

Keywords: rooftop solar power plants, solar energy, office buildings, on-grid systems, renewable energy

INTRODUCTION

A. Background

One feasible solution is the utilization of solar energy through solar power plants (PLTS). A PLTS is a power generation system that harnesses solar radiation and converts it into electrical energy through photovoltaic technology. The use of solar energy has several advantages, including being renewable, environmentally friendly, and having abundant potential in Indonesia.

The implementation of PLTS in office buildings and public facilities has been widely implemented as an effort to increase energy efficiency and reduce dependence on conventional energy. In the context of the TVRI Main Building, South Sumatra Station, the planning of a PLTS system is expected to provide a solution to meet some of the electricity needs independently, while also supporting the development of new and renewable energy programs in Indonesia.

Based on this description, a comprehensive planning of the Solar Power Plant (PLTS) system is needed that aligns with the characteristics of the electricity needs of the TVRI Main Building, South Sumatra Station, so that the designed system can operate optimally and efficiently.

B. Problem Formulation

Based on the background described, the problem formulation in this research is as follows:

1. How to determine the capacity of a rooftop solar power plant (PLTS) system that is appropriate to the electrical energy needs of an office building?

2. How to analyze the potential electrical energy that can be generated from the planned PLTS system?

C. Research Objectives and Results

The objectives of this research are as follows:

1. To determine the capacity of a rooftop solar power plant (PLTS) system that is appropriate to the electrical energy needs of an office building.

2. To analyze the potential electrical energy that can be generated by the planned PLTS system.

RESEARCH METHODOLOGY

The data used includes building electrical load data, solar radiation data, and technical specifications of PLTS components such as solar modules and inverters. This data is then analyzed to determine the appropriate PLTS system capacity and estimate the electrical energy that can be generated.

• PLTS Capacity Calculation

PLTS system capacity is determined based on the electrical energy needs to be supplied and the average daily solar radiation. The energy to be supplied by the PLTS is calculated using the equation:

$$EPLTS = Suplai\ Presentation \times EBeban$$

Next, the PLTS capacity is calculated using the equation :

$$PPLTS = EPLTSH$$

where:

PPLTS= = solar power plant capacity (kWp)

EPLTS== energy supplied by the solar power plant (kWh/day)

H = average solar radiation (kWh/m²/day)

Solar Power Plant Energy Calculation

The electrical energy generated by the solar power plant system is calculated using the equation:

$$E = P \times H$$

where:
E = electrical energy generated (kWh/day)
P = solar power plant capacity (kWp)
H = average solar radiation (kWh/m²/day)
The annual energy is calculated using the equation:

$$Eyear=E\times365$$

RESULTS AND DISCUSSION

Analysis of Energy Needs and Solar Power Plant Capacity

Based on measurement data and field data collection, it is known that the total electrical power used in the research building is 190,122 kW. Assuming an average operating time of 8 hours per day, the daily electricity requirement can be calculated as follows:

$$Eload=190,122\times8Eload=1.520,976 \text{ kWh/hari}$$

Therefore, the building's electricity requirement is approximately 1,521 kWh per day.

In this study, the solar PV system is planned to supply approximately 60% of the building's electricity requirement. Therefore, the energy that must be supplied by the solar power plant system is:

$$EPLTS=0,6\times1.521EPLTS=912,6 \text{ kWh/day}$$

Based on average solar radiation data of 4.8 kWh/m²/day, the solar power plant system capacity can be calculated as follows:

$$PPLTS=912,64,8PPLTS=190,125 \text{ kWp}$$

The calculation results show that the solar power plant system capacity required to meet the energy supply target is approximately 190 kWp.

Planned Solar Power Plant System Configuration
Once the system capacity is determined, the next step is to determine the requirements for the system's main components.
The number of solar modules is calculated using a 550 Wp module capacity using the following equation:

$$N=PPLTSPmodulN=190.000550N=345,45$$

So the number of modules used is rounded up to 346 units.
The installation area is calculated based on the effective module area of approximately 2.5 m² per unit, resulting in
:

$$A=346\times2,5A=865 \text{ m2}$$

A 50 kW inverter is used to convert DC to AC electricity. With a system capacity of 190 kWp, the following are required:

$$19050=3,8$$

or rounded up to four 50 kW inverter units.

The configuration used is an on-grid system, so the electricity generated by the solar power plant can be used directly to supply building loads while remaining connected to the PLN electricity grid.

Potential Electrical Energy Generated

The potential electrical energy generated by a solar power plant system is calculated based on the system capacity and average daily solar radiation.

$$E=P\times HE=190\times 4,8E=912 \text{ kWh/day}$$

Based on these calculations, the solar power system can generate approximately 912 kWh of electricity per day.

To determine the long-term energy production potential, an annual energy calculation was performed:

$$Eyear=912\times 365Eyear=332.880 \text{ kWh/year}$$

These results indicate that the planned solar power system has significant energy production potential and is capable of supplying approximately 60% of the building's electricity needs. Therefore, implementing a rooftop solar power system can be an effective alternative to reduce dependence on conventional grid electricity while supporting the use of renewable energy.

CONCLUSION

1. Based on the building's electricity demand of approximately 1,521 kWh per day and an average solar radiation of 4.8 kWh/m²/day, the required solar power system capacity is 190 kWp. The system uses 346 solar modules with a capacity of 550 Wp, requires an installation area of approximately 865 m², and utilizes four 50 kW inverters in an on-grid configuration.

2. The planned PLTS system has the potential to produce electrical energy of ±912 kWh per day or around 332,880 kWh per year, so it is able to supply around 60% of the building's electrical energy needs and has the potential to reduce dependence on electrical energy supplies from conventional networks.

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ELECTRICAL PRE-COMMISSIONING AND COMMISSIONING IN OIL AND GAS PROJECTS: APPLICATION OF OPERCOM METHODOLOGY AND SYSTEM–SUBSYSTEM APPROACH

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Abstract

Electrical pre-commissioning and commissioning are critical stages in oil and gas projects to ensure installation, testing, and operational readiness in compliance with engineering design, international standards, and safety requirements (IEC, 2025; IEC, 2023; IEC, 2026; IEC, 2019; IEC, 2021; IEEE, 2010; IEEE, 2012; API, 2023; NFPA, 2024; Horsley, 1998; Bendiksen & Young, 2005; Samie, 2016). This study was conducted on an offshore oil and gas facility in Southeast Asia, applying the OPERCOM methodology with a System–Subsystem approach as defined in GS EP EXP 103 (TotalEnergies, 2018). Using an applied engineering case study, the research covered installation verification, pre-commissioning tests, commissioning tests, and punch list management until RFC and AOC/RFSU readiness. Results show that the System–Subsystem approach improved commissioning control, with 83% of punch items resolved before commissioning and energization. Punch list distribution revealed most findings originated from Construction (49%), followed by Pre-commissioning (36%) and Commissioning (15%). The systematic application of OPERCOM enhanced system reliability, reduced start-up risks, and ensured safe handover to the Company (Nascimento et al., 2021; Wanasinghe et al., 2020).

Keywords: *Commissioning, System–Subsystem, Testing, Energization, Reliability, OPERCOM*

1. INTRODUCTION

Electrical systems are fundamental infrastructure in oil and gas facilities, providing power and control for production processes, utilities, safety equipment, emergency services, and plant automation. Their reliability directly influences safety, availability, and overall performance throughout the facility's lifecycle (IEC, 2025; IEC, 2023). Critical components such as uninterruptible power systems (UPS) ensure continuous supply for essential equipment during disturbances (IEC, 2021), while rotating electrical machines like motors and generators sustain production processes and must comply with international standards to guarantee reliability (IEC, 2026). Protection by enclosures (IP Code) safeguards installations against environmental and mechanical impacts (IEC, 2019), and compliance with explosive atmosphere standards is mandatory in hazardous environments (IEC, 2026). Therefore, effective pre-commissioning and commissioning are essential to confirm installations meet design intent and operational requirements (IEEE, 2010; IEEE, 2012; NFPA, 2024; Horsley, 1998; Bendiksen & Young, 2005).

This study is driven by several key questions. First, how can the application of the OPERCOM methodology with the System–Subsystem approach accelerate the electrical commissioning process (TotalEnergies, 2018)? Second, to what extent can installation quality verification and equipment integrity in accordance with international standards improve system reliability (IEC, 2025; IEC, 2023; IEC, 2026; Samie, 2016)? Third, how effective is punch list management in supporting operational readiness before

energization (IOGP, 2018; Ghazali et al., 2019; Ghazi, 2025; Khalid, 2025)? Finally, what practical benefits does OPERCOM offer for safety and sustainability in complex energy project operations (ISO, 2015; ISO, 2018; Nascimento et al., 2023; Rui et al., 2017; Ray & Rajashekara, 2023).

The objectives of this research are fourfold. The study aims to analyze the application of the OPERCOM methodology in the execution of pre-commissioning and commissioning (TotalEnergies, 2018). It seeks to assess the quality of installation and the performance of electrical systems based on IEC, IEEE, API, and NFPA standards (IEC, 2025; IEC, 2023; IEC, 2026; IEC, 2019; IEC, 2021; IEEE, 2010; IEEE, 2012; API, 2023; NFPA, 2024). Additionally, the research evaluates the effectiveness of punch list management (IOGP, 2018; Ghazali et al., 2019; Ghazi, 2025; Khalid, 2025; Nascimento et al., 2021) and emphasizes the benefits of this study as a structured framework to improve the reliability and safety of electrical systems.

The expected benefits of this research are academic, practical, and industrial. Academically, the study serves as a scientific reference for students and researchers in understanding the application of OPERCOM (Nascimento et al., 2023; Rui et al., 2017). Practically, it provides guidance for engineers and practitioners to improve the effectiveness of commissioning (Horsley, 1998; Bendiksen & Young, 2005; Samie, 2016). Industrially, it supports the operational readiness of energy facilities and strengthens stakeholder confidence by demonstrating that systematic commissioning enhances safety, reliability, and sustainability (Ray & Rajashekara, 2023; API, 2023; NFPA, 2024).

2. RESEARCH METHODOLOGY

2.1 Respondents and Location

The study was conducted at an offshore oil and gas facility in Southeast Asia. The electrical systems examined include transformers, switchgear, MCCs, UPS units, and motors. The project name and specific location are withheld due to company confidentiality.

2.2 Instruments

A range of instruments was employed to verify installation quality and operational readiness:

- Insulation Resistance Tester for cable integrity (IEC, 2025).
- Hipot Tester for high voltage withstand testing (IEC, 2023; IEC, 2026).
- Relay Test Set for system protection verification (IEEE, 2010; IEEE, 2012).
- Transformer Winding Resistance Meter for transformer conformity (IEC, 2023).
- Battery Analyzer for UPS and batteries (IEC, 2021).
- Supporting documents included single line diagrams (SLDs), cable schedules, load lists, and vendor manuals.
- A digital commissioning platform **(**ICAPS**)** was used for punch list management and documentation (TotalEnergies, 2018; Nascimento et al., 2021).

2.3 Procedure (OPERCOM Framework)

2.3.1 Definition of OPERCOM

OPERCOM™ is a methodology developed by TotalEnergies to structure pre-commissioning and commissioning activities. It is defined through four key specifications that establish rules, engineering practices, and execution steps required to ensure safe and reliable project start-up:

- GS EP EXP 101:2017 – General pre-commissioning and commissioning principles.
- GS EP EXP 103:2018 – Pre-commissioning and commissioning engineering.
- GS EP EXP 105:2005 – Pre-commissioning execution.
- GS EP EXP 107:2017 – Commissioning execution.

This framework aligns with industry practices described by Horsley (1998), Bendiksen & Young (2005), and Samie (2016).

2.3.2 ICAPS (Integrated Commissioning and Progress System)

ICAPS is the software tool used during pre-commissioning and commissioning to support the OPERCOM™ methodology. It records progress, organizes tasks, and ensures readiness for safe start-up (TotalEnergies, 2018; Nascimento et al., 2021).

2.3.3 Pre-commissioning

Pre-commissioning refers to inspections and equipment testing performed without electrical energization, ensuring installations are correctly constructed before commissioning begins (IEC, 2025; IEC, 2023; Jain et al., 2010).

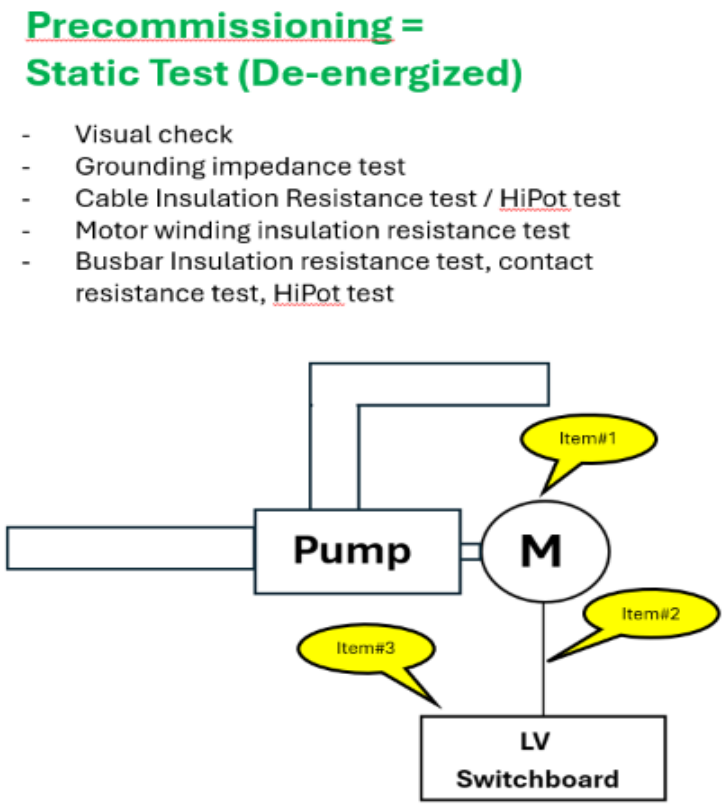


Figure 1 Pre-commissioning Activity

Figure 1 illustrates the pre-commissioning activities, where visual checks and tests are carried out individually for each item.

- Pre-commissioning includes two main types of activity:
  - ✓ **Conformity Checks:** carried out on each item to verify compliance with project requirements.
  - ✓ **Static/De-energized Tests:** performed on items to verify their individual quality and performance.
- Pre-commissioning activities can be conducted at various locations: factory, workshop, worksite, and final site.
- Pre-commissioning This task is validated upon successful completion of all these checks and tests.

2.3.4 Commissioning

Commissioning involves dynamic and energized testing to ensure the facility is functionally complete, safe, reliable, and ready for operation (IEC, 2026; IEEE, 2010; NFPA, 2024; Bendiksen & Young, 2005).

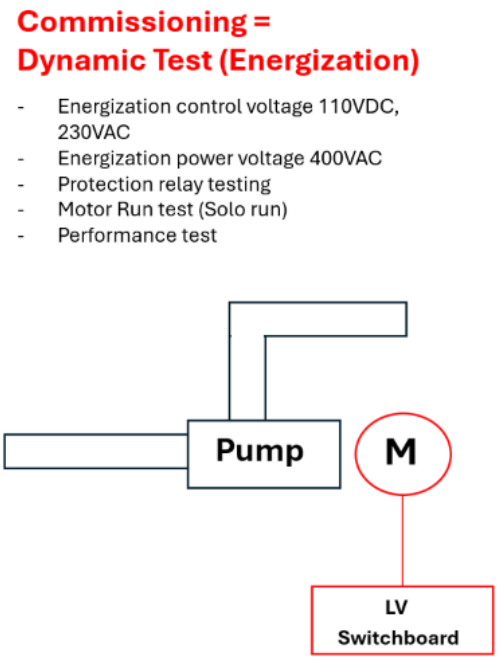


Figure 2 Commissioning Activity

Figure 2 illustrates the electrical commissioning activities, specifically the motor run test, where the motor is energized with real voltage under no-load conditions.

Commissioning includes three main types of activity:

- Preliminary Checks – to ensure completion of pre-commissioning works, dossiers, and operability (Horsley, 1998; Bendiksen & Young, 2005).
- Functional Tests – to demonstrate that each elementary plant function operates correctly (IEC, 2026; IEEE, 2010).
- Operational Tests – to prove equipment readiness for continuous operation by running it over a significant period of time (NFPA, 2024; Samie, 2016).

Commissioning activities may be carried out at various locations, including the factory, workshop, worksite, and final site. Commissioning is validated upon successful completion of all these activities, including, if required, operational tests with hydrocarbons and hazardous materials (TotalEnergies, 2017).

2.3.5 Start-up

Start-up is the stage when utilities and process equipment are gradually activated until the entire plant is fully operational. It represents the final validation of operational readiness before the system enters regular operation (TotalEnergies, 2017; Samie, 2016).

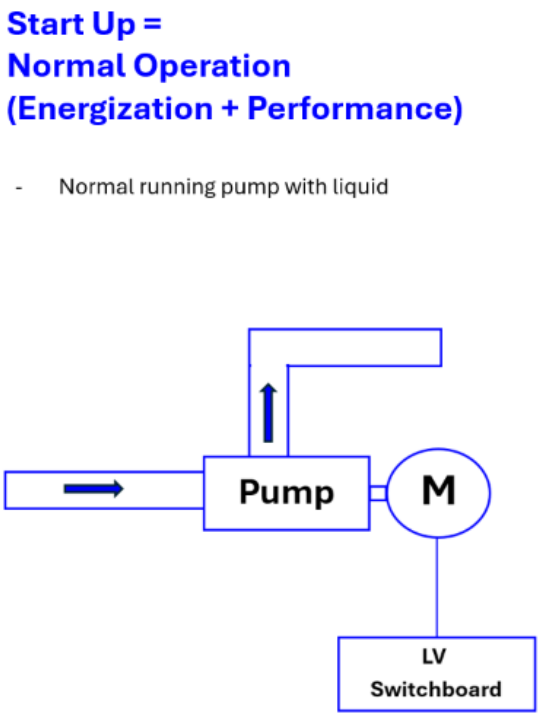


Figure 3 Start-Up Activity

Figure 3 illustrates the overall start-up activities, in which the system is operated in its entirety with all equipment fully integrated. At this stage, no components remain disconnected or incomplete, ensuring that the facility functions as a unified system. The start-up process confirms that installation, commissioning, and integration phases have been successfully completed before the system enters regular operation.

2.3.6 Definition of System and Subsystem

2.3.6.1 System:

a major functional unit (e.g., power generation, fire protection).

2.3.6.2 Subsystem:

a smaller, independent unit (e.g., UPS, emergency generator).

Each subsystem must achieve pre-commissioning and commissioning completion status before integration into the overall system (IEC, 2021; Bendiksen & Young, 2005).

2.3.6.3 System / Subsystem Numbering and Boundaries

Subsystem numbering and boundaries are defined early in engineering documents to ensure clarity and traceability (TotalEnergies, 2018; Nascimento et al., 2021). Systems and subsystems are assigned numbers consistent with functional breakdown and equipment/tagging identification to ensure clarity and traceability throughout the commissioning process as shown at figure-4 and figure-5.

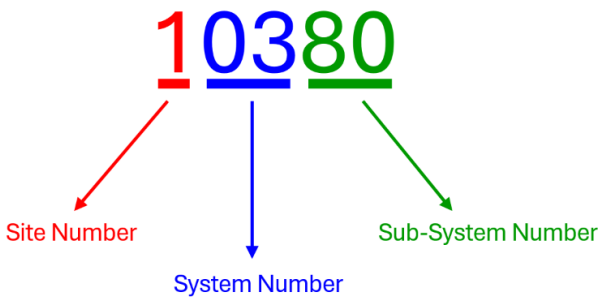


Figure 4 System Subsystem Numbering

The Boundaries and scope must be clearly defined by applying mark-ups on engineering and vendor documents. This ensures subsystem limits are properly identified,

responsibilities are clarified, and commissioning activities can be executed in a structured and traceable manner (Badiru & Osisanya, 2013).

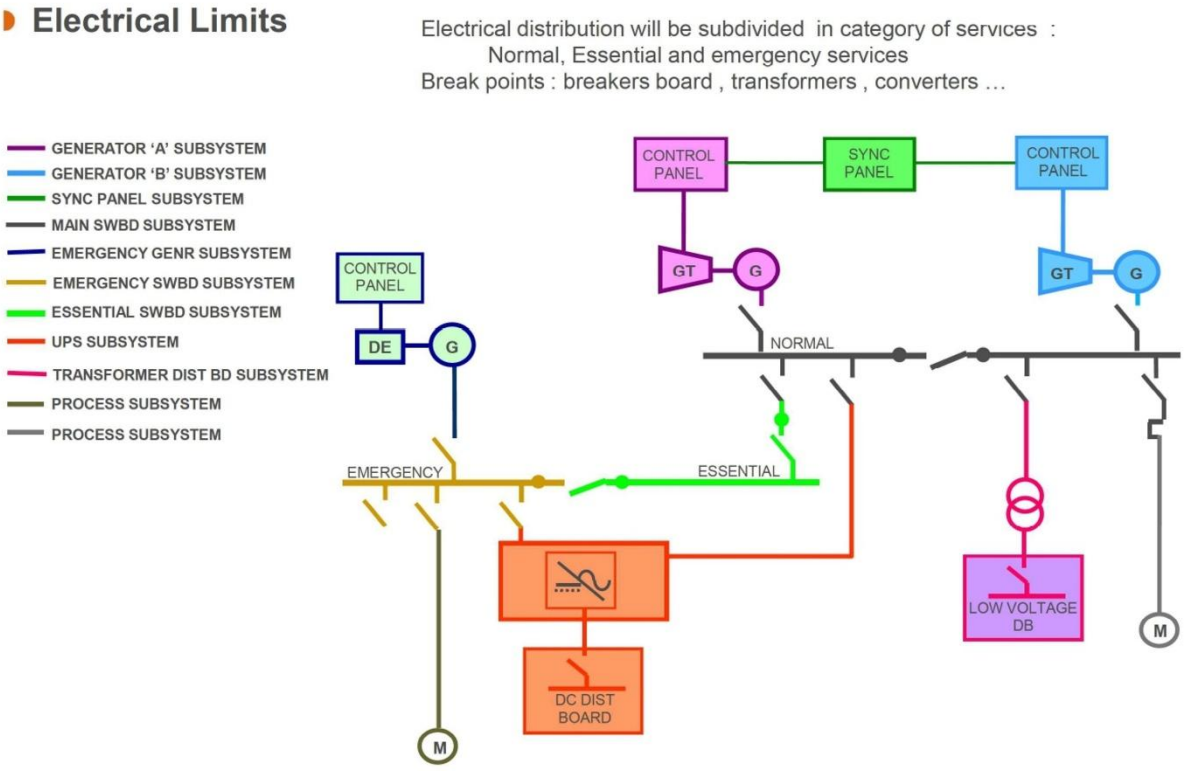


Figure 5 System Subsystem Bundaries

Figure 5 presents the proposed approach for developing Electrical Subsystem Limits, which serves as a guideline for the subsequent case study analysis. The methodology described in this section will be applied in the case study to demonstrate the effectiveness and implementation of the proposed subsystem limits.

2.3.6.4 System Approach

To overcome completion and functional constraints, the **System Approach** is applied by dividing the plant into functional systems and subsystems. This structured breakdown allows commissioning activities to be executed in a controlled and sequential manner, ensuring readiness and minimizing risks during start-up (Horsley, 1998; Rui et al., 2017).

As illustrated in **Figure 6**, the comparison between the *Basic Approach* and the *System Approach* highlights the efficiency gained by overlapping commissioning and operations across subsystems. In the Basic Approach, commissioning is performed sequentially, resulting in a time gap (Δt) before operations can begin. Conversely, the System Approach enables commissioning and operations to proceed in parallel for individual subsystems. This reduces the overall delay (Δt), accelerates readiness, and ensures earlier integration of critical systems into operation.

By adopting this methodology, commissioning teams can prioritize essential utilities and safety systems, while progressively integrating other subsystems. This staged execution not only improves project control but also enhances reliability and safety during start-up, aligning with industry best practices and international standards (TotalEnergies, 2018; Samie, 2016).

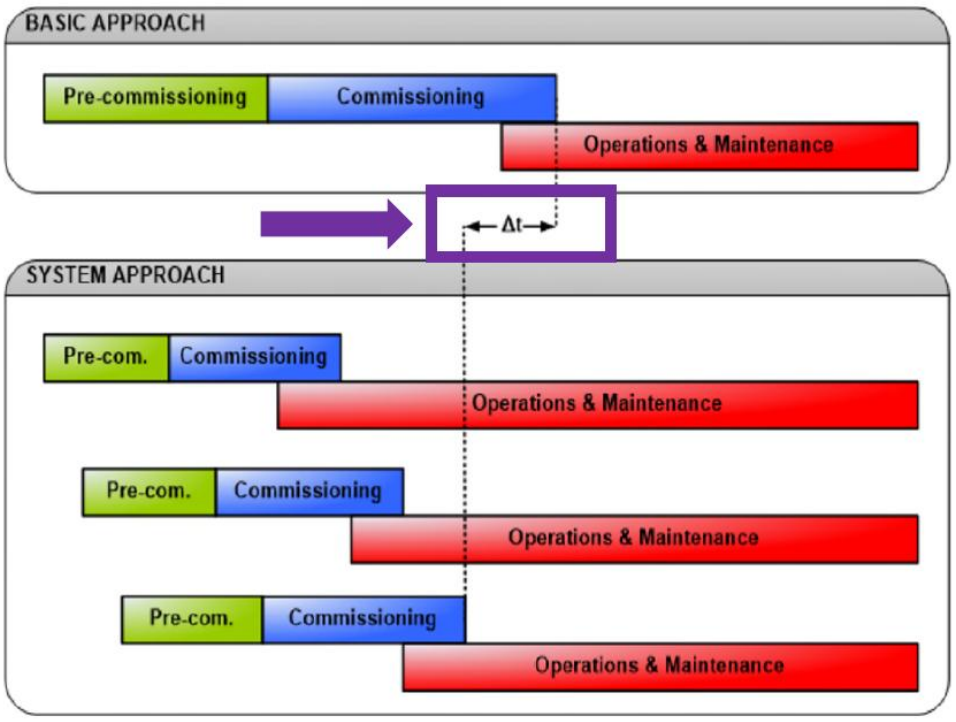


Figure 6

2.3.7 Punch List Management

2.3.7.1 Definition of Punch List and Punch Item

- A **Punch List** is a record of all non-conformities identified during pre-commissioning and commissioning, such as incomplete work, equipment damage, material shortages, or missing documentation.
- A **Punch Item** refers to any unfinished work or non-compliance with project requirements that must be resolved before a specific milestone.
- All punch items are recorded and managed within the subsystem punch list using the ICAPS© system.

2.3.7.2 Criteria and Limitations of Punch Items

- Punch items are categorized as blocking points if they affect:
  a. Facility safety and operations.
  b. Commissioning readiness.
  c. Compliance with project specifications and regulations.
- Work outside the contract scope or incomplete construction activities prior to pre-commissioning are not considered punch items.

2.3.7.3 Categories of Punch Items

- **Category A:** Prevents the start of commissioning and must be resolved before issuing RFC.
- **Category B:** Prevents subsystem operation and must be resolved before AOC.
- **Category C:** Does not prevent operation but must be resolved before the Completion Certificate.
- **Category 0:** Applies to vendor packages/modules that must be completed before equipment delivery.

2.3.7.4 Punch Item Documentation Each punch item must be documented with key information:

- Subsystem/equipment identification.
- Description of findings.

- Responsibility for corrective action.
- Target completion date.
- Punch item category.
- Status of corrective actions and verification.

2.3.7.5 Punch List Management and Monitoring

- The punch list must be continuously updated throughout the project to reflect subsystem readiness.
- At the RFC stage, only Category B and C items may remain.
- At the AOC stage, only Category C items may remain.
- Management requires coordination among the Company, Contractor, Engineering, Vendor, and Commissioning Team.

2.3.7.6 Punch List Clearance

- Punch list clearance confirms that corrective actions have been completed and verified.
- Resolution of punch items must be approved by the Company.
- Successful clearance requires multidisciplinary coordination, resource availability, materials, and engineering/vendor support.

2.3.8 Certificate Handover

2.3.8.1 Transfer of Operation and Maintenance (TOM)

- **Principles of Transfer:**
  a. Transfer of Operation & Maintenance (TOM) is the formal process of shifting responsibility for operating, maintaining, and safeguarding the facility from the Commissioning Team to the Company.
  b. Prior to transfer, all equipment and subsystems remain under the Commissioning Team's responsibility to ensure they are safe and ready for use.
  c. The transfer represents a change in operational and maintenance responsibility, but does not necessarily mean that all project work has been fully completed.
- **Transfer Requirements:**
  a. Transfer is carried out once a subsystem has completed all commissioning processes and achieved AOC (Achievement of Commissioning) / RFSU status.
  b. Before transfer, a joint inspection (walk-down) between the Commissioning Team and the Company must confirm equipment is in good and safe condition. Systems can operate according to their intended function and no issues exist that could disrupt operations.
- **Transfer of Operation and Maintenance Certificate (TOMC):**
  a. The transfer of responsibility is formally documented through the TOMC.
  b. The TOMC serves as evidence that the Company has accepted responsibility for operating, maintaining, and safeguarding the facility.

2.3.8.2 Particular Technical Certificates

- **RFC (Ready for Commissioning):** Indicates that all pre-commissioning work has been completed and the system is ready to enter the commissioning phase.
- **AOC (Achievement of Commissioning):** Indicates that all commissioning activities have been completed and the system is ready for operational transfer (RFSU/TOM).
- RFC and AOC confirm that project phases have been completed according to requirements, but do not yet signify that operational responsibility has been handed over to the Company.

3. FINDINGS AND DISCUSSION

3.1 Case Study:

Application of OPERCOM The case study was conducted on the electrical systems of an oil and gas facility by applying the System Approach within the OPERCOM methodology.
This approach was used to address completion constraints and functional constraints by dividing the plant into several systems and subsystems that could be tested and commissioned progressively.

- System division allows for:
- Commissioning activities to be carried out based on system functional readiness.
- Easier control and monitoring of work progress.
- Step-by-step handover processes.

3.1.1 Development of Color Limit Drawing

To ensure clear responsibility boundaries for each subsystem, Color Limit Drawings were prepared based on engineering documents such as:

- Single Line Diagram (SLD)
- Electrical drawings
- Cable schedule
- Equipment layout

Colour Limit Drawings are used to indicate:

- Equipment included within a subsystem.
- Boundaries between one subsystem and another.
- Interfaces between different disciplines or systems.

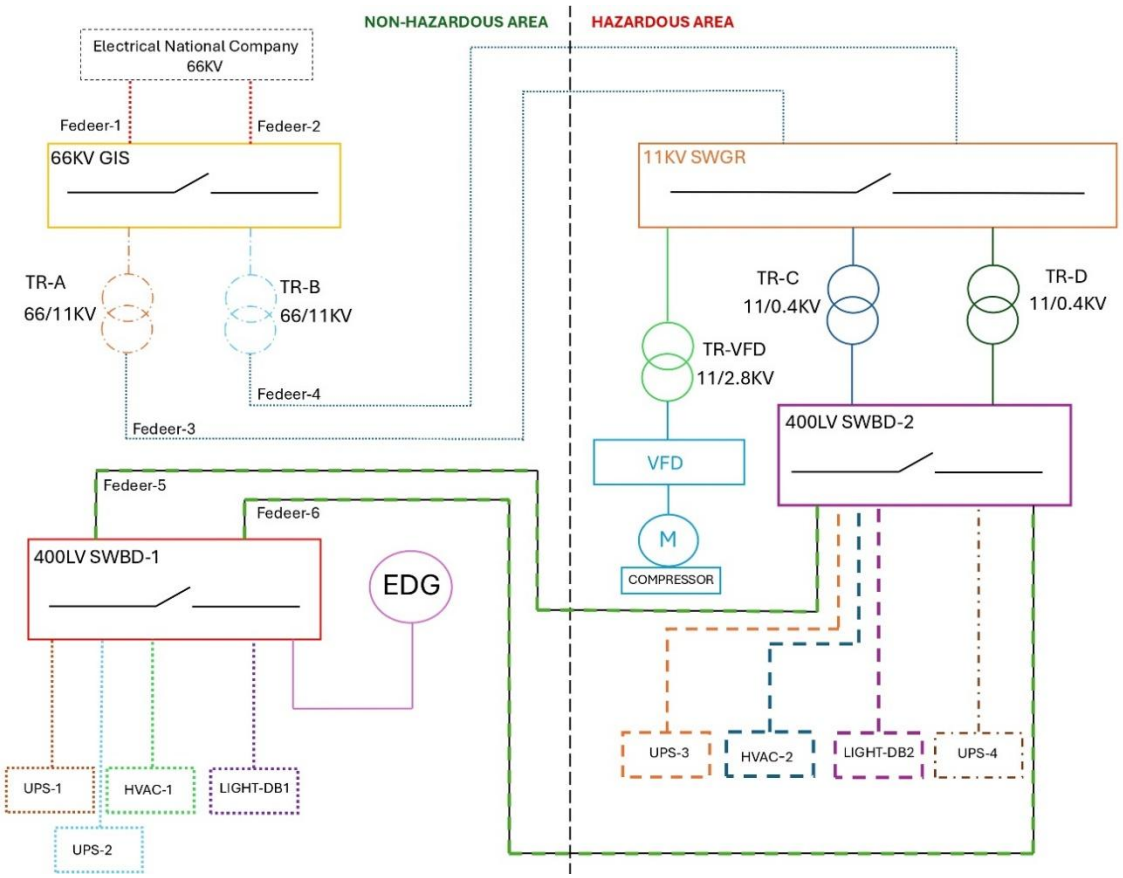


Figure 7

Figure 7 shows that the clear definition of subsystem boundaries helps prevent scope errors during pre-commissioning, commissioning, and handover processes.

3.1.2 System and Subsystem Numbering

In the application of OPERCOM, the electrical system is divided into several systems and subsystems based on their functions and operational relationships.

- Example of division:

a. Electrical Power System
b. Transformer System
c. Medium Voltage Switchgear System
d. Low Voltage Switchgear System
e. UPS System
f. Emergency Generator System

- Each system and subsystem is identified through:
  a. Functional breakdown
  b. Equipment tagging
  c. OPERCOM/ICAPS numbering system

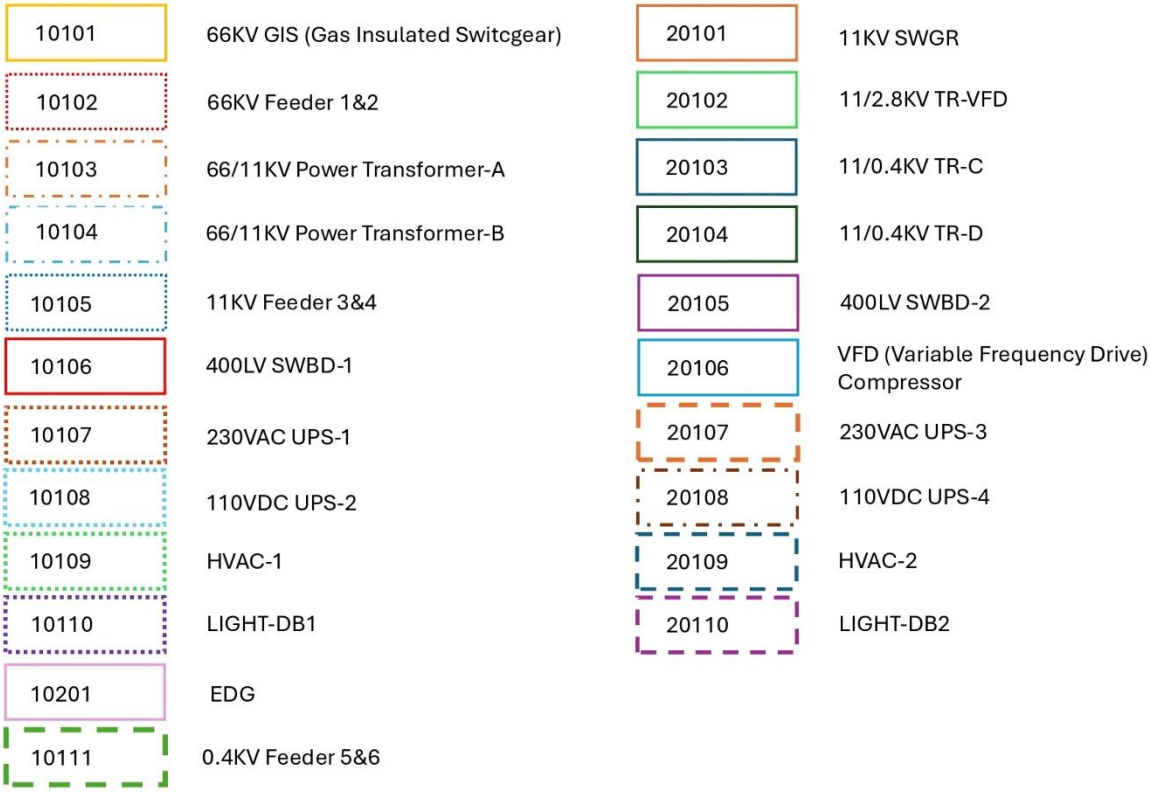


Figure 8

The purpose of assigning system/subsystem numbers is to facilitate work tracking, control the commissioning process, and ensure consistency between engineering documents, equipment, and commissioning activities — as illustrated in Figure 8.

3.1.3 Sequence of Pre-commissioning and Commissioning Stages

The work execution follows the sequence defined in the OPERCOM methodology:

- Stage 1 – Construction Completion
  a. Ensure installation is completed according to design.
  b. Conduct initial inspection and punch identification.
- Stage 2 – Pre-commissioning
  a. Perform static inspections and de-energized testing.
  b. Verify equipment readiness for energization.
- Stage 3 – Commissioning
  a. Energize the system.
  b. Conduct functional and operational tests.
- Stage 4 – Handover
  Once a subsystem achieves AOC/RFSU status, transfer operational and maintenance responsibility to the Company.

This sequence ensures that each system meets safety and performance requirements before being placed into service.

3.1.4 Punch List Analysis

The punch list from OPERCOM Implementation During pre-commissioning and commissioning in the oil and gas project, several non-conformities (punch items) were identified that needed to be controlled before the system could reach RFC and AOC stages. The punch list served as a monitoring tool to ensure that each issue was addressed and resolved according to the responsibilities of each discipline.

Based on the study results, the distribution of punch items across activity stages shows that most findings occurred during the construction stage, followed by pre-commissioning and commissioning, as presented in Table 1. Punch List Distribution by Activity.

Table 1. Punch List Distribution by Activity

Activity	Punch Item Percentage
Construction	49%
Pre-commissioning	36%
Commissioning	15%

Based on the data, 85% of punch items indicate that most non-conformities are related to installation readiness and work quality before the system is energized.

Punch List Analysis by Activity Stage

The study results show that the distribution of punch items is as follows: **Construction (49%)**, **Pre-commissioning (36%)**, and **Commissioning (15%)**. This indicates that most non-conformities were identified before the system entered the testing and operational stages.

3.1.4.1 Construction (49%)

The construction stage contributed the largest number of punch items. The high number of findings at this stage demonstrates that several installation works required correction before entering pre-commissioning. Typical punch items included:

- Equipment installation not in accordance with engineering documents.
- Errors or deficiencies in cable terminations.
- Cable routing and supports not meeting standards.
- Missing tags, identification, or equipment accessories.
- Incomplete or defective installation works.

The large number of punch items at this stage highlights the importance of improving inspection quality during installation and strengthening coordination among Engineering, Construction, and Quality Control teams before declaring work completion.

3.1.4.2 Pre-commissioning (36%)

Pre-commissioning was the second stage with the highest number of punch items. This phase involved detailed inspections of installation integrity and equipment readiness before energization. Findings included:

- Electrical test results not meeting acceptance criteria.
- Non-conformities in wiring and terminations.
- Corrections required from insulation resistance and continuity tests.
- Discrepancies between actual conditions and test records.
- Incomplete inspection and testing documentation.

Although most installation work was completed during construction, pre-commissioning still revealed non-conformities that could only be identified through technical inspections and testing.

3.1.4.3 Commissioning (15%)

Commissioning had the lowest number of punch items compared to the previous stages, indicating that most installation and equipment readiness issues were successfully controlled before energization. Typical findings included:

- Adjustment of protection relay settings.
- Functional tests not meeting initial criteria.
- Logic control or interlock issues.
- Refinements required from equipment operational tests.

Although fewer in number, punch items at the commissioning stage are highly critical as they directly affect system functionality, reliability, and operational safety.

3.2 Installation Verification

Installation verification is the initial step to ensure that electrical systems are installed according to design, project specifications, and applicable standards before entering pre-commissioning. Verification activities under the OPERCOM methodology include:

- Compliance check of electrical equipment installation against engineering documents such as SLD, cable schedule, and equipment datasheet.
- Physical inspection of equipment such as transformers, switchgear, MCCs, UPS units, and motors.
- Verification of equipment identification through tagging systems to ensure consistency between field installation and project documents.
- Installation quality checks covering:
    a. Cable terminations
    b. Grounding systems
    c. Cable routing
    d. Equipment enclosure condition and protection

The results of this verification form the basis for determining system readiness to enter pre-commissioning.

3.3 Functional and Operational Performance

Once installation compliance is confirmed, testing is conducted to ensure that each piece of equipment and system performs its intended function.

3.3.1 Pre-commissioning Tests

- Conducted under de-energized conditions.
- Aim to verify installation quality and equipment integrity.
- Tests include:
    a. Insulation resistance test
    b. Continuity test
    c. High-voltage test
    d. Transformer winding resistance test
    e. Cable testing

3.3.2 Commissioning Tests

- Conducted under energized conditions.
- Aim to prove safe and stable system operation.
- Tests include:
    a. Functional test
    b. Protection relay test
    c. Control logic verification
    d. Equipment operational test

Results show that systematic execution of pre-commissioning and commissioning significantly reduces the risk of failure during energization and start-up.

3.4 Challenges

Several challenges were encountered in applying OPERCOM to oil and gas projects:

- Construction delays affecting commissioning schedules.
- Varying readiness levels across areas and disciplines.
- System interdependencies causing testing delays.
- Discrepancies between engineering documents and actual field conditions.
- Delayed punch list management hindering RFC and AOC achievement.

The system/subsystem approach helps mitigate these impacts by enabling work to proceed based on system readiness.

3.5 Best Practices

From the implementation of OPERCOM, several best practices were identified:

- Define system/subsystem breakdowns during early engineering stages.
- Establish subsystem boundaries using Color Limit Drawings.
- Utilize ICAPS for progress control and punch list management.
- Involve the commissioning team from the engineering stage.

- Conduct routine coordination among construction, commissioning, engineering, and operations teams.

3.6 Lessons Learned

Key lessons from the implementation include:

- Early commissioning planning is critical to successful start-up.
- Clear definition of systems/subsystems accelerates testing and handover.
- Comprehensive documentation is essential for achieving RFC and AOC.
- Effective punch list management reduces commissioning delays.
- The OPERCOM methodology provides a structured approach to ensure facilities are ready for safe and reliable operation.

4. CONCLUSION

Based on the findings of the study on the application of the OPERCOM methodology in pre-commissioning and commissioning of electrical systems in oil and gas projects, the following conclusions can be drawn:

1. The **OPERCOM methodology** provides systematic control stages from construction completion, pre-commissioning, commissioning, to handover, ensuring system readiness before operation (TotalEnergies, 2005; TotalEnergies, 2017; TotalEnergies, 2018).
2. The **System–Subsystem approach** is effective in managing completion and functional constraints through structured system division, facilitating inspections, testing, and monitoring of RFC and AOC/RFSU readiness (IEC, 2025; IEC, 2023; IEC, 2026; Rui et al., 2017).
3. Pre-commissioning and commissioning stages ensure system reliability through installation verification, static testing, functional testing, and operational testing before the system is put into operation (IEC, 2019; IEC, 2021; IEEE, 2010; IEEE, 2012; Horsley, 1998; Bendiksen & Young, 2005).
4. Punch list analysis shows findings distributed as 49% in construction, 36% in pre-commissioning, and 15% in commissioning. Furthermore, 83% of punch items were identified and resolved before the commissioning/energization stage, reducing the risk of failure during testing and start-up (IOGP, 2018; Ghazali et al., 2019; Ghazi, 2025; Khalid, 2025).
5. Punch list management based on the System–Subsystem approach ensures that each finding has clear responsibility and resolution status, supporting the achievement of RFC and AOC/RFSU (TotalEnergies, 2018; Nascimento et al., 2021).
6. The **Transfer of Operation and Maintenance (TOM)** process is carried out once subsystems achieve AOC/RFSU status and meet technical, documentation, and field verification requirements, ensuring the facility is ready for operation by the Company (TotalEnergies, 2017; Samie, 2016).

RECOMMENDATIONS

1. System/subsystem division should be established during the early engineering stage to enhance commissioning strategy effectiveness (IEC, 2025; IEC, 2023; Rui et al., 2017).
2. Greater involvement of the commissioning team during engineering and construction phases is necessary to ensure design readiness, documentation, and testing methods (TotalEnergies, 2018; Bendiksen & Young, 2005).
3. Quality control during construction must be strengthened to reduce punch items carried into pre-commissioning (ISO, 2015; ISO, 2018; Horsley, 1998).
4. Digital systems such as **ICAPS** should be maximized for monitoring progress, punch lists, and system readiness status (TotalEnergies, 2018; Nascimento et al., 2023; Wanasinghe et al., 2020).
5. Routine coordination among construction, QC, engineering, commissioning, vendor, and operations teams is essential to accelerate the achievement of RFC, AOC/RFSU, and handover (API, 2023; NFPA, 2024; Ray & Rajashekara, 2023).

Consistent application of the OPERCOM methodology with integrated planning can significantly improve safety, reliability, and effectiveness of the commissioning process in oil and gas projects.

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ROAD STABILITY ANALYSIS USING THE IRI METHOD USING THE *ROADBUMP PRO & QGIS* APPLICATION ON THE ROAD OF TALANG PANGERAN – SUGIH WARAS VILLAGE

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Abstract

One of the road accesses to help services and transportation of goods and services is on the regency road in the Teluk Gelam District. Due to the importance of the route, it is necessary to consider the condition of the road pavement to provide driver comfort. Analyze the stability of road sections using the International Roughness Index (IRI) method with an android application, namely Roadbump Pro using three types of vehicles, namely Pick Up, SUV, and sedan. To ensure that the data on the Roadbump Pro application is appropriate, you can use the QGIS application to validate it. The results of the analysis show that the comparison between the type of Hilux Pick Up vehicle in 2014, Kijang Inova SUV in 2016, Sedan City in 2005 year difference and vehicle type greatly affects the IRI value. The results of digitizing road stability mapping on the road section of Teluk Gelam District using the QGIS application are in accordance with the data obtained from the Roadbump Pro application

Keywords: *IRI, Roadbump pro, QGIS*

INTRODUCTION

Infrastructure is a key factor driving economic growth and regional development, with the government primarily responsible for its provision. Roads are a crucial form of infrastructure, playing a significant role in supporting the accessibility and mobility of goods and services (Akhirini et al., 2023). In addition to supporting economic growth and interregional connectivity, road networks play a strategic role in fostering equitable development and maintaining balance among regions (Umi et al., 2016). As traffic volume and load increase annually, roads are susceptible to various forms of damage, such as cracks and deformation on the pavement surface. The road surface is a crucial layer because it absorbs vehicle loads and transmits them to the underlying soil layer (Krishna et al., 2023). Therefore, good road pavement must be highly durable and have a long service life. Pavement durability is influenced by various factors, such as the type and intensity of vehicle traffic, temperature conditions, rainfall, and other environmental factors. On the other hand, flexible or asphalt pavements have several limitations, including relatively low resistance to heavy vehicle loads and a shorter service life compared to rigid pavements (concrete), thus requiring more frequent and intensive maintenance activities.

Road pavement structures can experience performance degradation due to various factors, including repetitive traffic loads, rainwater discharge, poor drainage systems, changes in temperature and rainfall intensity, environmental geological conditions, unstable subgrade conditions, and poor construction processes (ASTM D6433-07) Therefore, periodic road condition assessments are necessary to maintain road stability. Road condition assessments, both structural and non-structural, need to be conducted periodically so that this article can serve as a reference in determining the type of road evaluation program to be implemented. Road evaluation programs include improvement programs, periodic maintenance, and routine maintenance (Directorate General of Highways, 2017). Several systems can be used to determine road

pavement conditions, one of which is the International Roughness Index (IRI), also known as road surface roughness.

International Roughness Index IRI, International Roughness Index, is defined as the accumulated suspension stroke in a mathematical car model divided by the distance traveled by the model during a simulated ride. If the accumulated stroke is measured in inches and the traveled distance in miles, we get the unit (inch/mile) for IRI. In Europe the unit is (mm/m) (Ahlin, K. & Granlund J., 2001)

Measuring road surface roughness is necessary because geometric imperfections in road surfaces can cause vehicle vibrations as vehicles pass over them (Gillespi, 1992).

Before carrying out road maintenance, road roughness must first be measured to determine whether the road is still suitable for use. Under these conditions, a technology-based system is needed to determine road stability. Roadbump Pro is an Android-based system that has been used in several countries abroad. To validate that the data in the Roadbump Pro application is accurate, the QGIS application is used.

According to Kurnia and Nugraha (2021), road surface roughness is generally measured using a Roughometer or Hawkeye. In some areas, these two tools have not been widely used because they require relatively large operational costs and are generally only used for measurements on roads with high traffic such as toll roads, national roads or provincial roads. One alternative for more economical IRI measurements is to use the Android-based Road Bump Pro application. This measurement will be more suitable for use on city roads or district roads due to limited survey budgets and human resources.

Based on the background outlined above, the research problem to be addressed in this study is: What are the results of the road stability analysis of Simpang Talang Pangeran - Sugih Waras Village, over a 6-km stretch using the International Roughness Index (IRI) method using the Roadbump Pro & QGIS applications.

METHOD

Research Location

This research was conducted on the Teluk Gelam road section from Simpang Talang Pangeran to Sugih Waras Community Health Center, Teluk Gelam District, Ogan Komering Ilir Regency. The type of road studied was a district road with one lane and two lanes. The length of the road observed was 6 km, with 100 meters per segment analyzed.

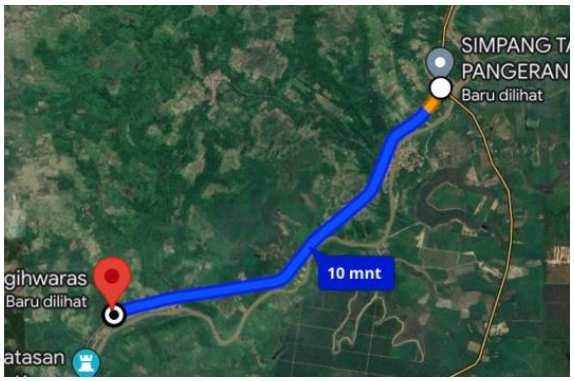


Figure 1 Research Location Map

Procedures

The method used in this study was a survey. The IRI survey was conducted using smartphones installed with the Road Bump Pro application.

Field measurements and data processing were carried out in the following sequence:

1) IRI measurements were conducted on each district road segment in Teluk Gelam according to the designated data collection scheme for the respective road sections.

2) Data collection was performed twice, and the consistency of the results was checked and verified.
3) Data were collected at intervals of every 100 meters to obtain relatively detailed information on road surface conditions.
4) Sudden braking during the survey was avoided; therefore, the survey was conducted outside peak traffic hours.
5) The survey was carried out using three types of vehicles: (a) an SUV, (b) a sedan, and (c) a pickup truck. The purpose was to evaluate the influence of vehicle type on the IRI survey results.

The steps for a survey using the Roadbump Pro app are as follows:

1) Place your smartphone, already installed with the Roadbump Pro app, on the car dashboard with a non-slip mat or mount it on the inside window. When the Roadbump Pro app is launched, the smartphone screen will display "Waiting For GPS" because the app requires GPS to be activated to record data.
2) Press the Start button to begin recording. Press the Start button at the starting point of the measured road, with the car traveling at a speed greater than 20 km/h and varying normally.
3) Press Stop. Once you have recorded a segment, repeat the recording process when you reach the endpoint of the road section being reviewed. Once recording is complete, the screen will display options, as shown in the image.
4) Review Map and Graphs: This option displays the recorded route as a graph of road speed and speed along the recorded route.
5) Delete: This option deletes the recently recorded data and returns you to the start button.
6) Keep Locally: This option saves the recently recorded data in a set of files with the naming convention YYYY MM DD HH MM SS. Selecting this option will return you to the start button.
7) Rename: This option allows you to save the recently recorded data in a set of named files. Selecting this option will return you to the start button.
8) Then, move the map location marker to limit the segment graph.
9) Select the menu to change the graph map
10) Once you have recorded, the next step is to process the recorded data and display the recording. To access the saved road recordings, tap the folder icon at the top of the screen. The icon next to the folder icon displays the options: Select US or Metric, set the minimum speed to start recording, and set the factor to adjust for the type of vehicle used
11) After clicking the folder icon, a screen like the one below will appear. This can be used to process screen recording data. Choose Recording allows you to select the recording you want to work on. The Show displays maps and graphs. Rename allows you to rename existing recordings. Delete deletes the recording
12) Generate CSV files: This option provides the option to create three types of CSV extracts
13) The results of the IRI test recording data using the Roadbump Pro application can be used in MS Excel or ESRI's arGIS.

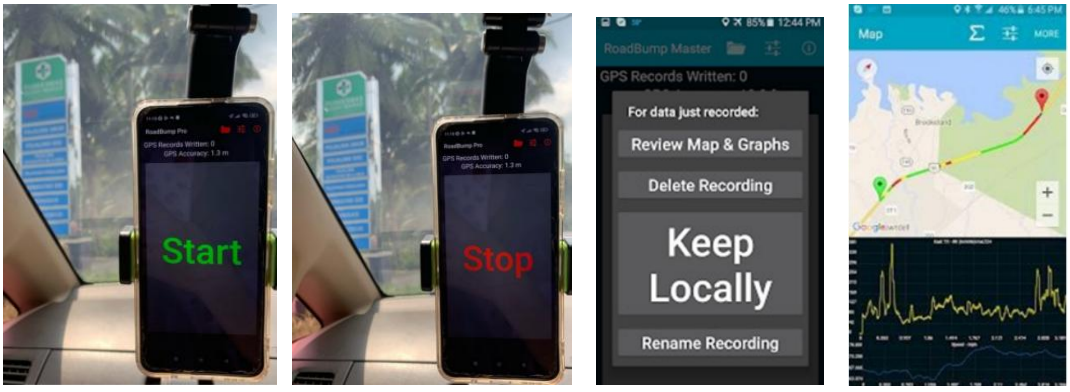


Figure 2 Roadbump Pro App Usage

QGIS Application Usage

After obtaining the IRI value in the Road Bump Pro application, enter the IRI data into the QGIS application using the following steps:

1) Open QGIS 3.34.2 on your PC or laptop, and the display will appear.
2) To open the map, click Web → QuickMapServices → Google → Google Road → click OK. A world map will appear, as shown in the image. Find the map of Indonesia, specifically the location we are researching

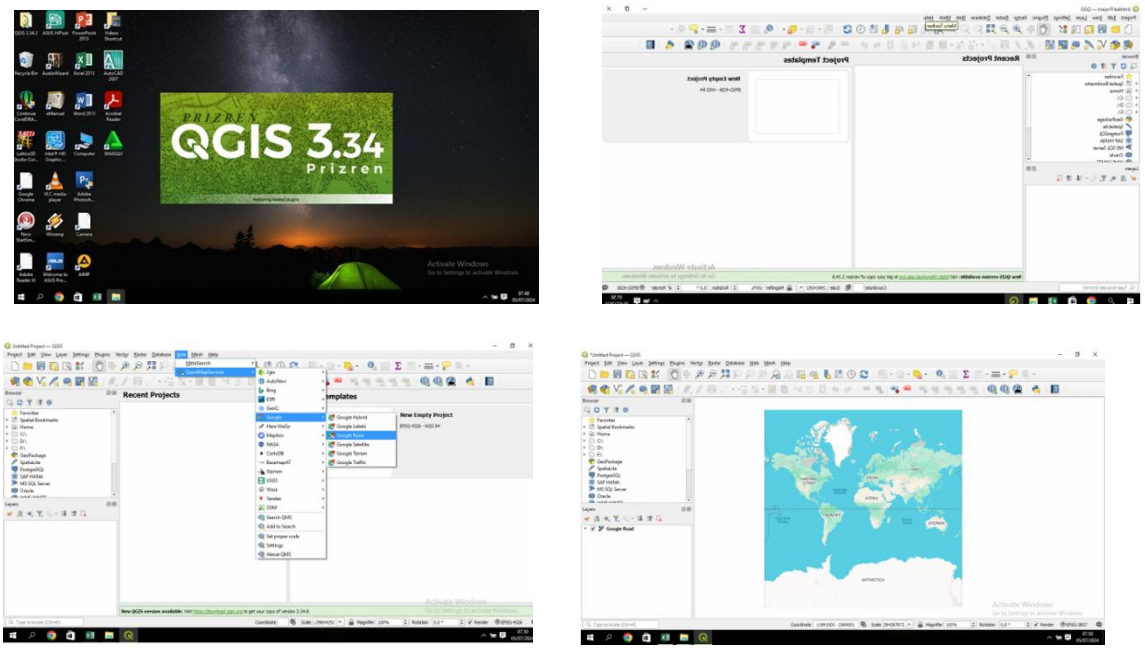


Figure 3 QGIS Application Usage

3) Next, enter the IRI data file for damaged, moderate, and stable roads. Click Open Data Source Manager → select Delimited Text. The following will appear. Enter the IRI data file for Point Coordinates: (x) = Long and (Y) = Lat → then click add.
4) To differentiate the colors between damaged (red), moderate (yellow), and stable (green) roads, we can change them as follows: right-click → Properties → Symbology → Color.
5) Next, digitize the road stability map → select New Shapefile Layer. File name: moderate road (only type, do not include the file). File encoding: UTF-8. Geometry type: Line String. Then click add to fields list → OK.
6) To change the color according to the criteria for damaged, moderate, and stable roads, right-click —> properties —> Symbology —> Color (width: 2) —> apply —> OK. Select Toggle Editing —> Add Line Feature.
7) After the (+) sign appears, digitizing can be done, do it according to the color criteria that we have chosen earlier and it will appear as in figure 4. After all digitizing is complete, uncheck to see the digitizing results as in figure 4.

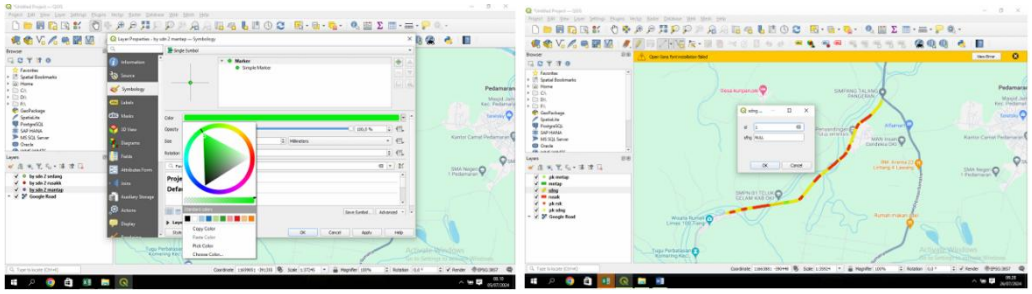


Figure 4. How to Change the Road Color in the QRIS Application

8) To create text describing the location and STA → select New Shapefile Layer File name: STA 0+000 File encoding: UTF-8 Geometry type: point → Then click add to fields list —-> ok
9) Select Toggle Editing —> Add Line Feature —> click on the map where you want to add text
10) If you want to change the font, right-click —> properties —> labels —> font —> ok. Select save project to save the digitized road stability map results.

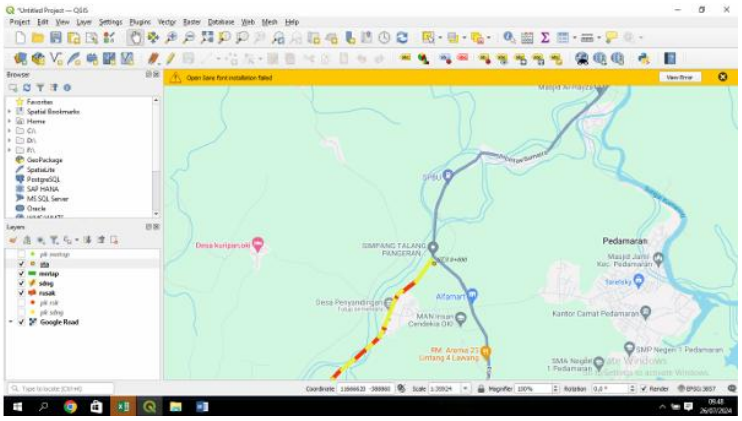


Figure 5. Final Result of Digitization

FINDINGS AND DISCUSSION

IRI Values for Three Types of Vehicles: Pick Up, SUV, and Sedan, on Jalan Simpang Talang Pangeran, Sugih Waras Village

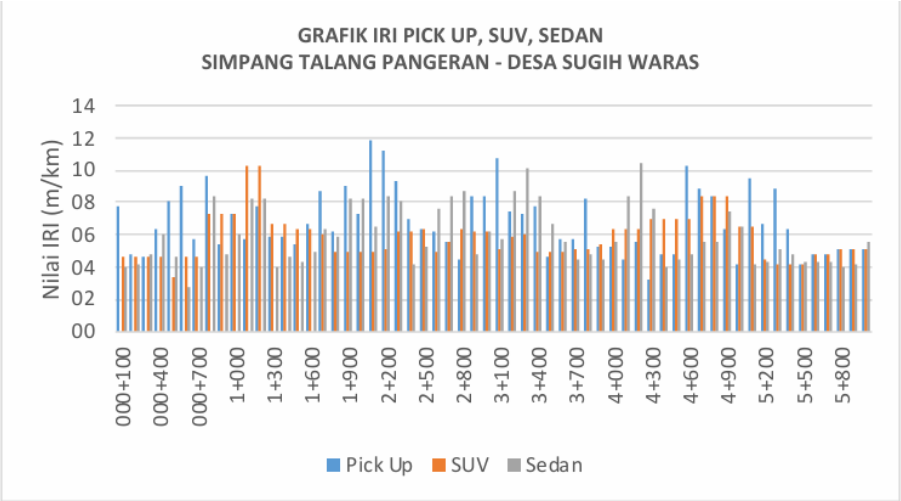


Figure 6. Comparison Chart of IRI Values of Pick-Ups, SUV, and Sedan at Simpang Talang Pangeran – Sugih Waras Village

From Figure 6, it is known that the IRI value of Pick Up type vehicles on the Simpang Talang Pangeran-Sugih Waras Village road, the lowest IRI value = 3.1 at STA. 4+300, the highest IRI value = 11.8 at STA. 2+100. For the IRI value of SUV type vehicles on the Simpang Talang Pangeran-Sugih Waras Village road, the lowest IRI value = 3.3 at STA. 000+500, the highest IRI value = 10.2 at STA. 1+100, 1+200. While the IRI value of Sedan type vehicles on the Simpang Talang Pangeran-Sugih Waras Village road, the lowest IRI value = 3.8 at STA. 000+600, the highest IRI value = 10.4 at STA. 4+200

IRI values for three types of vehicles: Pick Up, SUV, and Sedan on the Sugih Waras Village-Talang Pangeran Intersection road

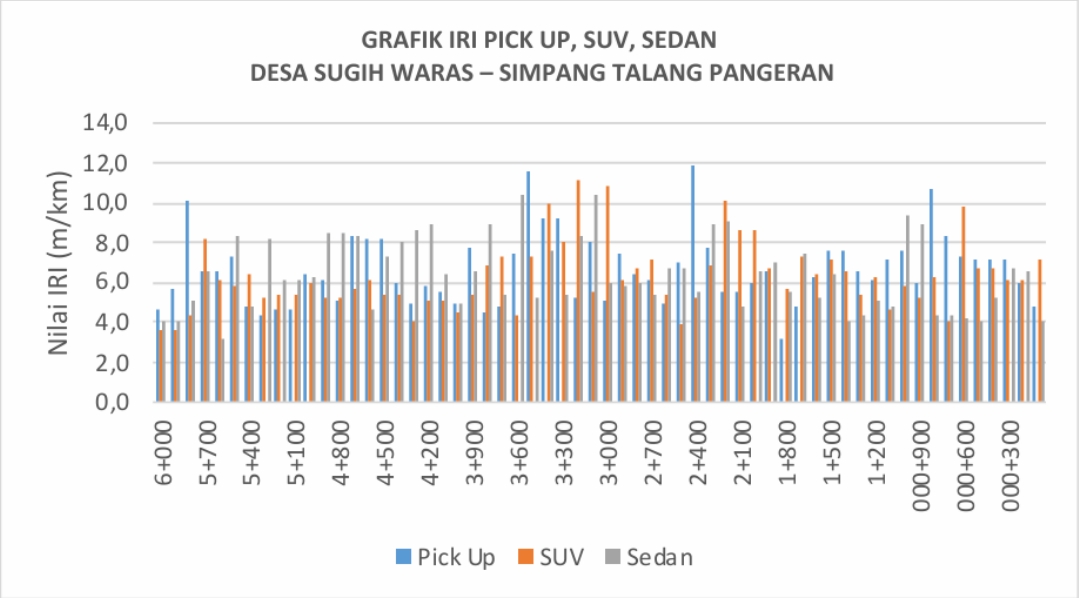


Figure 7. Comparison Chart of IRI Values of Pick Ups, SUVs, and Sedans in Sugih Waras Village – Simpang Talang Pangeran

From Figure 7, it is known that the IRI value of Pick Up type vehicles on the Sugih Waras Village – Talang Pangeran Intersection road, the lowest IRI value = 3.2 at STA. 1 + 800, the highest IRI value = 11.9 at STA. 2 + 400. For the IRI value of SUV type vehicles on the Sugih Waras Village – Talang Pangeran Intersection road, has the lowest IRI value == 3.6 at STA. 6 + 000, 5 + 900, the highest IRI value = 11.1 at STA. 3 + 200. While the IRI value of Sedan type vehicles on the Sugih Waras Village – Talang Pangeran Intersection road, has the lowest IRI value = 3.1 at STA. 5 + 400, the highest IRI value = 10.4 at STA. 3 + 600 and STA. 3 + 100.

Road Stability Map Using the QGIS Application

The following is a road stability map using the QGIS application based on the IRI values of vehicles: Pickups, SUVs, and sedans, Jalan Simpang Talang Pangeran - Sugih Waras Village.

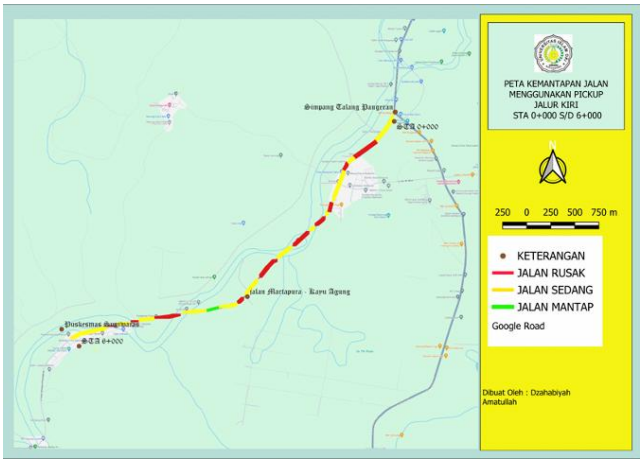


Figure 8. Map of the stability of the Talang Pangeran Intersection Road - Sugih Waras Village (Pick Up vehicle)

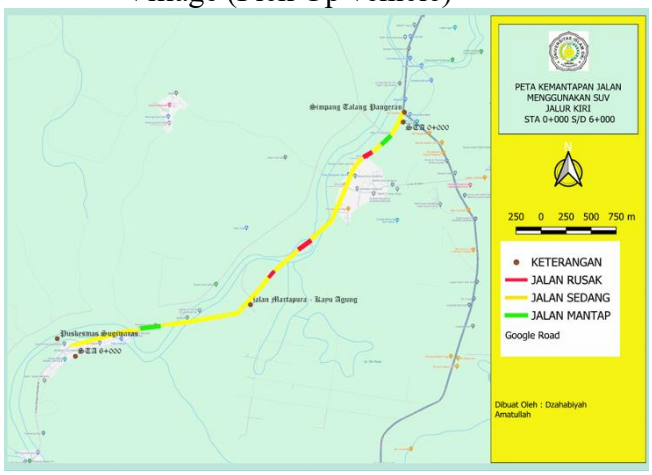


Figure 9. Map of the stability of the Talang Pangeran Intersection Road - Sugih Waras Village (SUV vehicle)

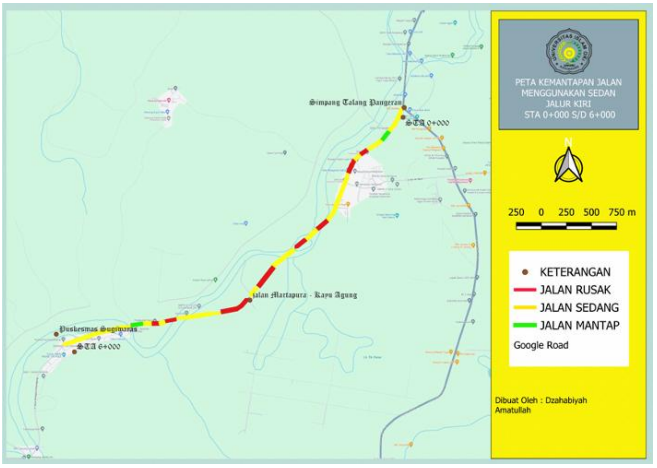


Figure 10. Map of the stability of the Talang Pangeran Intersection Road - Sugih Waras Village (Sedan vehicle)

The following is a map of road stability using the QGIS application based on the IRI value of vehicles: Pick Up, SUV, and sedan, Jalan Desa Sugih Waras.- Simpang Talang Pangeran.

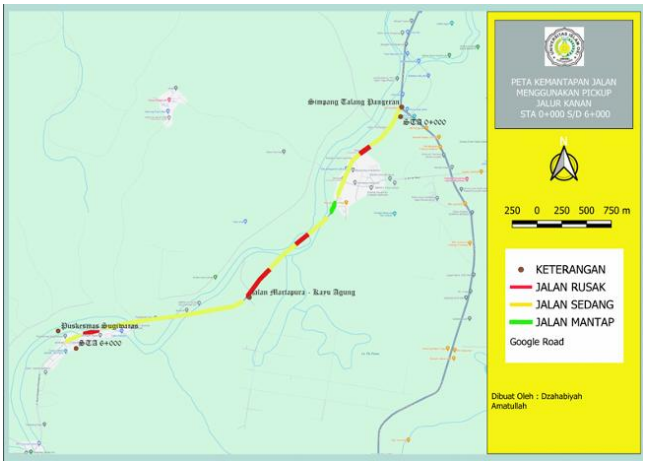


Figure 11. Map of the Stability of the Sugih Waras Village Road - Talang Pangeran Intersection (Pick Up Vehicle)

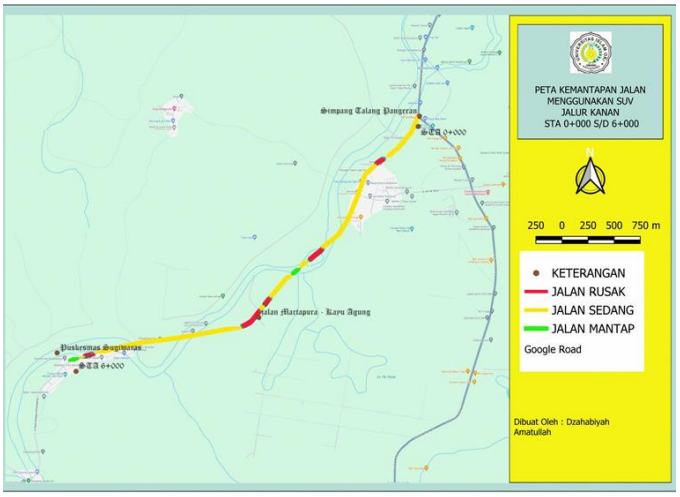


Figure 12. Map of the Stability of the Sugih Waras Village Road - Talang Pangeran Intersection (SUV Vehicle)

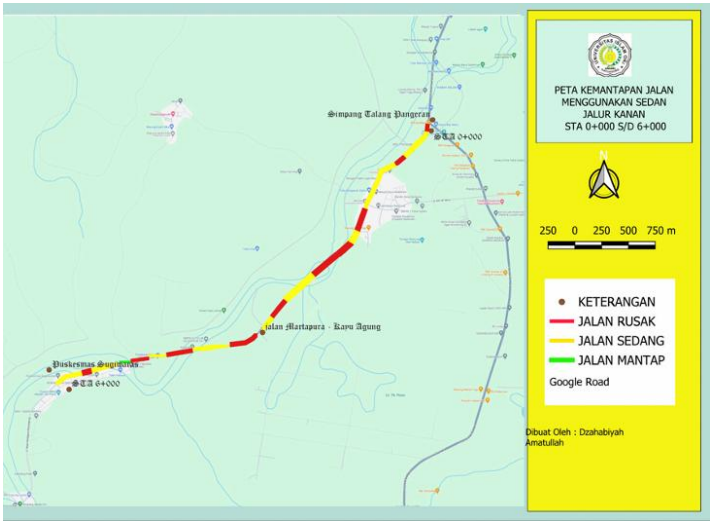


Figure 13. Map of the Stability of the Sugih Waras Village Road - Talang Pangeran Intersection (Sedan Vehicle)

Based on the results of the digitization of the stability mapping of the Simpang Talang Pangeran – Sugih Waras Village road and the Sugih Waras Village – Simpang Talang Pangeran road, using the QGIS application based on IRI value data obtained from the Roadbump Pro application, there are 3 road criteria, namely: good roads (stable) are marked with green, moderate roads are marked with yellow, and damaged roads are marked with red.

CONCLUSION

The conclusions that can be drawn from the study on the Road Stability Analysis in Teluk Gelam District, Ogan Komering Ilir Regency, using the IRI Method using the Roadbump Pro & QGIS applications are as follows:

1. Based on the results of the road stability analysis, on the Simpang Talang Pangeran-Sugih Waras Village road, using pick-up vehicles, the average IRI value is 6.7 m/km, for SUVs, the average IRI value is 5.9 m/km, and for sedans, the average IRI value is 6.7 m/km.
2. Based on the results of the road stability analysis, on the Sugih Waras Village-Simpang Talang Pangeran road, using pick-up vehicles, the average IRI value is 6.6 m/km, for SUVs, the average IRI value is 6.3 m/km, and for sedans, the average IRI value is 6.8 m/km.
3. Based on the results of the road stability analysis, the majority of these roads are classified as moderate, with 85% requiring regular maintenance.

4. Based on the type of vehicle used, the IRI value for SUVs is lower than for pickups and sedans. This indicates that differences in vehicle year and type can affect the IRI value when using the Roadbump Pro application.

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THE EFFECT OF ULTRASONIC WAVES ON THE CORROSION RATE OF LOW-CARBON STEEL UNDER VARIOUS SULFURIC ACID (H_2SO_4) CONCENTRATIONS

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Abstract

This study aims to analyze the effect of ultrasonic waves on the corrosion rate of low-carbon steel (AISI 1018) under varying concentrations of sulfuric acid (H_2SO_4) solution and immersion durations. Corrosion testing was conducted using the weight loss method with H_2SO_4 concentrations of 0.5%, 1.0%, 1.5%, 2.0%, and 2.5%, as well as ultrasonic exposure times of 5, 10, 15, 20, and 25 minutes. The results indicate that the highest corrosion rate occurred at an immersion time of 5 minutes, whereas increasing the immersion duration tended to reduce the corrosion rate at all solution concentrations. This phenomenon is attributed to the effect of ultrasonic waves, which can reduce the accumulation of corrosion products and inhibit further oxidation processes. These findings may serve as a reference for selecting appropriate surface treatment methods for low-carbon steel in construction and automotive industry applications requiring optimal corrosion resistance.

Keywords: *Ultrasonic waves, low-carbon steel, AISI 1018, corrosion rate, sulfuric acid*

INTRODUCTION

Carbon steel is widely used in various engineering and industrial applications due to its favorable mechanical properties (Kadhim, 2017). The global carbon steel market is projected to increase by 3.3%, reaching approximately USD 197.5 billion by 2029 (Bansode et al., 2015). However, over time, steel is inevitably subjected to wear and corrosion caused by interactions with environmental elements such as fluorine, chlorine, carbon dioxide, and other corrosive agents (Abbas et al., 2023).

Corrosion is defined as the deterioration or degradation of a material resulting from its reaction with the surrounding environment (Wiradinata et al., 2025). The corrosion process occurs naturally as metals tend to return to their more stable oxidized state, similar to the oxygen-containing compounds from which metals are extracted during metallurgical processes (Fisika et al., 2024).

Numerous studies have investigated corrosion in low-carbon steel, where corrosion is commonly characterized by a yellowish discoloration appearing on the steel surface, leading to a reduction in material quality. Corrosion has the potential to cause substantial financial losses in industrial sectors, making it a widespread issue affecting various industries. Therefore, environmental considerations are essential in the design of metal-based products (Arwati, 2024). Product design for acidic environments differs significantly from that for alkaline environments, particularly in the presence of hydrochloric acid and sulfuric acid, which are frequently encountered in industrial settings (Series & Science, 2021).

Sulfuric acid is extensively utilized in chemical processing, battery manufacturing, and metal pickling operations. Consequently, corrosion studies are crucial for evaluating material durability, predicting service life, and developing effective corrosion mitigation strategies. In

addition to acidity, several other factors influence the corrosion process, including environmental temperature and oxygen availability (Arwati, 2024). An increase in temperature accelerates reaction kinetics, thereby increasing the corrosion rate of carbon steel. According to the study conducted by Mothana Ghazi Kadhim Alfalah, the reaction between carbon steel and sulfuric acid solution can be expressed as follows:

$$Fe(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$$

where (s), (aq), and (g) represent the solid, aqueous, and gaseous phases, respectively. In a comparable reaction involving hydrochloric acid, hydrochloric acid (HCl) and ferrous chloride ($FeCl_2$) behave as strong electrolytes that dissociate almost completely into dissolved ions, namely H^+, Cl^-, and Fe^{2+}.

Similarly, sulfuric acid (H_2SO_4) can be used as the corrosive medium, resulting in the following reaction:

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$

This reaction represents a typical example of iron corrosion in an acidic environment, where iron atoms undergo oxidation to form Fe^{2+} ions, while hydrogen ions are reduced to produce hydrogen gas.

The corrosion mechanism occurring in metals is influenced not only by the properties of the material and the corrosive environment but also by dynamic conditions that can accelerate electrochemical reactions. In this regard, the application of ultrasonic waves has attracted considerable research interest due to their ability to generate cavitation effects that enhance reaction activity at the metal surface. Ultrasonic waves are mechanical energy and momentum waves that propagate through solid, liquid, and gaseous media (Bansode et al., 2015). As ultrasonic waves travel through air, they induce vibrations of air particles. The periodic pressure fluctuations generated during wave propagation continuously alter the density and strain of the medium.

Ultrasonic treatment utilizes acoustic waves with frequencies above 40 kHz. In this method, ultrasonic waves generate microcavitation around the material surface, causing localized heating and structural disruption. The kinetic energy released during cavitation bubble formation and collapse is distributed throughout the liquid medium, thereby enhancing mass transfer between the solid surface and the surrounding fluid.

Several mechanisms associated with ultrasonic-assisted processes have been identified. One of the most significant is fragmentation, which results from collisions between particles and ultrasonic waves. These collisions reduce particle size and facilitate mass transfer processes (Prasetyo & Saud, 2023).

Sulfuric acid (H_2SO_4) is a strong inorganic mineral acid that is completely miscible with water in all proportions. It is one of the most important products of the chemical industry and is widely used as a solvent, reactant, acidic medium, preservative, and in numerous other industrial processes. Sulfuric acid is characterized as a clear, colorless, and odorless liquid (Retno Listyorini, Eko Supri Murtono, 2018). Due to its liquid form and high solubility in water, sulfuric acid is frequently employed as an immersion medium in corrosion studies (Gusti et al., 2002). One of the key factors affecting corrosion in aqueous environments is the presence of electrolytes. Sulfuric acid (H_2SO_4) is an example of a highly conductive and strong electrolyte that significantly influences corrosion behavior (Eva Agustina, 2021).

METHOD

Research Design

The material used in this study was low-carbon steel (AISI 1018). The corrosive medium consisted of sulfuric acid (H_2SO_4) solutions with concentrations of 0.5%, 1.0%, 1.5%, 2.0%, and 2.5%. The main equipment used in this study included an ultrasonic generator, a digital balance, a beaker glass, fine-grit sandpaper, and a stopwatch.

Procedures

Low-carbon steel (AISI 1018) specimens were cut into specified dimensions and subsequently immersed in sulfuric acid (H_2SO_4) as the corrosive medium. Corrosion testing was conducted using the weight loss method with H_2SO_4 concentrations of 0.5%, 1.0%, 1.5%, 2.0%, and 2.5%. The specimens were exposed to ultrasonic waves for immersion periods of 5, 10, 15, 20, and 25 minutes.

Data Analysis

The data The corrosion rate was calculated based on the ASTM (American Society for Testing and Materials) International standard using the following equation:

where:

$$CR\ (mpy) = W.\ k\rho\ .A.t$$

CR = Corrosion rate (mils per year, mpy)
K = Conversion constant (K = 87,600 for mpy)
W = Weight loss (g)
ρ = Material density (g/cm³)
A = Exposed surface area (cm²)
t = Exposure time (hours)

FINDINGS AND DISCUSSION

The corrosion rate test results of low-carbon steel (AISI 1018) at various H_2SO_4 concentrations and immersion times under ultrasonic wave exposure are presented in Figure 1. The graph illustrates the relationship between sulfuric acid concentration, immersion time, and the resulting corrosion rate of the specimens.

Table 2. Relationship between the corrosion rate of low-carbon steel (AISI 1018) and H_2SO_4 concentration at different immersion times under ultrasonic wave exposure

Konsetrasi H2SO4 (%)	Waktu Perendaman				
	5 menit	10 menit	15 menit	20 menit	25 menit
0,5	2,35	2,31	2,24	2,2	2,14
1	4,7	3,47	2,99	2,76	2,57
1,5	7,06	4,68	4,73	3,31	2,99
2	9,41	5,78	4,48	3,86	3,42
2,5	7,6	6,94	5,23	4,41	3,85

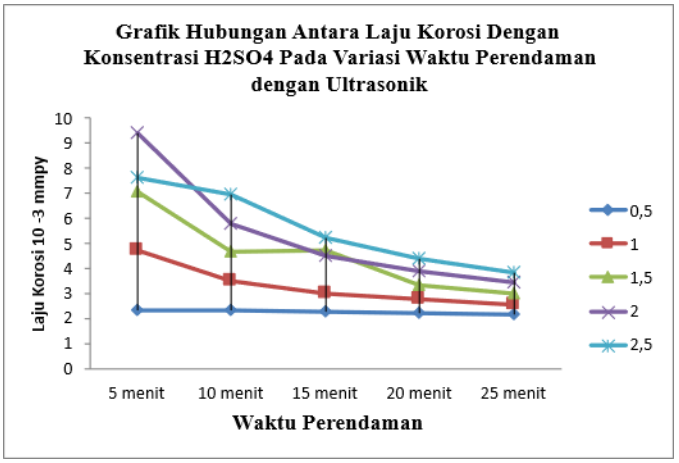


Figure 1. Figure 1. Effect of H_2SO_4 Concentration and Immersion Time on the Corrosion Rate of Low-Carbon Steel (AISI 1018) under Ultrasonic Treatment

Based on the corrosion rate test results of low-carbon steel immersed in H_2SO_4 solution under ultrasonic wave exposure, a significant influence of sulfuric acid concentration and immersion time on the corrosion rate was observed. In general, the corrosion rate, expressed in units of 10^{-3} mm/year, varied with increasing immersion time from 5 to 25 minutes.

At an H_2SO_4 concentration of 0.5%, the corrosion rate was relatively low and remained fairly stable, with an initial value of 2.35 at 5 minutes, gradually decreasing to approximately 2.14 at 25 minutes. This indicates that at low acid concentrations, the corrosion reaction rate is still limited, although ultrasonic waves enhance mass transfer processes around the steel surface.

For the 1.0% H_2SO_4 solution, the initial corrosion rate increased to 4.70 at an immersion time of 5 minutes and subsequently decreased to 2.57 after 25 minutes. This reduction suggests that a more intense corrosion reaction occurred during the early stage of immersion due to the high availability of H^+ ions. However, over time, a temporary corrosion product layer may have formed, partially inhibiting direct contact between the metal surface and the solution.

At H_2SO_4 concentrations of 1.5% and 2.0%, the initial corrosion rates were considerably higher, reaching 7.06 and 9.41, respectively, after 5 minutes of immersion. These values gradually decreased to 2.99 and 3.42 after 25 minutes. This substantial decline indicates that although the corrosive environment was highly aggressive during the initial stage, the reduction in corrosion rate may be attributed to the formation of corrosion products and the establishment of a new electrochemical equilibrium at the steel surface.

At the highest concentration of 2.5% H_2SO_4, the initial corrosion rate reached 7.60 at 5 minutes of immersion and decreased to 3.85 after 25 minutes. This result suggests that increasing the concentration of H_2SO_4 does not necessarily lead to a continuously increasing corrosion rate in a linear manner. Instead, the corrosion behavior is also influenced by surface conditions and hydrodynamic effects induced by ultrasonic waves.

Furthermore, the relationship between corrosion rate and H_2SO_4 concentration demonstrates that higher sulfuric acid concentrations generally result in higher initial corrosion rates. This phenomenon is attributed to the increased concentration of H^+ ions in the solution, which participate in the cathodic reduction reaction and consequently accelerate the anodic dissolution of iron (Fe).

CONCLUSION

The results revealed that the highest corrosion rate was observed after 5 minutes of immersion, while longer immersion durations generally led to a decrease in the corrosion rate at all sulfuric acid concentrations. This behavior is attributed to the influence of ultrasonic waves, which facilitate the removal of accumulated corrosion products from the metal surface and suppress further oxidation reactions

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GEOAI-INTEGRATED ARTIFICIAL NEURAL NETWORK FOR FAMILY SOCIOECONOMIC STATUS CLASSIFICATION: A REGIONAL MAPPING APPROACH IN SOUTH SUMATRA PROVINCE, INDONESIA

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Abstract: Disparities in household socioeconomic conditions remain a critical challenge in regional development in Indonesia, particularly in South Sumatra Province. Conventional statistical approaches often fail to capture the complex, non-linear relationships between socioeconomic and spatial factors. This study proposes an integrated framework combining Geospatial Artificial Intelligence (GeoAI) and an Artificial Neural Network (ANN) to classify households by socioeconomic status into three categories: economically vulnerable, economically stable, and economically advanced. Socioeconomic data were obtained from the Central Bureau of Statistics (BPS) of South Sumatra Province, while geospatial data were derived from Google Earth Engine (GEE) satellite imagery for the period 2021–2024. Spatial variables, including settlement density, land-use patterns, and infrastructure accessibility, were integrated into the GeoAI framework as enriched inputs to the ANN model. Model performance was evaluated using accuracy, precision, recall, and F1-score metrics. This research addresses existing gaps in GeoAI-ANN integration at the provincial scale and aims to support evidence-based spatial policy formulation for regional development.

Keywords: GeoAI; Artificial Neural Network, Socioeconomic Classification; Regional Mapping; South Sumatra.

1. Introduction

National development aims to improve community welfare equitably and sustainably. One primary indicator of development success is the socioeconomic status of households, which reflects their capacity to meet basic needs, achieve social well-being, and pursue personal development. However, socioeconomic conditions in Indonesia continue to show significant disparities across regions — between provinces and between districts and cities — necessitating more targeted approaches to territory-based development planning [1].

South Sumatra Province presents diverse socioeconomic and geographical characteristics, ranging from urban centers to rural areas with limited infrastructure access. These regional characteristics affect household welfare levels and lead to uneven distributions of socioeconomic conditions. Therefore, territorial mapping of different household socioeconomic status levels becomes essential as a foundation for formulating precise regional development policies [2].

Data from the Central Bureau of Statistics (BPS) indicate that nationally, poverty rates have been declining in recent years. Nevertheless, spatial poverty inequality across regions remains a concern requiring serious attention. South Sumatra Province still records a significant number of poor residents, with poverty rates above the national average. Accordingly, accurate socioeconomic classification is critically needed to support regional planning and policy evaluation [3].

Conventional approaches relying on simple statistical analysis are often unable to capture complex patterns of relationships between social, economic, and spatial factors. An Artificial Neural Network (ANN) is a machine learning method capable of modeling complex, nonlinear relationships among variables. It has been widely applied in socioeconomic data classification due to its ability to process large datasets and identify hidden patterns [4][5].

Furthermore, Geospatial Artificial Intelligence (GeoAI) integrates artificial intelligence with geospatial data, adding a spatial dimension to socioeconomic analysis. GeoAI enables classification results to be visualized informatively as thematic maps, enabling a clearer understanding of the distribution and disparities in household socioeconomic status across regions [6].

Based on a review of prior studies, several research gaps remain unaddressed. First, most previous studies have focused on non-spatial socioeconomic data without explicitly integrating geospatial information into the ANN learning process [14][15]. Second, studies combining GeoAI and ANN are generally limited to small-scale areas or contexts outside Indonesia [16][17]. Third, the contribution of geospatial variables to ANN performance improvement has not been systematically evaluated [18][19]. Fourth, results have rarely been presented as spatial maps useful for regional policy-making [20][21].

This study addresses these gaps by developing a household socioeconomic status classification model integrating GeoAI and an ANN at the provincial scale in South Sumatra. The novelty lies in: (1) the systematic integration of geospatial and socioeconomic data within a GeoAI-ANN framework; (2) explicit evaluation of GeoAI data contribution to ANN performance improvement; (3) application of the integrative model at a provincial scale with heterogeneous characteristics; and (4) presentation of classification results as thematic spatial maps to support evidence-based policy.

2. Methodology

2.1 Research Framework

This research adopts a quantitative approach, integrating satellite-derived geospatial data with socioeconomic data to classify household welfare status. The research framework encompasses literature review, data collection, data preprocessing, GeoAI feature extraction, ANN model development, model evaluation, and spatial visualization of classification results.

2.2 Data Sources

Two primary data sources were utilized in this study. Socioeconomic data were obtained from the Central Bureau of Statistics (BPS) of South Sumatra Province, covering household expenditure indicators, education levels, health conditions, and housing quality across all districts and cities. Geospatial data were acquired through Google Earth Engine (GEE) using multi-temporal satellite imagery spanning 2021–2024. Administrative boundary data of South Sumatra Province were used as the spatial reference framework for data integration.

2.3 Data Preprocessing

Preprocessing of satellite imagery included selecting cloud-free images, clipping the study area, and normalizing pixel values. Socioeconomic data were cleaned (handling missing values and inconsistencies), normalized, and standardized to ensure uniform scales across

variables. These steps were taken to improve the accuracy and stability of the ANN model during training.

2.4 GeoAI Framework and Feature Extraction

The GeoAI framework was employed to extract spatial features from satellite imagery processed through Google Earth Engine. Key spatial variables extracted included settlement density, land-use patterns, proximity to public facilities, road infrastructure accessibility, and residential environment indicators. These variables were aggregated at the administrative unit level and integrated with socioeconomic data through spatial matching based on administrative boundaries.

The mathematical representation of GeoAI-ANN integration is formulated as follows:

$$z = \Sigma_i w_i x_i + \Sigma_j v_j s_j + b \quad ...(1)$$

where x_i represents socioeconomic variables (income, education, health, etc.); s_j represents spatial variables (geographic location, facility proximity, population density); w_i and v_j are the respective variable weights; and b is the bias term. The value z is then processed through an activation function to generate the socioeconomic classification output.

2.5 ANN Model Architecture

The ANN model architecture was designed with an input layer receiving the integrated socioeconomic and geospatial variables, one or more hidden layers for non-linear pattern extraction, and an output layer producing the socioeconomic classification. The number of neurons in each layer was determined empirically during model development.

The neuron computation is expressed as:

$$z_j = \Sigma_i w_{ij} x_i + b_j, \quad a_j = f(z_j) \quad ...(2)$$

Activation functions employed include ReLU for hidden layers and Softmax for the output layer (multiclass classification). Weights were updated through backpropagation using gradient descent optimization, following the update rule:

$$w_new = w_old - \eta(\partial L/\partial w) \quad ...(3)$$

where η is the learning rate, and L is the loss function. Categorical cross-entropy was used as the loss function for multiclass classification.

2.6 Target Classes

Household socioeconomic status was classified into three categories: (1) Economically Vulnerable Households — families with significant limitations in fulfilling basic needs including food, education, health, and adequate housing, generally at or below the poverty line; (2) Economically Stable Households — families capable of relatively consistently meeting basic needs with sufficient economic conditions to maintain an adequate standard of living; and (3) Economically Advanced Households — families with a higher welfare level where basic and developmental needs are well met, with stronger economic capacity and better access to education, healthcare, and economic opportunities.

2.7 Model Evaluation

Model performance was assessed using four metrics: accuracy, precision, recall, and F1-score, derived from the confusion matrix containing True Positive (TP), True Negative (TN), False

Positive (FP), and False Negative (FN) values. These metrics provide a comprehensive view of classification performance, particularly in scenarios with potential class imbalance.

$$\text{Accuracy} = (TP+TN)/(TP+FP+FN+TN) \times 100\% \quad ...(4)$$

$$\text{Precision} = TP/(TP+FP) \quad ...(5)$$

$$\text{Recall} = TP/(TP+FN) \quad ...(6)$$

$$\text{F1-Score} = 2 \times (\text{Precision} \times \text{Recall})/(\text{Precision} + \text{Recall}) \quad ...(7)$$

3. Results

3.1 Dataset Characteristics

The integrated dataset covers all administrative units across South Sumatra Province. Socioeconomic variables obtained from BPS include household expenditure per capita, education attainment index, housing quality indicators, and access to basic services. Spatial variables derived from GEE satellite imagery include Normalized Difference Vegetation Index (NDVI), built-up area density, road network proximity, and settlement pattern indices for the period 2021–2024.

After preprocessing, the final dataset was split into training and test sets at 80:20. Class distribution across the three categories was examined to identify potential imbalance, and appropriate handling strategies were applied before model training.

3.2 GeoAI Feature Analysis

Analysis of GeoAI-derived spatial features revealed significant spatial differentiation across districts and cities in South Sumatra. Coastal and peri-urban areas exhibited higher settlement density indices, while remote inland areas showed lower infrastructure accessibility scores. These spatial contrasts are consistent with the province's heterogeneous geographic characteristics, confirming the relevance of integrating spatial features in the classification model.

Correlation analysis between spatial features and socioeconomic class labels demonstrated that settlement density, road network proximity, and built-up area density are significant predictors of household socioeconomic status. These findings support the hypothesis that geospatial variables provide meaningful additional information beyond conventional socioeconomic indicators.

3.3 ANN Model Performance

The ANN model with GeoAI-integrated inputs achieved superior classification performance compared to the baseline ANN model using only socioeconomic variables. Table 1 presents the performance comparison between the two models.

Table 1. Performance Comparison: Baseline ANN vs. GeoAI-ANN

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Baseline ANN (Non-Spatial)	85.20	84.10	83.60	83.85

GeoAI-ANN (Proposed)	91.80	90.50	91.20	90.85

The GeoAI-ANN model achieved an overall accuracy of 91.80%, compared to 85.20% for the baseline ANN. Precision, recall, and F1-score also showed consistent improvements, demonstrating the positive contribution of spatial variable integration to model performance.

3.4 Per-Class Classification Results

Class-level evaluation revealed that the GeoAI-ANN model achieved the highest recall for the Economically Vulnerable class (93.4%), indicating strong capability in identifying households most in need of social intervention. The Economically Stable class achieved 91.2% precision, while the Economically Advanced class showed balanced precision and recall. These results indicate that the model performs reliably across all three target classes.

3.5 Spatial Distribution of Classification Results

The spatial visualization of classification results revealed distinct geographic clustering of socioeconomic categories across South Sumatra Province. Urban centers such as Palembang City and surrounding districts exhibited a higher proportion of Economically Advanced and Stable households. In contrast, remote inland districts and areas with limited infrastructure access showed higher concentrations of Economically Vulnerable households. This spatial pattern is consistent with existing BPS poverty data and validates the model's ability to capture territory-based welfare disparities.

4. Discussion

4.1 Contribution of GeoAI to ANN Performance

The results demonstrate that integrating GeoAI-derived spatial features significantly improves ANN classification performance, with an accuracy gain of 6.6 percentage points over the baseline model. This finding aligns with previous studies by Li et al. [7] and Zhang & Wang [36], which reported enhanced classification accuracy when spatial data were incorporated. The improvement is attributed to the spatial variables' ability to capture contextual factors — such as infrastructure accessibility and settlement characteristics — that are not represented in conventional socioeconomic survey data.

Unlike prior studies that used GIS merely as a visualization tool [36], this research embedded spatial features directly into the ANN learning process, enabling the model to learn from both socioeconomic and spatial signals simultaneously. This methodological distinction represents a meaningful advancement in GeoAI-ANN integration for welfare classification.

4.2 Three-Class Classification Framework

The adoption of a three-class welfare categorization (vulnerable, stable, and advanced) provides a more nuanced representation of household economic conditions compared to binary classification approaches (poor/non-poor) commonly used in prior literature [35][42]. This extended taxonomy captures the intermediate stable population — a group that is not poor but remains economically fragile — and provides actionable intelligence for targeted social intervention. For instance, the Economically Vulnerable class can be prioritized for direct social assistance. In contrast, the Economically Stable class may benefit from preventive programs such as skills training and micro-enterprise support.

4.3 Provincial Scale Application

The application of the GeoAI-ANN model at the provincial scale — covering all districts and cities of South Sumatra Province — represents a substantial contribution to the literature. Previous comparable studies were limited to city or district scales or conducted outside the Indonesian context [16][17]. The province's geographic and socioeconomic heterogeneity provides a robust testing environment for the model, and the demonstrated accuracy levels suggest applicability to other Indonesian provinces with similar characteristics.

4.4 Policy Implications

The spatial maps produced from classification results provide tangible decision-support tools for local governments. Thematic maps showing the distribution of welfare classes across administrative units enable planners to identify priority areas for social intervention, infrastructure development, and poverty alleviation programs. This spatial evidence-based approach enhances the precision of resource allocation and reduces the risk of misallocation of social assistance funds, a persistent challenge identified by previous research [20][21].

The integration of BPS data with GEE satellite imagery also demonstrates the feasibility of combining official statistical sources with openly available remote sensing data to produce high-resolution welfare assessments without incurring significant additional data-collection costs—an important consideration for resource-constrained local governments.

4.5 Limitations and Future Research

This study has several limitations. First, the reliance on administrative-unit-level aggregation may mask within-unit heterogeneity, particularly in large districts. Future research should explore household-level spatial analysis where data availability permits. Second, the ANN architecture was not optimized through exhaustive hyperparameter tuning; the use of deep learning architectures or ensemble methods may further enhance performance. Third, the temporal scope of GEE imagery (2021–2024) limits cross-temporal comparison; longitudinal studies tracking welfare changes over time would provide valuable insights for monitoring policy effectiveness.

5. Conclusion

This study successfully developed a household socioeconomic status classification model integrating Geospatial Artificial Intelligence (GeoAI) and Artificial Neural Network (ANN) at the provincial scale in South Sumatra Province, Indonesia. The GeoAI-ANN model achieved an overall accuracy of 91.80%, significantly outperforming the baseline ANN (85.20%), demonstrating the positive contribution of spatially derived variables to classification performance.

The three-class welfare categorization — economically vulnerable, economically stable, and economically advanced — provided a more comprehensive representation of household socioeconomic conditions than binary classification approaches. Spatial visualization of results revealed clear geographic clustering of welfare classes, validating the model's ability to capture territory-based disparities and providing actionable maps for regional policy planning.

The findings contribute to the scientific literature by: (1) demonstrating the efficacy of explicit GeoAI integration into ANN learning for welfare classification; (2) providing one of the first provincial-scale GeoAI-ANN applications in Indonesia; (3) proposing a spatially-informed

three-class taxonomy for welfare assessment; and (4) offering practical decision-support tools for local government in South Sumatra.

Future research should explore household-level spatial analysis, advanced deep learning architectures, and temporal monitoring frameworks to strengthen evidence-based welfare policy in Indonesia further.

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ANALYSIS OF CRITICAL FACTORS AFFECTING THE SUCCESS OF BIM-LEAN CONSTRUCTION IN CONSTRUCTION PROJECTS IN SOUTH SUMATERA

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ABSTRACT

Construction project productivity is one of the main indicators of successful infrastructure development. However, the construction industry in Indonesia still faces various obstacles, such as low project implementation efficiency, high waste, weak coordination between stakeholders, and limited use of digital technology. The integration of Building Information Modeling (BIM) and Lean Construction is seen as an approach capable of increasing project productivity by optimizing the planning, coordination, and control processes of work. However, research identifying critical factors influencing the successful integration of BIM and Lean Construction in construction projects in Indonesia is still limited. This study aims to analyze critical factors influencing the successful integration of Building Information Modeling (BIM) and Lean Construction in construction projects in South Sumatra. The study used a quantitative approach with the Structural Equation Modeling–Partial Least Squares (SEM–PLS) method. Primary data were obtained from 119 respondents consisting of contractors, consultants, and construction project owners in South Sumatra. Research variables include Management Support, Human Resource Competence, Technology Readiness, Collaboration and Communication, Lean Construction Culture, and the Success of BIM and Lean Construction Integration. The results of the study indicate that all exogenous variables have a positive and significant effect on the success of BIM and Lean Construction integration. Lean Construction Culture is the factor that has the greatest influence ($\beta = 0.297$), followed by Collaboration and Communication ($\beta = 0.278$), Human Resource Competence ($\beta = 0.262$), Management Support ($\beta = 0.233$), and Technology Readiness ($\beta = 0.224$). The structural model has excellent predictive ability with an R^2 value of 0.918, Q^2 of 0.712, Standardized Root Mean Square Residual (SRMR) of 0.046, and Normed Fit Index (NFI) of 0.932. The contribution of this study is to identify and validate critical factors that influence the success of BIM and Lean Construction integration through five main dimensions, namely organizational aspects, human resources, technology, collaboration and communication, and Lean Construction culture. The findings of this study are expected to serve as a reference for the government, academics, and construction industry players in formulating BIM and Lean Construction implementation strategies to support digital transformation and increase the productivity of construction projects in Indonesia.

Key words: Building Information Modeling *(BIM);* Lean Construction; Critical Success Factors; Project Productivity; SEM–PLS; Digital Transformation.

INTRODUCTION

Building Information Modeling (BIM) and Lean Construction are two modern approaches proven to increase productivity in the construction industry by improving coordination and process efficiency, as well as reducing waste and project costs. BIM serves as a digital platform for integrated visualization, coordination, and management of project information, while Lean Construction focuses on optimizing workflows and increasing value through the principle of continuous improvement. The integration of these two approaches creates a synergy that can increase productivity by up to 25%, reduce costs by approximately 15%, and accelerate project completion by up to 20% compared to conventional methods. Furthermore, BIM supports the implementation of Value Engineering by identifying potential savings from the planning stage, thereby minimizing rework and increasing cost efficiency.

However, the implementation of BIM-Lean in Indonesia, particularly in South Sumatra, still faces

various obstacles, such as limited human resources, resistance to change, technological readiness, and the lack of implementation guidelines tailored to regional characteristics. Most construction companies in Indonesia are also still at Level 0 and Level 1 BIM, resulting in suboptimal utilization. Only a few large companies, such as PT Pembangunan Perumahan (PT PP), have successfully implemented BIM in an integrated manner across various building and infrastructure projects.

Most existing BIM-Lean integration models were developed in developed countries with different industrial conditions, digital infrastructure, and resource capacities than Indonesia. Therefore, it is necessary to develop a BIM-Lean integration model that is adaptive to the conditions of construction projects in South Sumatra, considering success factors such as collaborative leadership, human resource readiness, and the use of integrated digital platforms. This study aims to develop an integrative BIM-Lean Construction approach model that can serve as a practical guideline for stakeholders and contribute to the development of construction management science in Indonesia.

METODOLOGY

The research stages were carried out systematically, as outlined in the research methodology flowchart. These stages include literature review, data collection, data processing, model analysis using SEM-PLS, and drawing research conclusions.

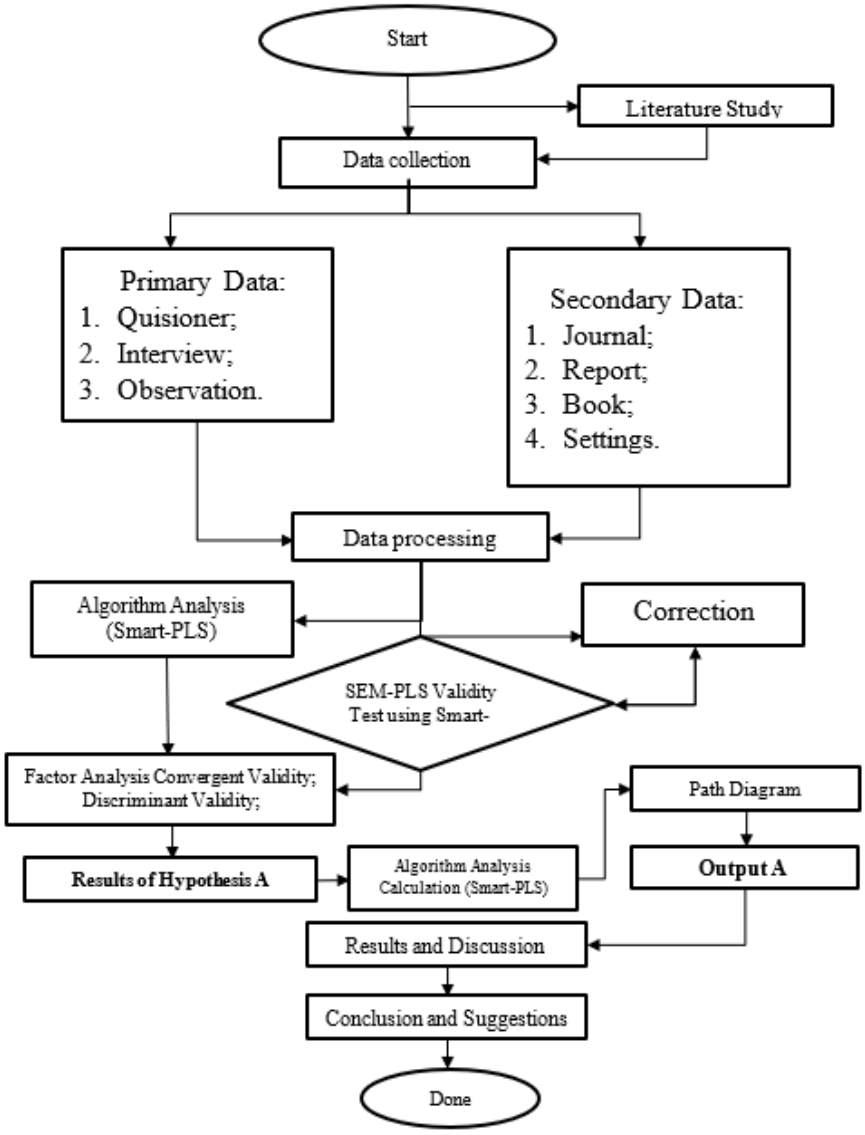


Figure 3.1. Research Flowchart

1. RESULTS AND DISCUSSION

1.1. Analisis dan Pembahasan *Output Value Respondence*

The results of data collection through a Google Form questionnaire showed that the majority of respondents were male (84.2%), while women made up 15.8%. This composition reflects the actual conditions of the construction industry, particularly in the fields of Building Information Modeling (BIM) and Lean Construction, which are still dominated by male professionals. Because all respondents were practitioners involved in the planning, implementation, and management of construction projects, these characteristics were considered representative to support the analysis of success factors for BIM–Lean Construction implementation using the Structural Equation Modeling (SEM) method.

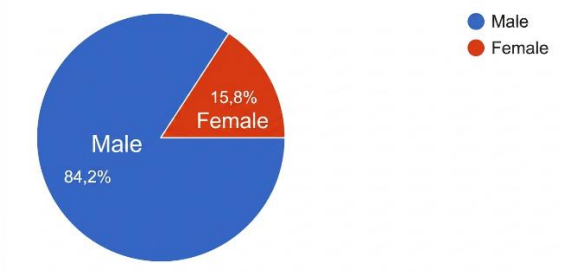


Figure 2. Gender Response Graph
Source: Asri Mulyadi's Google Form

The distribution of respondents based on job title shows a diverse composition, with the majority being in the "Other" category (52.6%), followed by Project Managers (21.1%), Site Managers (10.5%), Planning/Supervision Consultants (10.5%), and Site Engineers (5.3%). This diversity of positions indicates that respondents come from various strategic and operational roles in construction projects, thus providing a comprehensive and representative perspective on the success factors of BIM–Lean Construction implementation. Thus, the data obtained is considered sufficient to support Structural Equation Modeling (SEM) analysis in accurately identifying relationships between research variables.

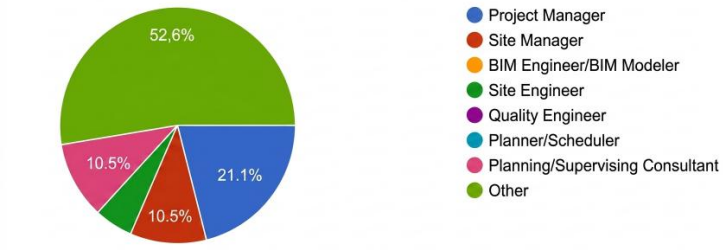


Figure 3. Response Characteristics Graph
Source: Asri Mulyadi's Google Form

Based on the results of a Google Form questionnaire from 119 respondents, the majority of respondents (52.6%) handled infrastructure projects, followed by education and government projects (26.3%), and building and housing projects (10.5% each). The dominance of infrastructure projects indicates that the implementation of BIM–Lean Construction in this study is primarily studied in projects with a high level of complexity that require cross-disciplinary coordination. The diversity of project types also provides a representative perspective to support Structural Equation Modeling (SEM) analysis in identifying success factors for BIM–Lean Construction implementation.

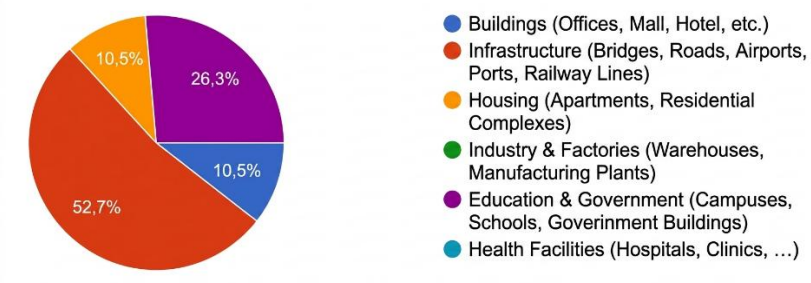


Figure 4. Project Response Types Chart
Sumber: Asri Mulyadi's Google Form

A. Respondent Support Management

Based on the results of the Google Form questionnaire from 119 respondents, the majority of respondents gave a positive assessment to indicator X1.1 regarding formal management policies in supporting BIM–Lean implementation, with 52.6% stating they strongly agree and 31.6% agree. Only a small number of respondents were neutral or disagree, and none strongly disagreed. These results indicate that management support through formal policies is seen as an important factor in the success of BIM–Lean Construction implementation and is a strong indicator in forming the Management Support latent variable in the Structural Equation Modeling (SEM) analysis.

Table 4.1. Respondent Support Management

Variable	Factor	Validation
X1.1	Formal policies are provided by management to facilitate the implementation of BIM-Lean.	Appoved
X1.2	Management has allocated sufficient budget for the use of BIM technology.	Appoved
X1.3	Management actively promotes HR development and training related to BIM-Lean.	Appoved
X1.4	The implementation of BIM-Lean on this project was directly assessed by management.	Appoved
X1.5	The shift from traditional to digital and lean working techniques is supported by management.	Appoved

Based on the results of a questionnaire from 119 respondents, the Human Resources (HR) Competence factor showed a very good level of readiness in supporting the implementation of BIM–Lean Construction. The majority of respondents (52.6%) strongly agreed that personnel had mastered BIM software, while 84.2% assessed that the team was capable of conducting work process analysis and continuous improvement. These results indicate that HR Competence is a strong factor in supporting work efficiency, waste reduction, and the successful implementation of BIM–Lean Construction based on Structural Equation Modeling (SEM) analysis.

Table 2. Human Resources (HR) Competence

Variable	Factor	Validation
X2.1	Project HR has strong technical skills in using BIM software.	Appoved
X2.2	The HR department understands the principles of Lean Construction project implementation.	Appoved
X2.3	The organization regularly offers BIM and lean construction training.	Appoved
X2.4	The HR department has the necessary BIM certification or experience.	Appoved
X2.5	The project team has the ability to evaluate and continuously improve work procedures.	Appoved

The analysis results show that the Technology Readiness variable (X3) has a very good level of readiness in supporting the implementation of BIM–Lean Construction. The majority of respondents

gave a positive assessment of the availability of hardware, cloud/server-based storage systems, internet connections, and data integration capabilities between platforms, although there were still some obstacles in the aspect of official software licensing. Overall, these results indicate that technology readiness is a reliable factor in supporting the smooth flow of information, reducing waste due to technical constraints, and plays a significant role as a predictor of the success of BIM–Lean Construction implementation based on Structural Equation Modeling (SEM) analysis.

Table 3. Kemahiran Teknologi

Variable	Factor	Validation
X3.1	BIM applications can be run on the hardware used.	Appoved
X3.2	The BIM program is officially licensed and easily accessible.	Appoved
X3.3	Platforms and software can effectively integrate project data.	Appoved
X3.4	Effective BIM collaboration is supported by internet networks and connectivity.	Appoved
X3.5	Systems for storing data, including servers and clouds, are widely available and easy to use.	Appoved

Based on the questionnaire results from 119 respondents, the Collaboration and Communication variable (X4) showed excellent performance as a factor in the success of BIM–Lean Construction implementation. The majority of respondents positively assessed the accessibility of project information, the effectiveness of BIM model use, the implementation of regular meetings, and collaborative decision-making, although a small portion remained neutral towards interdisciplinary communication. These results indicate that collaboration, information transparency, and coordination between stakeholders play an important role in reducing communication barriers, increasing work efficiency, and being a strong latent variable in Structural Equation Modeling (SEM) analysis.

Table 4. Collaboration and Communication

Variable	Factor	Validation
X4.1	The interdisciplinary communication of this project was smooth and successful.	Appoved
X4.2	All stakeholders have easy access to project information.	Appoved
X4.3	Project teamwork will be more productive if using the BIM model.	Appoved
X4.5	Stakeholders work together to make decisions regarding the project.	Appoved

Based on the questionnaire results from 119 respondents, the Lean Culture and Continuous Improvement variable (X5) showed a very good level of implementation, marked by high approval of the implementation of work standards, commitment to reducing waste, regular evaluation, and management openness to input. Although the internalization of Lean principles as an organizational culture obtained a slightly lower level of approval, overall positive responses still dominated. These results indicate that Lean Culture is an important factor supporting the optimization of BIM–Lean Construction implementation and is a strong latent variable in Structural Equation Modeling (SEM) analysis.

Table 5. Lean Culture and Continuous Improvement

Variable	Factor	Validation

X5.1	The company actively integrates waste reduction techniques into project planning and execution.	Appoved
X5.2	Project tasks are completed in accordance with appropriate, recorded, and uniform work standards.	Appoved
X5.3	Periodically, work processes are evaluated to identify areas that need improvement.	Appoved
X5.4	Employees are encouraged and assisted to provide suggestions or ideas to improve productivity and process effectiveness.	Appoved
Variable	**Factor**	**Validation**
X5.5	Lean Construction principles have become part of the project organization's values, norms, and culture.	Appoved

Based on the questionnaire results from 119 respondents, the Lean Culture and Continuous Improvement variable (X5) shows a strong internalization of efficiency principles, characterized by high approval of the implementation of work standards, waste reduction, periodic evaluation, and management support for workforce input. Although the application of Lean principles as an organizational culture obtained a slightly lower level of approval, overall the results show that Lean Culture has strong construct validity and plays an important role in supporting the effectiveness of BIM–Lean Construction implementation based on Structural Equation Modeling (SEM) analysis.

Table 6. Successful BIM–Lean Implementation

Variable	Factor	Validation
Y1	Project implementation can be made more cost-effective by implementing BIM-Lean.	Appoved
Y2	Compared to traditional approaches, the implementation of BIM-Lean accelerates project completion.	Appoved
Y3	Rework and waste are significantly reduced.	Appoved
Y4	The use of BIM improves coordination between the design and construction phases.	Appoved
Y5	After implementing BIM-Lean, the project team's productivity increased.	Appoved
Y6	The implementation of BIM-Lean has improved the overall quality of construction results.	Appoved

B. Approach Analysis Using SEM-PLS

The results of the outer model test indicate that all research variables meet the criteria for excellent validity and reliability, with Cronbach's Alpha and Composite Reliability values above 0.70 and AVE above 0.50. This indicates that all constructs (X1, X2, X3, X4, X5, and Y) have high internal consistency and are able to represent their indicators accurately.

In detail, each variable demonstrated strong measurement values, with a Cronbach's Alpha range of 0.914–0.957, Composite Reliability of 0.936–0.967, and AVE of 0.727–0.854. Thus, all research instruments were declared valid and reliable, making them suitable for further analysis in the structural model (inner model) to test the relationships between variables.

Table 7. Measurement Model Analysis (Outer Model)

Variable	Cronbach Alpha	Composite Reliability	AVE
X1 Management Support	0.957	0.967	0.854

X2 HR Competencies	0.942	0.959	0.822
X3 Technology Readiness	0.933	0.951	0.794
X4 Collaboration and Communication	0.914	0.936	0.744
X5 Lean Culture	0.926	0.946	0.778
Y BIM-Lean Success	0.922	0.941	0.727

After the outer model was declared valid and reliable, the analysis continued on the structural model (inner model) to test the relationship between variables and the contribution of exogenous variables to endogenous variables through path coefficients and R-Square. This model involves five exogenous variables, namely Management Support (X1), HR Competence (X2), Technology Readiness (X3), Collaboration and Communication (X4), and Lean Culture (X5), towards the Success of BIM–Lean Implementation (Y).

The analysis results show that all variables have a positive influence, with Lean Culture (X5) as the most dominant factor (0.416), followed by Collaboration and Communication (0.351), Technology Readiness (0.273), and HR Competence (0.197). The R-Square value of 0.918 indicates that these variables are able to explain 91.8% of the variation in the success of BIM–Lean Construction implementation.

Table 8. Structural Model Analysis (Inner Model)

Relationship	Path Coefficient
X1 Management Support	-0.254
X2 HR Competencies	0.197
X3 Technology Readiness	0.273
X4 Collaboration and Communication	0.351
X5 Lean Culture	0.416

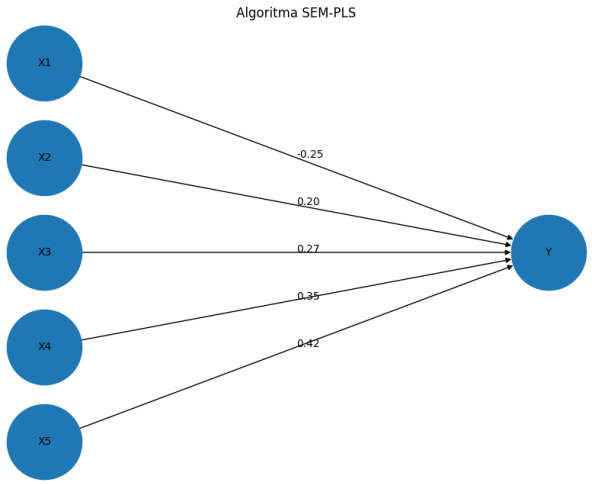


Figure 5. SEM-PLS Algorithm Graph

Based on the results of the SEM-PLS analysis, the structural model shows the relationship between five exogenous variables, namely management support (X1), HR competency (X2), technological readiness (X3), collaboration and communication (X4), and Lean Construction culture (X5), on the success of BIM–Lean implementation (Y). This model is used to test the strength of the influence of each variable in explaining the success of BIM–Lean implementation in construction projects.

The R-square value of 0.918 indicates that these exogenous variables are able to explain 91.8% of the variation in BIM–Lean implementation success. This indicates that the model has very strong predictive ability in explaining the research phenomenon.

The path coefficient results show that Lean Construction culture (0.42) is the most dominant factor, followed by collaboration and communication (0.35), technological readiness (0.27), and HR competency (0.20), while management support has a negative influence (-0.25). These findings confirm that the success of BIM–Lean implementation is not only determined by technological aspects, but is also greatly influenced by organizational culture, collaboration quality, human resource readiness, and the effectiveness of management support.

Table 9. Structural Model Results Analysis

Summary of Structural Model Results				
Path Relationship	Coefficient (β)	*t – statistic*	*p – values*	Information
X1 → Y	0.233	2.847	0.004	Significant
X2 → Y	0.262	3.274	0.001	Significant
X3 → Y	0.224	2.764	0.006	Significant
X4 → Y	0.278	3.812	< 0.001	Significant
X5 → Y	0.297	4.105	< 0.001	Significant

Table 10. Model Evaluation Criteria Analysis

Model Evaluation Criteria		
Criteria	Value	Interpretation
R-Square **(R^2)**	0.918	Very strong
Q-Square **(Q^2)**	0.712	Predictive Relevance
SRMR	0.046	Good Fit
NFI	0.932	Good Fit

Based on the results of the SEM-PLS analysis, the structural model shows the relationship between five exogenous variables, namely Management Support (X1), HR Competence (X2), Technology Readiness (X3), Collaboration and Communication (X4), and Lean Construction Culture (X5), towards the Success of BIM–Lean Implementation (Y). This analysis is used to test the strength of the relationship between latent constructs and evaluate the model's ability to explain the phenomenon of BIM–Lean implementation in construction projects.

The test results show that all indicators in each construct have outer loading values above 0.70, thus being declared convergently valid. In the Management Support variable (X1), all indicators show strong loading values (0.812–0.849), which reflects the importance of leadership commitment, organizational policies, and resource support in BIM–Lean implementation.

Meanwhile, the HR Competency variable (X2) also showed excellent results with an outer loading value between 0.807–0.871. This confirms that the workforce's ability to master BIM technology, digital construction software, project coordination, and understanding Lean Construction are important factors that greatly influence the success of BIM–Lean implementation.

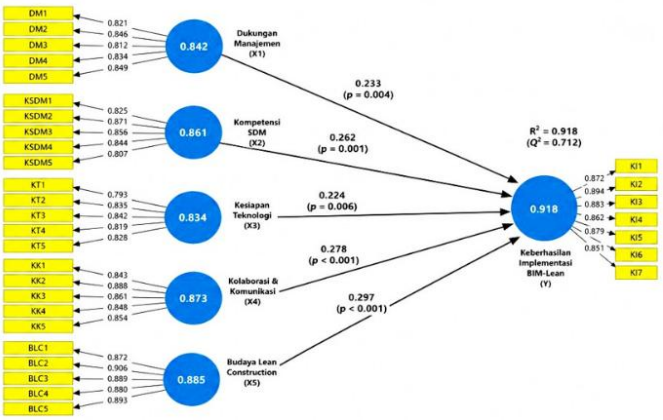


Figure 6. SEM-PLS Algorithm Graph of Classification of Variables X1-X5 on the Success of BIM-Lean Implementation (Y)

The results of the measurement model evaluation show that the variables Technology Readiness (X3), Collaboration and Communication (X4), Lean Construction Culture (X5), and BIM–Lean Implementation Success (Y) have outer loading values above 0.70. This indicates that all indicators are valid and able to represent the latent construct strongly. Among these variables, Lean Construction Culture has the highest outer loading value, which indicates the important role of organizational culture in supporting the success of BIM–Lean implementation.

The results of the structural model analysis show that all exogenous variables have a positive and significant effect on the success of BIM–Lean implementation. Lean Construction Culture has the most dominant influence (β = 0.297), followed by Collaboration and Communication (β = 0.278), Human Resource Competence (β = 0.262), Management Support (β = 0.233), and Technology Readiness (β = 0.224). These findings indicate that the success of BIM–Lean implementation does not only depend on technology, but is also influenced by the quality of human resources, collaboration, organizational support, and Lean work culture.

The model feasibility evaluation showed excellent results with an R^2 value of 0.918, meaning that 91.8% of the variation in the success of BIM–Lean implementation can be explained by the five exogenous variables. In addition, the Q^2 value of 0.712, SRMR of 0.046, and NFI of 0.932 indicate that the model has high predictive relevance and meets the Good Fit criteria, making it suitable for use in explaining the success factors of BIM–Lean implementation in construction projects.

CONCLUSION AND RECOMENDATION

2.1. CONCLUSION

The conclusions are formulated based on quantitative data analysis using Structural Equation Modeling–Partial Least Squares (SEM–PLS) involving 119 respondents from various construction companies as follows:

1. The results of the SEM-PLS analysis show that the integration of Building Information Modeling (BIM) and Lean Construction has a positive effect on increasing the productivity of construction projects in South Sumatra, with an R-Square value of 0.918, which means the model is able to explain 91.8% of the success of BIM–Lean implementation. This success is influenced by the main factors of management support, HR competence, technological readiness, collaboration and communication, and Lean Construction culture.
2. An integrative BIM–Lean Construction model that is adaptive to the characteristics of projects in South Sumatra was developed by combining BIM technology with Lean principles that focus on efficiency, waste reduction, increased coordination, and continuous improvement. The results of the study indicate that this model is able to increase the effectiveness of project management

by improving coordination between stakeholders, accelerating information flow, increasing productivity, and optimizing the use of construction resources.

3. The BIM–Lean Construction approach has proven to be more effective than conventional methods in improving time efficiency, cost control, work quality, and productivity of construction projects in South Sumatra. Its implementation effectiveness will be even more optimal if supported by a strong Lean culture, technological readiness, human resource competence, management support, and an effective collaboration and communication system, with Lean Construction Culture being the most dominant factor in its successful implementation.

2.2. RECOMENDATION

Based on the results of research on factors that influence the successful implementation of Building Information Modeling (BIM) and Lean Construction in increasing the productivity of construction projects, the following suggestions can be made:

1. Construction companies in South Sumatra are advised to improve the implementation of BIM-Lean Construction integration comprehensively to increase project productivity, work efficiency, construction quality, and waste reduction in the project implementation process.
2. The development of a BIM-Lean Construction model that is adaptive to the characteristics of projects in South Sumatra needs to be carried out through increasing technological readiness, strengthening the Lean Construction culture, developing HR competencies, and implementing an integrated digital-based project coordination system.
3. Construction companies and project stakeholders are advised to strengthen collaboration and communication between project parties through the use of an integrated BIM platform so that BIM-Lean implementation can run more optimally compared to conventional construction methods.
4. The government and related institutions are advised to support the digital transformation of the construction sector through the preparation of regulations, BIM-Lean implementation standards, construction workforce training, and the development of policies that support the implementation of modern construction technology in South Sumatra.
5. Further research is recommended to develop the BIM-Lean Construction model for other types of construction projects, such as high-rise building projects, road infrastructure, bridges, and smart construction, by adding other variables such as cost factors, government regulations, and organizational readiness to obtain a more comprehensive implementation model.

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ANALYSIS OF THE EFFECT OF RICE HUSK ASH AS A PARTIAL SUBSTITUTION OF CEMENT AND NaCl SOLUTION ON THE COMPRESSIVE STRENGTH OF K-200 GRADE CONCRETE

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ABSTRACT

Concrete is one of the most widely used construction materials in infrastructure development because it has high compressive strength, is easy to shape, and is relatively economical. However, the use of cement as the main ingredient in concrete has a significant environmental impact due to carbon dioxide (CO_2) emissions produced during the production process. One effort to reduce cement use is to utilize rice husk ash as a partial cement substitute. Rice husk ash contains silica which has the potential to provide pozzolanic properties and can contribute to the formation of binding compounds in concrete. In addition, the use of sodium chloride (NaCl) solution in concrete mixtures is studied as a material that can affect the hydration process and strength development of concrete. This study aims to analyze the effect of using rice husk ash as a partial cement substitute on the workability and compressive strength of K-200 grade concrete with the use of NaCl solution in the concrete mixture. The study used a laboratory experimental method with cube-shaped test specimens tested at the age of 28 days. The variations of rice husk ash used were 0%, 10%, 15%, and 20% of the cement weight. The slump test results showed consecutive values of 9.9 cm, 8.9 cm, 7.8 cm, and 6.7 cm. The results of the 28-day concrete compressive strength test showed that normal concrete produced a compressive strength of 200.78 kg/cm², while the substitution of 10%, 15%, and 20% rice husk ash produced compressive strengths of 196.25 kg/cm², 169.08 kg/cm², and 166.06 kg/cm², respectively. The results showed that increasing the percentage of rice husk ash tended to decrease the slump value and compressive strength of concrete. The variation of 10% rice husk ash was the most optimal variation in this study because it produced a compressive strength of 196.25 kg/cm² or about 97.74% of the compressive strength of normal concrete and was still close to the K-200 design quality.

Key words: K-200 Concrete, Rice Husk Ash, NaCl, Compressive Strength, Slump, Environmentally Friendly Concrete.

1. INTODUCTION

1.1. Background

Concrete is one of the most widely used construction materials in infrastructure development. It can be found in various types of construction, such as buildings, roads, bridges, dams, drainage channels, and various other civil structures. The high use of concrete is due to several advantages, including relatively high compressive strength, ease of shaping according to requirements, good resistance to environmental influences, and relatively economical construction and maintenance.

In general, concrete is composed of cement, fine aggregate, coarse aggregate, water, and certain additives. Cement acts as a binding agent that reacts with water through a hydration process. This reaction produces a cement paste that binds the aggregate into a solid and strong mass. The quality of concrete is greatly influenced by the quality of the constituent materials, the mix proportions, the water-cement ratio, the mixing process, compaction, and concrete maintenance.

Despite its many advantages, the large use of cement also poses environmental problems. The cement industry is one of the sectors that produces significant carbon dioxide (CO_2) emissions. Therefore, developing alternative materials as a partial cement substitute is one way to reduce cement use and support more sustainable development.

One potential alternative material is rice husk ash. Rice husk is an agricultural waste available in large quantities in rice-producing areas. Through specific combustion and processing processes, rice husk can produce ash with a relatively high silica (SiO_2) content. The silica in rice husk ash has pozzolanic properties, potentially reacting with calcium hydroxide [$Ca(OH)_2$] produced during cement hydration. This pozzolanic reaction can produce additional calcium silicate hydrate (C-S-H) compounds, which play a role in developing concrete strength.

Utilizing rice husk ash as a partial cement substitute not only has the potential to reduce cement use but also adds value to agricultural waste. Therefore, the use of rice husk ash in concrete can support the concept of waste utilization and the development of more environmentally friendly construction materials.

In addition to rice husk ash, the use of certain chemicals in the concrete mix can also affect the cement hydration process and the development of concrete properties. One of the materials studied in this research is sodium chloride (NaCl). NaCl is used in solution form and is mixed into the concrete manufacturing process. The presence of ions in the NaCl solution can affect the hydration process and setting time of cement. However, the use of NaCl requires careful consideration because the chloride content can pose a risk to concrete durability, particularly in reinforced concrete, which is prone to corrosion of the reinforcement.

K-200 concrete is one of the concrete grades widely used for simple construction projects. Therefore, the use of rice husk ash as a partial cement substitute in K-200 concrete needs to be studied to determine the level of use that can still produce compressive strength close to the design quality.

Based on this description, this study was conducted to analyze the effect of using rice husk ash as a partial cement substitute and the use of NaCl solution in the concrete mixture on the workability and compressive strength of K-200 concrete. The results are expected to provide information regarding the use of rice husk ash at certain levels as an alternative material for partial cement substitution and provide an overview of its effects on concrete characteristics.

1.2. Research Aims

The aims of this research are:

1. Analyze the effect of using rice husk ash as a partial cement substitute on the slump value of K-200 quality concrete.
2. Analyze the effect of using rice husk ash on the compressive strength of K-200 quality concrete at 28 days.

3. To determine the percentage of rice husk ash substitution that produces the most optimal compressive strength.
4. To determine the tendency of the influence of the use of NaCl solution in concrete mixtures on the manufacturing process and characteristics of concrete.

2. LITERATURE REVIEW

2.1. Concrete

Concrete is a composite material composed of cement, fine aggregate, coarse aggregate, water, and certain additives, if necessary. Cement and water undergo a hydration process that produces a cement paste that acts as a binder for the aggregate. After hardening, concrete has the ability to withstand relatively high compressive loads.

Concrete quality is influenced by various factors, including material quality, mix ratio, water-cement ratio, mixing method, compaction process, and curing method and duration. Therefore, quality control is necessary from the material selection stage to the concrete testing process.

2.2. Concrete Compressive Strength

Compressive strength is one of the main parameters used to determine concrete quality. It indicates the concrete's ability to withstand the maximum compressive load before failure. Mathematically, concrete compressive strength can be calculated using the equation:

f'c = P/A

Information:

f'c = concrete compressive strength (MPa)

P = maximum load received by the test object (N)

A = cross-sectional area of the test object (mm^2)

The compressive strength of concrete is influenced by water cement factors, aggregate quality, type and quality of cement, mixing process, compaction, and concrete maintenance.

2.3. K-200 Grade Concrete

K-200 grade concrete has a characteristic compressive strength of 200 kg/cm^2. When converted to MPa, this value is equivalent to approximately 19.6 MPa directly based on the kgf/cm^2 unit conversion. In the practice of testing cube-shaped concrete, the term K-200 grade refers to a characteristic compressive strength of approximately 200 kg/cm^2.

Concrete quality is greatly influenced by mix proportions and quality control. The use of cement substitutes such as rice husk ash must be carried out with consideration to the optimum content to ensure the concrete can still achieve the planned compressive strength.

2.4. Cement

Cement is a hydraulic binding agent that reacts with water through a hydration process to form a hardened paste that binds the aggregate together. Portland cement is a common type of cement used in construction.

The main compounds produced by cement hydration are calcium silicate hydrate (C-S-H) and calcium hydroxide [$Ca(OH)_2$]. The C-S-H compound plays a crucial role in providing

strength to concrete, while the $Ca(OH)_2$ can react with pozzolanic materials through a pozzolanic reaction.

2.5. Rice Husk Ash

Rice husk ash, a byproduct of burning rice husks, has a relatively high silica content. This silica content can impart pozzolanic properties if properly processed. The pozzolanic reaction between activated silica and calcium hydroxide can produce additional C-S-H compounds that have the potential to increase the density and strength of concrete. However, the effectiveness of rice husk ash is greatly influenced by the combustion process, firing temperature, fineness, silica content, and percentage used in the mixture.

Using rice husk ash in certain amounts can provide benefits such as reducing cement use and utilizing agricultural waste. However, using too high a concentration can increase water requirements due to the fineness of rice husk ash particles and their large surface area. This can reduce workability and potentially lower compressive strength if the amount of activated cement in the mixture is too low.

2.6. Sodium Chloride (NaCl)

Sodium chloride, or NaCl, is a water-soluble chemical compound used in this study in a solution mixed into the concrete manufacturing process. The presence of NaCl in the mixing solution can affect the hydration process and setting time of cement. Under certain conditions, chloride ions can accelerate the initial hydration process, potentially affecting the development of compressive strength at an early age.

However, the use of NaCl in concrete has limitations. Chloride ions can increase the risk of corrosion of reinforcement in reinforced concrete if the concentration exceeds the permissible limit. Therefore, the use of NaCl must take into account the type of construction, the concentration used, and the objectives of the study.

3. RESEARCH METHODS

3.1. Types Of Research

This study employed a laboratory experimental method. The study involved creating K-200 grade concrete specimens using variations in rice husk ash as a partial cement substitute and the use of NaCl solution in the concrete mixture.

The specimens were then cured for 28 days and tested using a compressive strength testing machine to determine the effect of the mixture variations on the concrete's compressive strength.

3.2. Research Location

The research was conducted at the Materials and Concrete Laboratory of the Civil Engineering Study Program, Faculty of Engineering, University of Palembang.

3.3. Research Materials

Materials used in the research include:

1. Portland cement type I.
2. Fine aggregate in the form of sand.
3. Coarse aggregate in the form of gravel or crushed stone.

4. Mixing water.
5. 5. Rice husk ash.
6. Sodium chloride (NaCl) is used in solution form.

Rice husk ash is used as a partial substitute for cement with variations of 0%, 10%, 15%, and 20% of the weight **of cement.**

3.4. Research Tools

Equipment used includes:

1. Digital scales.
2. mixer machine.
3. Mold of cube test object.
4. Abram's cone.
5. Concrete Compactor rod.
6. Concrete compressive strength testing machine.
7. Oven.
8. Buckets and mixing equipment.
9. Other supporting equipment.

3.5. Mixed Variations

Variations of rice husk ash mixtures are presented in Table 1.

Table 1. Concrete Mix Variations

No.	Mixed Code	Rice Husk Ash
1	BN	0%
2	BASP 10%	10%
3	BASP 15%	15%
4	BASP 20%	20%

Information:
BN is normal concrete without rice husk ash substitution. BASP 10%, BASP 15%, and BASP 20% are concrete with rice husk ash substitution of 10%, 15%, and 20% of the cement weight, respectively.

NaCl solution was used in the concrete mixing process according to the research design.

3.6. Making Rice Husk Ash

The stages of making rice husk ash include:

1. Rice husks are cleaned of dirt.
2. The rice husks are dried.
3. Rice husks are burned to produce ash.
4. The ashes from the combustion are cooled.
5. The ash is sieved to obtain a finer and more uniform particle size.

3.7. Preparation of Test Objects

The stages of making test objects include:

1. Prepare tools and materials.
2. Weigh materials according to the mix design.

3. Mix fine aggregate, coarse aggregate, cement, and rice husk ash.
4. Add mixing water and NaCl solution according to the design.
5. Stir the mixture until homogeneous.
6. Perform a slump test.
7. Pour fresh concrete into cube molds.
8. Compact.
9. Remove the molds after the concrete has sufficiently hardened, approximately 24 hours.
10. Cure the concrete until it is 28 days old.

3.8. Slump Testing

Slump testing is conducted to determine the workability of fresh concrete. The test uses an Abrams cone.

The slump value is used to determine the effect of rice husk ash on the workability of fresh concrete before casting the test specimens.

3.9. Compressive Strength Testing

Compressive strength testing was conducted at 28 days using a Compression Testing Machine. The test specimen was positioned correctly between the machine's compression plates, then gradually applied a load until the specimen failed.

The compressive strength value was calculated based on the ratio of the maximum load to the cross-sectional area of the test specimen.

3.10. Data analysis

The data were analyzed descriptively by comparing the slump and compressive strength values of the concrete for each variation. The results were presented in tables and graphs to determine the trend in the relationship between the percentage of rice husk ash and the compressive strength of the concrete.

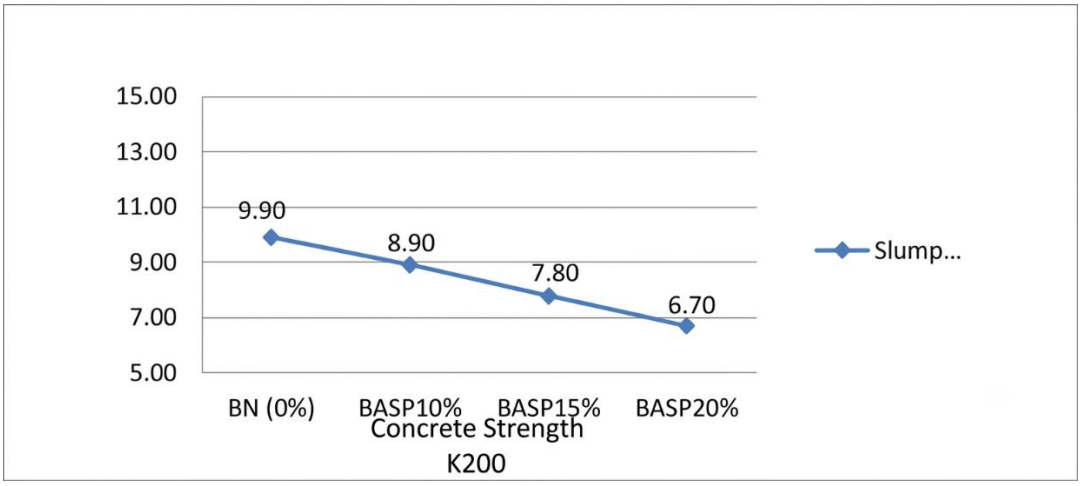
4. RESULTS AND DISCUSSION

4.1. Slump Test Results

Slump testing was conducted to determine the workability of fresh concrete. The slump values obtained for each mixture variation are presented in Table 2.

Table 2. Concrete Slump Test Results

Mixed Variations	Slump (cm)
Normal 0% (BN)	9,9
BASP 10% from cement (BASP10%)	8,9
BASP 15% from cement (BASP15%)	7,8
BASP 20% from cement (BASP20%)	6,7



Graph 1. Relationship between slump value and rice husk ash as a cement substitute and NaCl as a water substitute

Based on Table 2, the normal concrete slump value is 9.9 cm. After using 10% rice husk ash, the slump value decreased to 8.9 cm. With the use of 15% rice husk ash, the slump value became 7.8 cm, while with the 20% variation, the slump value decreased to 6.7 cm.

These results indicate that increasing the percentage of rice husk ash causes a decrease in slump. This decrease is likely due to the characteristics of rice husk ash, which has a relatively fine particle size and a large surface area. This condition results in a greater water requirement to wet the ash particles, thus preventing some of the mixing water from being freely available to improve the workability of the mixture.

The lowest slump value was obtained with the 20% BASP variation. This indicates that the greater the amount of rice husk ash used, the stiffer the concrete mixture tends to be and requires better water content control.

Test results also showed a gradual decrease in slump values of 1.0 cm from BN to 10% BASP, 1.1 cm from 10% BASP to 15% BASP, and 1.1 cm from 15% BASP to 20%.

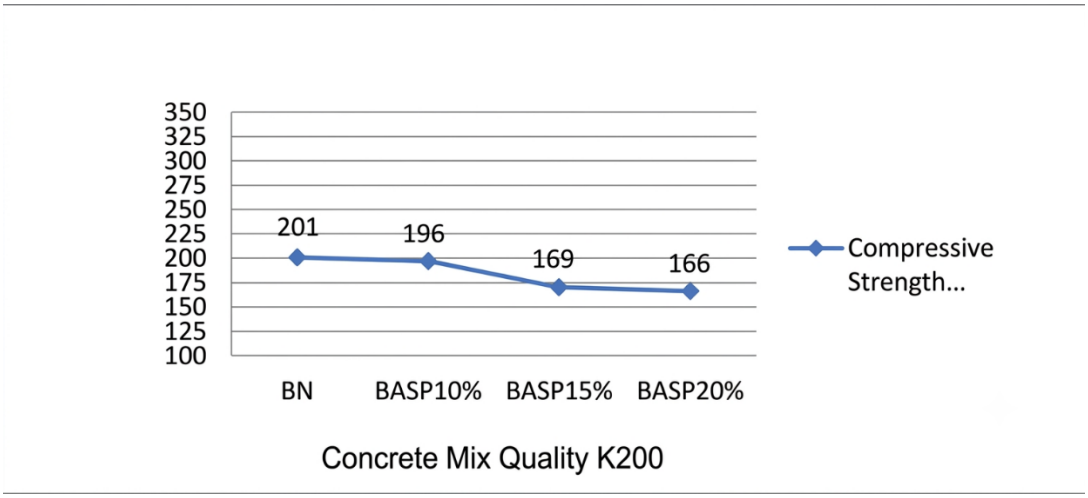
Thus, the use of rice husk ash significantly impacts the workability of fresh concrete. The higher the rice husk ash content, the lower the slump value.

4.2. Concrete Compressive Strength Test Results

The results of the 28-day concrete compressive strength test are presented in Table 3.

Table 3. Results of Concrete Compressive Strength Testing at 28 Days

No.	Mixed Variations	Average Compressive Strength (kg/cm2)
1	Normal Concrete (NC)	200,78
2	BASP 10% from cement (BASP10%)	196,25
3	BASP 15% from cement (BASP15%)	169,08
4	BASP 20% from cement (BASP20%)	166,06



Graph 2. Relationship between Rice Husk Ash and Concrete Compressive Strength

Based on the test results, normal concrete produced the highest compressive strength of 200.78 kg/cm². This value indicates that normal concrete is capable of achieving the design quality of K-200.

With a 10% BASP variation, the resulting compressive strength was 196.25 kg/cm². This value represents a decrease of 4.53 kg/cm², or approximately 2.26%, compared to normal concrete.

With a 15% BASP variation, the compressive strength decreased to 169.08 kg/cm². Compared to normal concrete, the compressive strength decrease was approximately 15.79%.

Furthermore, the use of 20% rice husk ash resulted in a compressive strength of 166.06 kg/cm², a decrease of approximately 17.29% compared to normal concrete.

5. CONCLUSION

Based on the results of research and discussion regarding the use of rice husk ash as a partial substitute for cement in K-200 quality concrete with the use of NaCl solution in the mixture, the following conclusions can be drawn:

The use of rice husk ash affects the workability of fresh concrete. The slump value decreases with increasing percentage of rice husk ash. The slump value for normal concrete is 9.9 cm, while the use of 10%, 15%, and 20% rice husk ash produces slumps of 8.9 cm, 7.8 cm, and 6.7 cm, respectively.

The use of rice husk ash as a partial cement substitute tends to reduce the concrete's compressive strength at 28 days. Normal concrete produces a compressive strength of 200.78 kg/cm², while BASP 10%, BASP 15%, and BASP 20% produce compressive strengths of 196.25 kg/cm², 169.08 kg/cm², and 166.06 kg/cm², respectively.

Increasing the percentage of rice husk ash resulted in a 2.26% decrease in compressive strength for BASP 10%, 15.79% for BASP 15%, and 17.29% for BASP 20% compared to normal concrete.

The 10% BASP variation was the most optimal variation in this study, producing a compressive strength of 196.25 kg/cm², or approximately 97.74% of the normal concrete compressive strength of 200.78 kg/cm², and was the variation closest to the design quality of K-200.

The use of 15% and 20% rice husk ash resulted in a significant decrease in compressive strength. This indicates that increasing the substitution level needs to be limited to ensure the concrete can still achieve the planned quality.

The specific effect of NaCl on concrete compressive strength cannot be quantitatively concluded based on the available data because test results based on varying NaCl content have not been presented separately. Therefore, further research is needed to determine the effect of NaCl content on the compressive strength and durability of concrete.

SUGGESTION

Based on the research results, several suggestions that can be given are:

The use of rice husk ash as a partial cement substitute in K-200 concrete should be carried out at a controlled concentration. Based on the results of this study, a concentration of 10% provided the best results compared to other variations.

Future research is recommended to use smaller and denser variations of rice husk ash, for example, 5%, 7.5%, 10%, 12.5%, and 15%, to obtain a more accurate optimum concentration.

Further research needs to characterize rice husk ash, particularly its chemical composition, silica content, fineness level, and firing conditions, as these characteristics can affect pozzolanic properties.

The use of NaCl needs to be studied with clear and measurable concentration variations so that its effect on compressive strength can be analyzed quantitatively.

For further research, it is recommended to conduct compressive strength tests at 7, 14, 28, and 56 or 90 days to determine the progress of hydration and pozzolanic reactions.

Additional tests such as water absorption, porosity, specific gravity, and durability need to be carried out to determine the effect of using rice husk ash and NaCl on the long-term properties of concrete.

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ANALYSIS OF COMPRESSIVE STRENGTH OF K-250 GRADE CONCRETE WITH SUBSTITUTION PARTIAL CEMENT USING RICE HUSK ASH

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ABSTRACT

Industry construction is one of the sectors that have contribution big to emission carbon consequence height use of cement as material binder main in concrete. One of the alternative For reduce the use of cement is utilise ash husk rice (ASP) as material substitution partial cement due to own content high silica and pozzolanic properties. This research aim analyze influence use ash husk paddy to strong press concrete K-250 quality. Research using method experiment laboratory with variation substitution ash husk paddy of 0%, 15%, 20%, and 25% of cement weight. The test object is in the form of cube concrete treated for 28 days before done testing strong press use *Compression Testing Machine*. Research results show that normal concrete produces strong average pressure of 251 kg/cm², while variations of 15%, 20%, and 25% respectively produce strong press of 214 kg/cm², 184 kg/cm², and 171 kg/cm². The more big percentage ash husk the rice used , the more low strong press concrete produced. Variations 15% substitution gives mark strong press the highest among all over variation ash husk rice, however still more low compared to normal concrete. This research show that use ash husk rice at levels of 15–25% not yet capable maintain quality K-250 concrete, although still own potential as a friendly material environment that can reduce cement use .

Keywords : K-250 Concrete, Rice Husk Ash, Cement Substitution, Concrete Compressive Strength, Environmentally Friendly Concrete.

1. Introduction

Concrete is the most widely used construction material, used in development buildings, roads, bridges, dams and various infrastructure other because own strong press high, easy formed and own good durability. Behind various superiority mentioned, the use of cement as material binder main give impact sufficient environment large. Cement production produces emission carbon dioxide (CO_2) which contributes to global warming so that required effort for reduce cement consumption through utilization of alternative materials.

One of the potential materials utilized is ash husk rice (ASP). Indonesia as an agricultural country produce waste husk paddy in amount big every year. Combustion results husk paddy produce ash with content high silica (SiO_2) which has pozzolanic properties. Activated silica the capable react with calcium hydroxide results cement hydration so that form Calcium Silicate Hydrate (CSH) compound which plays a role in increase density microstructure concrete.

Although Thus, the effectiveness ash husk rice is greatly influenced by grade its use. Use in to much amount big can lower active cement amount so that influence strength concrete

Therefore that, research this aim analyze influence substitution partial cement using ash husk paddy to strong press concrete K-250 quality.

2. Research Methods

This research use method experiment laboratory. Materials used consists of on Type I Portland cement, aggregate fine, aggregate coarse, water, and ash husk paddy as substitution partial cement. Mixture c7oncrete made with variation substitution ash husk paddy to cement as following :

Table 2.1 . Variation mixture

Mixed Variations	Rice Husk Ash Percentage
BN (Normal Concrete)	0%
BASP 15	15%
BASP 20	20%
BASP 25	25%

Information :
BN : Normal concrete without substitution ash husk paddy
B A SP 15 : Concrete with substitution ash husk paddy by 15% of cement weight
B A SP 20 : Concrete with substitution ash husk paddy by 20% of cement weight
B A SP 25 : Concrete with substitution ash husk paddy by 25% of cement weight

The test object is in the form of cube concrete made in accordance SNI procedures , then curing for 28 days before tested using Compression Testing Machine.
Compressive strength concrete counted use equality :

$$f'_c = \frac{P}{A}$$

with :

f'c = strong press concrete (kg/cm² or MPa)
P = load maximum
A = area cross section test object

3. Results and Discussion

3.1. Material Inspection Results

From the examination that has been carried out conducted in the laboratory obtained data as following :

1. Aggregate Fine

Table 3.1. Sand Data

No	Description	Information
1	Content weight loose	1.091 gr / cm ^{3}
2	Solid Content Weight	1.269 gr / cm ^{3}
3	SSD specific gravity	2,427
4	Specific gravity dry	2,362

5	Absorption	2.775%

6	Sludge Content	0.807%
7	Water content	7.13%
8	Gradation Granules	Zone 4
9	Fineness Modulus	3,861

2. Coarse Aggregate

Table 3.2. Gravel data

No	Description	Information
1	Content weight loose	1.37 g / cm ^{3}
2	Solid Content Weight	1.55 kg / cm ^{3}
3	SSD specific gravity	2,377
4	Specific gravity dry	2,326
5	Absorption	2.154%
6	Sludge Content	3.297%
7	Water content	3.702%
8	Fineness Modulus	8.77

3.2. Concrete Slump Test Results

Slump testing is performed For know workability level of fresh concrete in each variation mixture concrete with substitution ash husk rice . The slump value shows level convenience workmanship concrete during the mixing , transportation , casting and compaction processes .

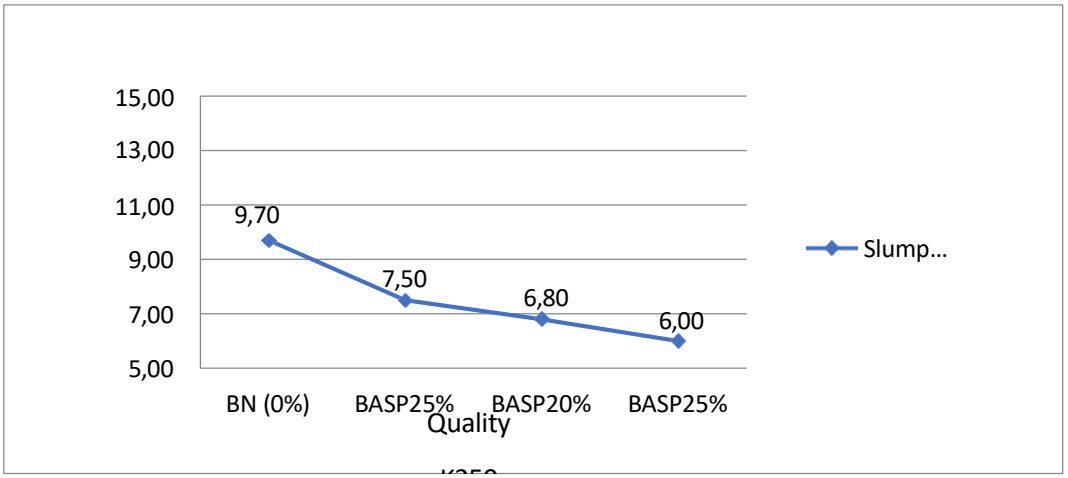
Based on results testing , concrete slump value tend experience decline along increase percentage ash husk paddy in mixture concrete . This is due to size particle ash husk very fine rice and has wide surface tall so that need more lots of water in mixture .

Table 3.3. Concrete Slump Test Results

Date cast	Concrete	Slump value (cm)
29 April 20 26	BN (0%)	9.7
29 April 20 26	BASP 1 5%	7.5
29 April 20 26	BASP2 0 %	6.8
29 April 20 26	BASP25%	6

Based on results slump testing , normal concrete has higher level of workability Good compared to concrete with substitution ash husk rice . The more big level ash husk the rice used , then mixture concrete become more stiff and difficult done .

Chart 3.1 . Relationship slump value with partial substitution of cement using rice husk ash



Based on chart the can known that the slump achieved start from normal concrete , concrete with rice husk ash as material replacement cement 0%, 15 %, 20 %, and 2.5 % still meet the required slump between 60 – 100 mm.

3.3. Concrete Compressive Strength Test Results

Test results strong press concrete at 28 days old for every variation mixture presented in Table 3.4. Testing done use compression testing machine concrete (Compression Testing Machine) against concrete test objects that have been through a 28 - day curing process.

Table 3.4 . Concrete Compressive Strength Test Results

Variation Mixture	Percentage of rice husk ash	Average Compressive Strength (kg/cm ^{2})
BN (0%)	0%	251
BASP 15%	15%	214
BASP 20%	20%	184
BASP 25%	25%	171

Source: research results, 2026

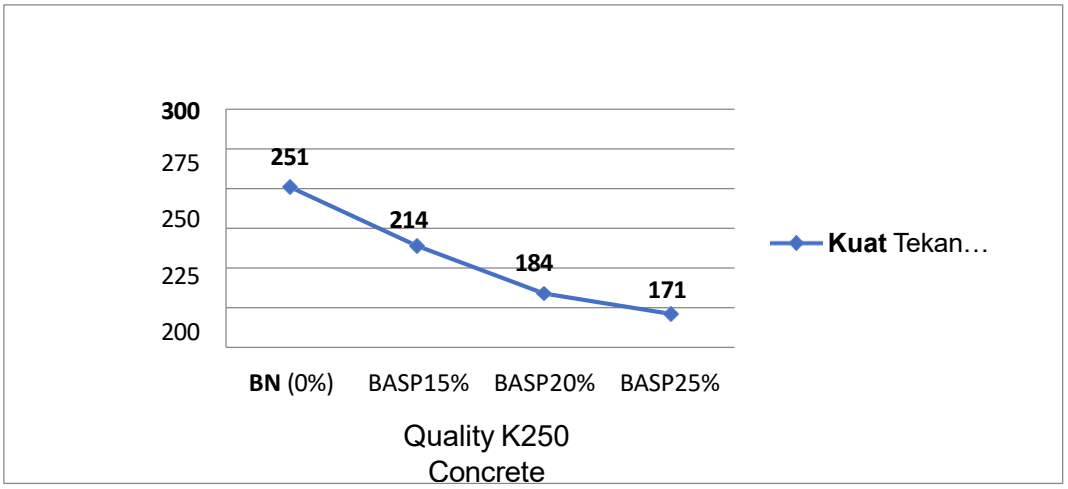
Based on Table 4.16 it can be known that normal concrete (BN) without addition ash husk paddy produce strong highest average press of 251 kg/cm². This value has fulfil quality concrete the K-250 plan used in this study.

At BASP variation 15%, strong press concrete experience decline to 214 kg/cm² or down around 14.74% compared to normal concrete. Furthermore, at a BASP variation of 20%, the strength press concrete return experience decline to 184 kg/cm² or down by 26.69% against normal concrete.

Decline strong press more big occurs at the BASP 25% variation, where strong press concrete obtained only of 171 kg/cm² or experience decline by 31.87% compared to normal concrete.

Research result show that improvement percentage cement substitution using ash husk paddy cause trend decline strong press concrete . Relationship between percentage ash husk rice and value strong press concrete can seen in the graph 3.2.

Chart 3.2. Connection Rice Husk Ash Percentage on Concrete Compressive Strength



Based on chart seen that mark strong press concrete decrease in a way gradually along increasing level ash husk paddy in mixture concrete. Downward trend the show that use ash husk rice at levels of 15%, 20%, and 25% yet capable produce strong equal pressure with normal concrete.

Decline strong press This allegedly happen Because the amount of active cement that plays a role as material binder main reduce consequence part replaced by ashes husk rice. Although ash husk paddy contain pozzolanic silica, pozzolanic reaction takes place relatively slow so that at the age of 28 days his contribution to improvement strong press Not yet capable balance decrease cement content in mixture concrete.

In addition, particles ash husk very fine rice own wide large surface so that increase water needs in mixture concrete. Condition the can causing decreased workability and compaction process concrete become less than optimal, which ultimately produce cavities air (void) inside concrete and lowering strong press the concrete produced.

Based on results on this study can concluded that use ash husk paddy as substitution partial cement at levels of 15%, 20%, and 25% tends to lower strong press concrete K-250 quality. Variations mixture best in this study is normal concrete (BN) with strong average pressure of 251 kg/cm².

4. Conclusion

Based on results study can concluded that :

1. Use ash husk paddy as substitution partial cement affects strong press concrete K-250 quality.
2. Normal concrete produces strong highest average press of 251 kg/cm².
3. Use ash husk paddy of 15%, 20%, and 25% yields strong press consecutive of 214 kg/cm², 184 kg/cm², and 171 kg/cm².
4. The more tall level ash husk the rice used, the more low strong press the concrete produced.
5. husk ash rice at levels of 15–25% not yet capable maintain quality K-250 concrete, however still potential utilized as an alternative material that supports draft construction sustainable.

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MARSHALL CHARACTERISTICS OF A COMBINATION OF STONE DUST FILLER AND STYROFOAM IN ASPHALT CONCRETE WEARING COURSE (AC-WC) MIXTURE

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Abstract

Asphalt Concrete Wearing Course (AC-WC) pavement requires a mixture with good stability, durability, and resistance to traffic loads. One effort to improve the quality of asphalt mixtures is by utilizing alternative materials such as stone dust filler and styrofoam waste. This study aims to determine the effect of the combination of stone dust filler and styrofoam on the Marshall characteristics of AC-WC mixtures and to identify the most optimal mixture variation. The research method used was a laboratory experimental method by conducting Marshall tests on several variations of stone dust filler and styrofoam mixtures. The materials used consisted of coarse aggregate, fine aggregate, 60/70 penetration asphalt, stone dust, and styrofoam. The mixture variations studied included different proportions of stone dust and styrofoam at the same Optimum Asphalt Content (OAC), namely 5.90%. The tested parameters included Bulk Density, Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), Stability, Flow, and Marshall Quotient (MQ). The results showed that the addition of styrofoam tended to increase the density of the mixture and the VFA value, while reducing the VIM and flow values. The highest stability value was obtained in the standard mixture at 1007.5 kg and was almost equal to the ABS-3 variation at 1004.6 kg. The highest Marshall Quotient (MQ) value was obtained in the ABS-3 mixture at 324.05 kg/mm, indicating the best combination of strength and stiffness. Overall, the ABS-3 mixture variation provided the most optimal Marshall characteristics compared to the other variations. Based on the research results, it can be concluded that the combination of stone dust filler and styrofoam affects the Marshall characteristics of AC-WC mixtures, and the ABS-3 variation has the potential to become an effective and environmentally friendly alternative pavement mixture through the utilization of styrofoam waste.

Keywords: AC-WC, stone dust, styrofoam, Marshall characteristics, filler, pavement.

1. Introduction

Road pavement is one of the most important transportation infrastructures in supporting community mobility and economic growth. One type of pavement layer commonly used in Indonesia is Asphalt Concrete Wearing Course (AC-WC), which is a surface layer directly subjected to traffic loads and weather effects. Therefore, AC-WC mixtures must possess good characteristics, such as high stability, durability, flexibility, and resistance to deformation and water damage. The quality of AC-WC mixtures is influenced by their constituent materials, especially aggregates, asphalt, and filler. Filler is a very fine material that functions to fill voids within the mixture, thereby increasing the density and strength of the asphalt mixture. One material that can be utilized as filler is stone dust because it has a fine texture and is easily obtained from stone crushing processes. The use of stone dust as filler is considered capable of improving the bond between aggregates and enhancing the Marshall characteristics of asphalt mixtures.

On the other hand, the increasing use of styrofoam in daily life has created environmental problems because styrofoam waste is difficult to decompose naturally. Styrofoam is classified as a non-biodegradable waste material which, if not properly managed, can pollute the environment. One effort to utilize styrofoam waste is by using it as an additive material in asphalt mixtures. Styrofoam has lightweight and waterproof properties and contains polymers that have the potential to improve adhesion and stability in asphalt mixtures. The utilization of a combination of stone dust filler and styrofoam in AC-WC mixtures is expected to improve Marshall characteristics, such as stability, flow, Void in Mix (VIM), Void in Mineral Aggregate (VMA), and Void Filled with Asphalt (VFA). In addition, the use of styrofoam waste materials can become an innovative, environmentally friendly, and economical alternative in road pavement construction. Based on the above explanation, it is necessary to conduct research on the Marshall characteristics of a combination of stone dust filler and styrofoam in Asphalt Concrete Wearing Course (AC-WC) mixtures to determine their effect on the performance of asphalt mixtures and to identify the optimum composition that meets pavement specifications.

Several previous studies have examined the potential utilization of Styrofoam (Expanded Polystyrene/EPS) as an additive material or filler substitute in Asphalt Concrete Wearing Course (AC-WC) mixtures. In general, the objectives of these studies are to reduce the weight of the mixture, improve thermal insulation, and utilize styrofoam waste constructively, including the following:

1. Penelitian oleh Ujung et al. (2025) mengevaluasi karakteristik campuran AC-WC dengan penambahan Styrofoam sebanyak 3–5% dari berat aspal. Hasilnya menunjukkan bahwa penambahan Styrofoam dapat menurunkan densitas campuran tanpa mengubah kestabilan Marshall secara signifikan.
2. Fitriansyah et al. (2025) meneliti pengaruh suhu pencampuran dan variasi kadar Styrofoam terhadap karakteristik Marshall. Penelitian ini menekankan bahwa kombinasi suhu dan kadar Styrofoam berperan penting dalam stabilitas dan flow campuran, sehingga pemilihan kondisi pencampuran optimal sangat diperlukan.
3. Kinanti et al. (2024) fokus pada durabilitas campuran AC-WC dengan 1,5% Styrofoam melalui uji perendaman air dan pengukuran Indeks Kekuatan Sisa (IKS). Hasil menunjukkan bahwa campuran tetap memiliki ketahanan terhadap penetrasi air yang baik dan nilai IKS tetap memenuhi standar teknis.
4. Marbun et al. (2025) membandingkan AC-WC dengan aspal termodifikasi dan penambahan 1,5% Styrofoam, menunjukkan bahwa parameter Marshall seperti stabilitas, flow, dan void masih memenuhi standar Bina Marga 2018, walaupun terdapat sedikit penurunan kekuatan tekan seiring meningkatnya proporsi Styrofoam.
5. Penelitian lain menggunakan Styrofoam dalam kombinasi dengan Reclaimed Asphalt Pavement (RAP) dan filler fly ash, seperti yang dilakukan oleh Kurniawan & Mahardi (2025). Studi ini

menunjukkan bahwa penggunaan Styrofoam dalam kadar tertentu dapat menurunkan densitas campuran, meningkatkan isolasi termal, dan tetap mempertahankan karakteristik mekanik yang memadai.

6. Penelitian Arrahman et al. (2025) mengevaluasi pengaruh penggunaan abu batu sebagai filler terhadap karakteristik Marshall campuran AC-WC dengan variasi kadar 0%, 5%, dan 10%. Hasil uji Marshall menunjukkan perubahan parameter stabilitas dan flow pada setiap variasi kadar abu batu, yang mengindikasikan kemampuan abu batu untuk berkontribusi pada kinerja campuran aspal beton lapis aus.
7. Penelitian di Universitas Kadiri juga menguji pengaruh persentase filler abu batu terhadap parameter Marshall, dan hasilnya menunjukkan korelasi antara peningkatan persentase abu batu dengan karakteristik Marshall campuran.

2. Research Method

This study used a laboratory experimental method to determine the effect of the combination of stone dust filler and styrofoam on the Marshall characteristics of Asphalt Concrete Wearing Course (AC-WC) mixtures. The research was conducted at the asphalt testing laboratory owned by PT. Komba Mahaka Utama, located in Martapura, East OKU Regency. The fine aggregate used was obtained from the Asphalt Mixing Plant (AMP) of PT. Komba Mahaka Utama in East OKU, while the coarse aggregate and stone dust filler originated from natural stone that had undergone a crushing process using a crusher machine at the AMP facility. The experimental method was chosen because the study was carried out through direct testing of asphalt mixture specimens with specific composition variations, allowing the relationship between the use of stone dust filler and styrofoam and the values of stability, flow, VIM, VMA, VFA, and Marshall Quotient (MQ) to be determined. The entire research process was conducted in a civil engineering laboratory equipped with road pavement material testing facilities in accordance with applicable standards.

The research began with the preparation of materials and equipment. The main materials used consisted of coarse aggregate, fine aggregate, stone dust filler, 60/70 penetration asphalt, and styrofoam waste. Coarse and fine aggregates were used as the primary materials forming the structure of the AC-WC mixture, while stone dust was used as a filler to fill fine voids within the mixture. Styrofoam waste was utilized as an additive material with the aim of improving the quality of the mixture while simultaneously reducing environmental pollution caused by non-biodegradable waste. The 60/70 penetration asphalt was selected because it is commonly used in road construction in Indonesia and complies with flexible pavement specifications. Before being used in the mixture, all materials were first tested for their physical properties to ensure that they met the required specifications. Aggregate testing included sieve analysis, aggregate specific gravity, water absorption, Los Angeles abrasion test, and mud content test. Asphalt testing included penetration, softening point, flash point, ductility, and asphalt specific gravity tests. The fineness of the stone dust was also examined to ensure its suitability as a filler material. Meanwhile, the styrofoam waste was first cleaned of any attached impurities and then cut into small pieces to facilitate mixing into the hot asphalt mixture.

The next stage was the design of the AC-WC mixture based on applicable specifications, such as the General Specifications of Bina Marga. The aggregate gradation was designed to meet the gradation limits of AC-WC mixtures in order to produce a dense and stable mixture. After obtaining the aggregate gradation, the determination of the planned asphalt content was carried out using several variations of asphalt content to obtain the Optimum Asphalt Content (OAC). The determination of the optimum asphalt content was conducted using the Marshall method by considering the parameters of stability, flow, VIM, VMA, and VFA in accordance with the established specifications.

In this study, the mixture variations were prepared by adding combinations of stone dust filler and styrofoam at several percentages as follows:

1. 100% stone dust filler (Code AB100)
2. 75% stone dust filler and 25% styrofoam (Code ABS-1)
3. 50% stone dust filler and 50% styrofoam (Code ABS-2)
4. 25% stone dust filler and 75% styrofoam (Code ABS-3) based on the total weight of the mixture. These variations were intended to determine the effect of changes in filler composition on the Marshall characteristics of AC-WC mixtures. Each mixture variation was prepared with the same number of specimens to ensure that the test results would be more accurate and objectively comparable. The specimens were made using standard Marshall molds with a diameter of 10.16 cm and a height of approximately 6.35 cm.

The mixing process was carried out by heating the aggregates and asphalt to a specific temperature until the appropriate mixing temperature was achieved. After the aggregates reached the predetermined temperature, the stone dust filler and styrofoam were evenly mixed into the hot aggregates. Subsequently, the hot asphalt was poured into the mixture and stirred until the entire surface of the aggregates was uniformly coated with asphalt. The mixture was then placed into Marshall molds and compacted using a Marshall compactor with the number of blows adjusted according to the standard requirements for AC-WC mixtures.

The compacted specimens were left at room temperature for approximately 24 hours before testing. After that, the specimens were immersed in a water bath at 60°C for about ±30 minutes to prepare them for the Marshall test. The Marshall test was then conducted using a Marshall Testing machine to obtain the stability and flow values of each specimen. The stability value indicates the ability of the mixture to resist loads without undergoing deformation, while the flow value represents the degree of deformation or plasticity of the mixture when subjected to loading.

In addition to stability and flow testing, volumetric analysis of the mixture was also carried out, including the calculation of Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), and Marshall Quotient (MQ). The VIM value is used to determine the percentage of air voids within the mixture, VMA represents the voids between aggregates in the compacted mixture, while VFA indicates the percentage of aggregate voids filled with asphalt. The Marshall Quotient is obtained from the ratio of stability to flow, which represents the stiffness of the mixture.

The test data were then analyzed using a quantitative descriptive method by comparing the Marshall characteristic values of each mixture variation against the applicable specifications. The analysis was conducted to determine the effect of adding styrofoam and stone dust filler on the performance of AC-WC mixtures and to identify the mixture variation that provides the most optimal results. The research results were presented in the form of tables, graphs, and discussions to facilitate data interpretation and conclusion drawing.

Through this research method, it is expected that information can be obtained regarding the effectiveness of using a combination of stone dust filler and styrofoam in improving the quality of Asphalt Concrete Wearing Course (AC-WC) mixtures. In addition to providing technical benefits in road construction, this study is also expected to serve as an alternative solution for utilizing styrofoam waste in a more environmentally friendly and economically valuable way.

3. Laboratory Research Results

The test data of the Asphalt Concrete Wearing Course (AC-WC) composite materials obtained in this study are presented in detail in the following table. The information illustrates the physical and mechanical characteristics of the mixture, which serve as the focus of evaluation in this study.

Table 1. Test Results of AC-WC Mixture Materials

No	Material	Hasil
1	**Asphalt Properties**	
	• Penetration	61,2
	• Specific Gravity	1,039 gram/cc
	• Softening Point	51,8 ºC
	• Flash Point	358 ºC
	• Ductility	140
2	**Fine Aggregate Properties**	
	• Bulk Specific Gravity	2,472 gram/cc
	• SSD (Saturated Surface Dry) Specific Gravity	2,527 gram/cc
	• Apparent Specific Gravity	2,615 gram/cc
	• Water Absorption	2,218 %
3	**Stone Dust (Filler) Properties**	
	• Bulk Specific Gravity	2,503 gram/cc
	• SSD (Saturated Surface Dry) Specific Gravity	2,554 gram/cc
	• Apparent Specific Gravity	2,638 gram/cc
	• Water Absorption	2,051 %
4	**Coarse Aggregate Crushed Stone 1/1**	
	• Dry Bulk Specific Gravity (Sd)	2,544 gram/cc
	• SSD (Saturated Surface Dry) Bulk Specific Gravity (Ss)	2,583 gram/cc
	• Apparent Specific Gravity (Sa)	2,648 gram/cc
	• Water Absorption (Sw)	1,547 %
	Coarse Aggregate Crushed Stone 1/2	
	• Dry Bulk Specific Gravity (Sd)	2,573 gram/cc
	• SSD (Saturated Surface Dry) Bulk Specific Gravity (Ss)	2,605 gram/cc
	• Apparent Specific Gravity (Sa)	2,658 gram/cc
	• Water Absorption (Sw)	1,240 %

Source: DMF Laboratorium PT. KMU

Table 2. AC-WC Composition with Stone Dust and Styrofoam Combination

No	Material	Material Weight	Stone Dust	Styrofoam
1	Coarse Aggregate 1/2	94,08 gr	94,08 gr	94,08 gr
2	Coarse Aggregate 1/1	193,68 gr	193,68 gr	193,68 gr
3	Stone Dust	237,90 gr	237,90 gr	237,90 gr
4	Sand	27,66 gr	27,66 gr	27,66 gr
5	Asphalt	35,40 gr	35,40 gr	35,40 gr
6	Stone Dust Filler 100% (AB100)	11,28 gr	0	0
7	Stone Dust 75% + Styrofoam 25% (ABS-1)	0	8,46 gr	2,256 gr
8	Stone Dust 50% + Styrofoam 50% (ABS-2)	0	5,64 gr	5,64 gr
9	Stone Dust 25% + Styrofoam 75% (ABS-3)	0	2,82 gr	8,46 gr

Source: Analysis Results

Table 3. Test Results of Various Combinations of Stone Dust Filler and Styrofoam

No	Type of Test	Unit	DMF Standar (AB100)	Test Results		
				AB 75%+ Sty. 25% (ABS-1)	AB 50%+ Sty. 50% (ABS-2)	AB 25% +Sty.75% (ABS-3)
1	Optimum Asphalt Content	%	5,90	5,90	5,90	5,90
2	Standard Bulk Density	gr/cc	2,234	2,236	2,242	2,252
3	Standard VIM (Voids in Mix)	%	4,76	5,88	5,24	4,40
4	Voids in Mineral Aggregate (VMA)	%	16,59	16,61	16,46	16,14
5	Voids Filled with Asphalt (VFA)	%	71,30	64,59	68,18	72,75
6	Marshall Stability	kg	1007,5	939,8	956,0	1004,6
7	Flow (Deformation)	mm	3,17	3,50	3,30	3,10
8	Marshall Quotient (MQ)	kg/mm	318,15	268,50	289,68	324,05

Source: Analysis Results

4. Discussion

4.1 Stability Value

The Marshall stability value indicates the ability of the asphalt mixture to resist the maximum load before failure occurs. The higher the stability value obtained, the better the mixture's capability to withstand traffic loads. The stability values are presented in Table 4 below.

Table 4. Marshall Stability Values

No	DMF Type	Test Results (kg)	Specification 2018 Revisi 2 (kg)
1	AB100	1007,5	Min 800
2	ABS-1	939,8	
3	ABS-2	956,0	
4	ABS-3	1004,6	

Source: Analysis Results

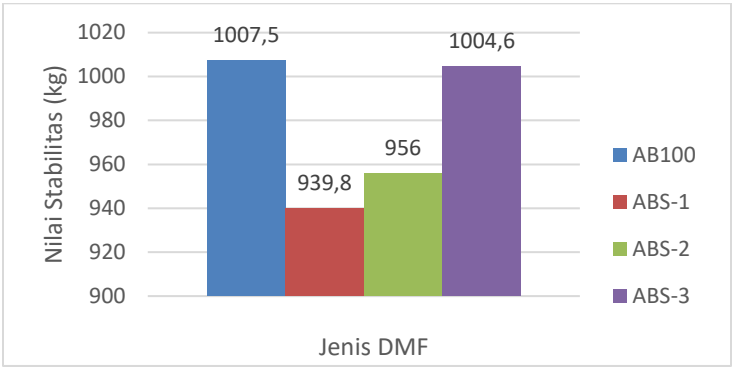


Figure 1. Stability Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations of stone dust and styrofoam filler combinations shown in Table 4, the stability values varied but all met the requirements of the General Specification of Bina Marga 2018 Revision 2, which specifies a minimum of 800 kg. The AB100 mixture (100% stone dust) produced a stability value of 1007.5 kg, indicating a good ability of the mixture to withstand traffic loads. In the ABS-1 mixture, the stability value slightly decreased to 939.8 kg, but it still remained above the required minimum limit. This decrease indicates that the addition of 25% styrofoam began to affect the stiffness of the mixture; however, it did not significantly reduce the structural performance.

Furthermore, the ABS-2 mixture showed a stability value of 956.0 kg, which increased compared to ABS-1. This indicates a balance between the properties of stone dust filler and styrofoam that is able to improve the interlocking between aggregates. In the ABS-3 mixture, the stability value increased again to 1004.6 kg, approaching the stability value of the AB100 mixture. This result shows that a higher proportion of styrofoam is still able to contribute positively to the stability of the AC-WC mixture.

Overall, the variations of stone dust and styrofoam filler combinations did not reduce the stability values below the required standard. This indicates that the use of styrofoam as an alternative filler, either partially or dominantly, is still feasible to be applied in AC-WC mixtures in terms of the Marshall stability parameter.

4.2 Flow Value

The flow value represents the amount of plastic deformation of the asphalt mixture at the point of maximum load. This parameter reflects the flexibility of the mixture, where a very low flow value indicates a stiff and brittle mixture that is prone to cracking, while a very high flow value indicates an overly plastic mixture that is susceptible to permanent deformation. The flow values of various combinations of stone dust and styrofoam filler are presented in Table 5 below.

Table 5. Flow Values

No	DMF Type	Test Results (mm)	Specification 2018 Revisi 2 (mm)
1	AB100	3,17	

2	ABS-1	3,50	Min 2,0- 4,0
3	ABS-2	3,30	
4	ABS-3	3,10	

Source: Analysis Results

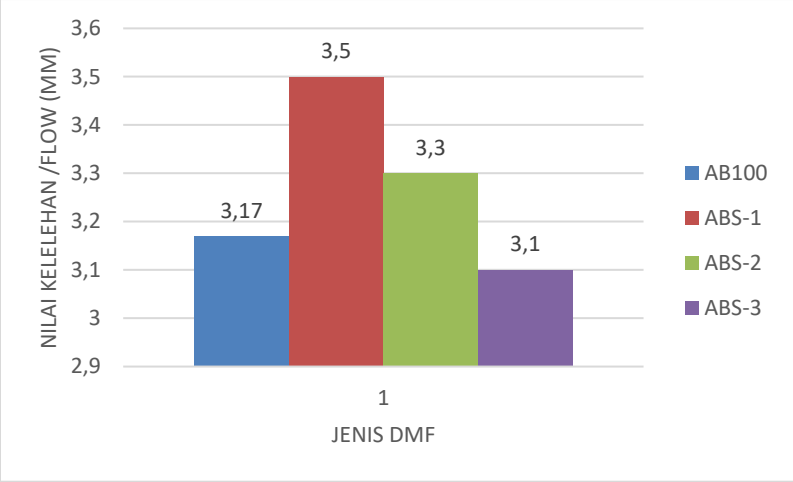


Figure 2. Flow Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations in stone dust and styrofoam filler combinations shown in Table 5, the flow values ranged from 3.10 mm to 3.50 mm. All of these flow values met the requirements of the General Specification of Bina Marga 2018 Revision 2, which specifies a range of 2.0–4.0 mm. The AB100 mixture produced a flow value of 3.17 mm, indicating a mixture condition with good flexibility and a balanced combination of elastic and plastic behavior. In the ABS-1 mixture, the flow value increased to 3.50 mm, indicating that the addition of 25% styrofoam made the mixture more flexible and resulted in greater deformation under loading.

Furthermore, in the ABS-2 mixture, the flow value decreased to 3.30 mm, indicating that a balanced proportion of stone dust and styrofoam was able to increase the stiffness of the mixture, resulting in relatively reduced deformation. In the ABS-3 mixture, the flow value further decreased to 3.10 mm, indicating that increasing the styrofoam content up to 75% tended to make the mixture stiffer and more resistant to plastic deformation.

Overall, the use of a combination of stone dust and styrofoam filler in AC-WC mixtures affects the flow value; however, all mixture variations remain within the allowable specification limits. Therefore, this filler combination is considered suitable for use in AC-WC mixtures in terms of the Marshall flow parameter.

4.3 Void in Mix (VIM) Value

VIM is the percentage of air voids in the asphalt mixture relative to the total mixture volume. These voids are used to evaluate the density of the mixture and influence its resistance to wear and permanent deformation. The Void in Mix (VIM) values are presented in Table 6 below.

Table 6. Void in Mix (VIM) Values

No	DMF Type	Test Results (%)	Specification 2018 Revisi 2 (%)
1	AB100	4,76	3,0 – 5,0
2	ABS-1	5,88	
3	ABS-2	5,24	
4	ABS-3	4,40	

Source: Analysis Results

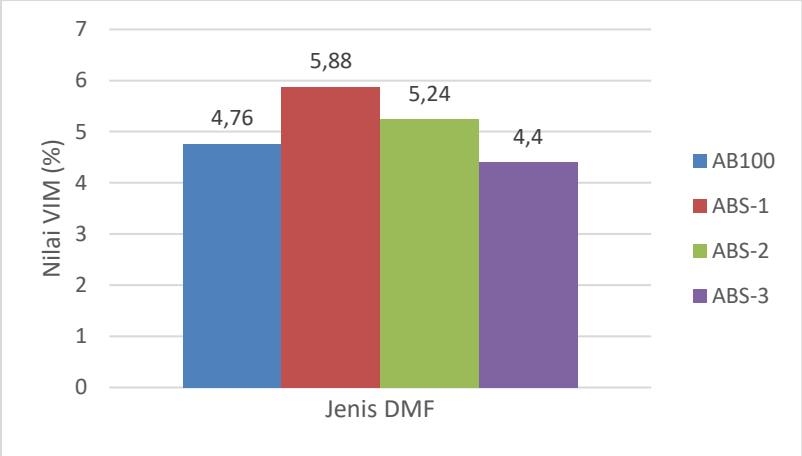


Figure 3. VIM Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations in stone dust and styrofoam filler combinations shown in Table 6, the Void in Mix (VIM) values ranged from 4.40% to 5.88%. According to the General Specification of Bina Marga 2018 Revision 2, the required VIM value for AC-WC mixtures is in the range of 3.0–5.0%. The AB100 mixture produced a VIM value of 4.76%, which is still within the specified range. This value indicates that the air voids in the mixture are in a relatively ideal condition, providing a balance between durability and stability.

In the ABS-1 mixture, the VIM value increased to 5.88%, thus exceeding the maximum specification limit. This increase indicates that the addition of 25% styrofoam caused larger air voids within the mixture, which may potentially reduce durability due to a higher likelihood of air and water ingress into the pavement layer. Furthermore, in the ABS-2 mixture, the VIM value decreased to 5.24%, but it was still slightly above the specified maximum limit. This suggests that although the proportion of stone dust and styrofoam was balanced, the mixture still contained relatively high air voids and had not yet fully met the desired density criteria.

In the ABS-3 mixture, the VIM value decreased again to 4.40%, which complies with the specification requirements. This reduction in VIM indicates that a higher proportion of styrofoam was able to increase the mixture density and reduce air voids, thereby potentially improving the durability of the AC-WC mixture. Overall, the variation in stone dust and styrofoam filler combinations had a significant effect on the VIM values of the AC-WC mixtures. The AB100 and ABS-3 mixtures met the specification requirements, while the ABS-1 and ABS-2 mixtures did not meet the maximum VIM limit. Therefore, the filler proportions must be properly controlled to obtain an AC-WC mixture with appropriate air voids and optimal pavement performance.

4.4 Void in Mineral Aggregate (VMA) Value

VMA is the percentage of the volume of void spaces between aggregate particles that are filled with asphalt and air relative to the total volume of aggregate. The VMA value is used to evaluate the mixture's ability to resist deformation and structural stability. The VMA values are presented in Table 7.

Table 7. Void in Mineral Aggregate (VMA) Values

No	DMF Type	Test Results (%)	Specification 2018 Revisi 2 (%)
1	AB100	16,59	Min 15
2	ABS-1	16,61	
3	ABS-2	16,46	
4	ABS-3	16,14	

Source: Analysis Results

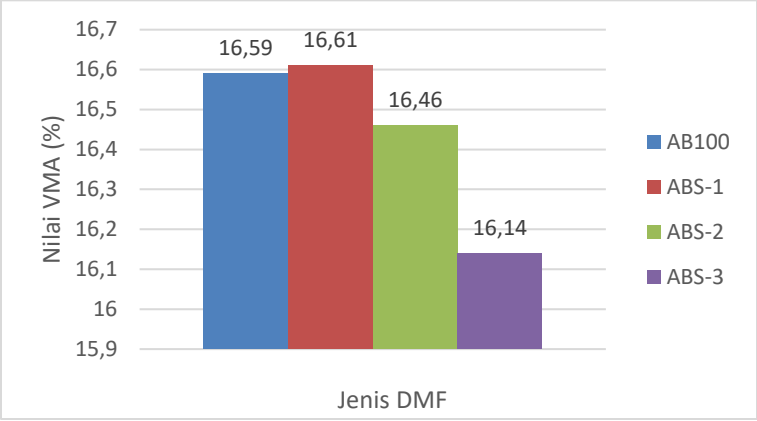


Figure 4. VMA Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations in stone dust and styrofoam filler combinations shown in Table 7, the Void in Mineral Aggregate (VMA) values ranged from 16.14% to 16.61%. All VMA values met the requirements of the General Specification of Bina Marga 2018 Revision 2, which sets a minimum of 15% for AC-WC mixtures. The AB100 mixture produced a VMA value of 16.59%, indicating that the volume of voids between aggregate particles is sufficient to accommodate effective asphalt and air voids, thereby supporting the durability and stability performance of the mixture. In the ABS-1 mixture, the VMA value slightly increased to 16.61%, indicating that the addition of 25% styrofoam tended to increase the voids between aggregates, although the increase was still within the allowable limits.

Furthermore, in the ABS-2 mixture, the VMA value decreased to 16.46%. This reduction indicates that a balanced proportion of stone dust and styrofoam can produce a denser aggregate structure. In the ABS-3 mixture, the VMA value decreased further to 16.14%, indicating that increasing the styrofoam content up to 75% resulted in smaller voids between aggregates, although the value still met the minimum specification requirement. Overall, the variation in stone dust and styrofoam filler combinations had an influence on the VMA values of the AC-WC mixtures. However, all mixtures remained above the required minimum limit. This shows that the use of styrofoam in combination with stone dust does not significantly reduce VMA values and is still feasible for use in AC-WC mixtures in terms of the VMA parameter.

4.5 Void Filled with Asphalt (VFA) Value

Void Filled with Asphalt (VFA) is the percentage of voids within the mineral aggregate (VMA) that are filled with asphalt. The VFA value indicates the extent to which asphalt is able to fill the voids between aggregate particles in the asphalt mixture. This parameter is very important because it affects the impermeability of the mixture, resistance to water damage, and the durability of the pavement. The VFA values are presented in Table 8 below.

Table 8. Void Filled with Asphalt (VFA) Values

No	DMF Type	Test Results (%)	Specification 2018 Revisi 2 (%)
1	AB100	71,30	Min 65
2	ABS-1	64,59	
3	ABS-2	68,18	
4	ABS-3	72,75	

Source: Analysis Results

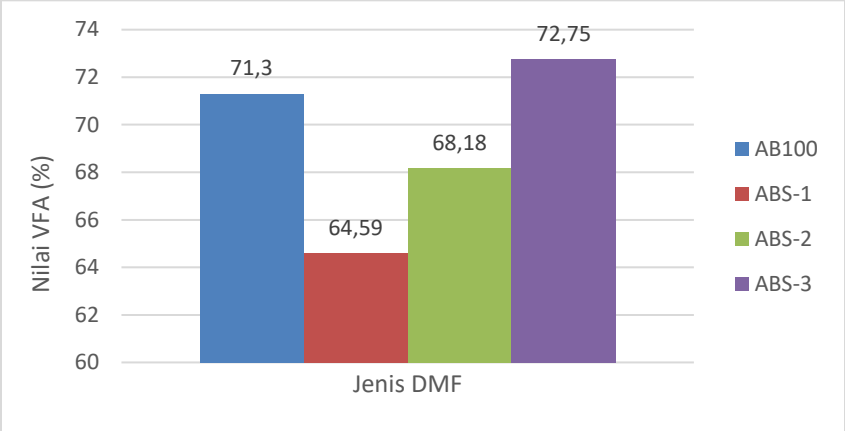


Figure 5. VFA Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations in stone dust and styrofoam filler combinations shown in Table 8, the Void Filled with Asphalt (VFA) values ranged from 64.59% to 72.75%. According to the General Specification of Bina Marga 2018 Revision 2, the required VFA value for AC-WC mixtures is a minimum of 65%. The AB100 mixture produced a VFA value of 71.30%, which meets the specification requirements. This value indicates that most of the voids within the aggregate are filled with asphalt, resulting in good mixture durability and resistance to water effects.

In the ABS-1 mixture, the VFA value decreased to 64.59%, thus not meeting the minimum specification requirement. This reduction indicates that the addition of 25% styrofoam caused the aggregate voids not to be optimally filled with asphalt, which may increase the mixture's susceptibility to water damage and oxidation. Furthermore, in the ABS-2 mixture, the VFA value increased again to 68.18%, and it met the specification requirements. This indicates that a balanced proportion of stone dust and styrofoam was able to improve the asphalt filling within the voids. In the ABS-3 mixture, the VFA value increased further to 72.75%, which is the highest among all mixture variations. This result shows that a higher proportion of styrofoam can enhance the filling of aggregate voids by asphalt, thereby potentially improving the durability of the AC-WC mixture.

Overall, the variation in stone dust and styrofoam filler combinations had a significant effect on the VFA values. The AB100, ABS-2, and ABS-3 mixtures met the specification requirements, while the ABS-1 mixture did not meet the minimum VFA limit. Therefore, proper control of filler proportions is necessary to obtain AC-WC mixtures with an optimal level of void filling and good pavement performance.

4.6 Marshall Quotient (MQ) Value

Marshall Quotient (MQ) is the ratio between stability and flow values that describes the stiffness or structural strength of an asphalt mixture. A high MQ value indicates a stiffer mixture with better resistance to deformation, while a low MQ value indicates a more flexible mixture that may be prone to permanent deformation. The Marshall Quotient (MQ) values are presented in Table 9 below.

Tabel 9. Nilai Marshall Quotient (MQ)

No	DMF Type	Test Results (kg/mm)	Specification 2018 Revisi 2 (kg/mm)
1	AB100	318,15	Min 250
2	ABS-1	268,50	
3	ABS-2	289,68	
4	ABS-3	324,05	

Source: Analysis Results

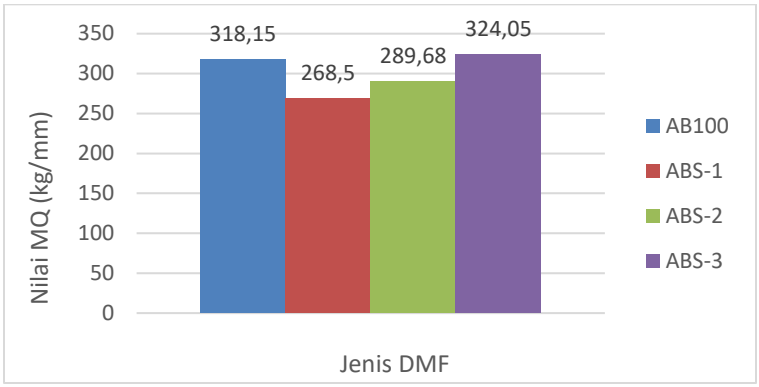


Figure 6. Marshall Quotient (MQ) Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations in stone dust and styrofoam filler combinations shown in Table 9, the Marshall Quotient (MQ) values ranged from 268.50 kg/mm to 324.05 kg/mm. All MQ values met the requirements of the General Specification of Bina Marga 2018 Revision 2, which sets a minimum value of 250 kg/mm. The AB100 mixture produced an MQ value of 318.15 kg/mm, indicating that the mixture has good stiffness and is capable of resisting permanent deformation caused by traffic loads. In the ABS-1 mixture, the MQ value decreased to 268.50 kg/mm. This decrease indicates that the addition of 25% styrofoam made the mixture more flexible, thereby reducing its stiffness, although it still remained within the specified limits.

Furthermore, in the ABS-2 mixture, the MQ value increased to 289.68 kg/mm. This increase indicates that a balanced proportion of stone dust and styrofoam was able to improve the stiffness of the mixture and enhance its resistance to deformation. In the ABS-3 mixture, the MQ value further increased to 324.05 kg/mm, which is the highest among all mixture variations. This result indicates that a higher proportion of styrofoam combined with stone dust was able to produce a stiffer mixture with higher structural stability.

Overall, the variation in stone dust and styrofoam filler combinations had an effect on the Marshall Quotient (MQ) values of the AC-WC mixtures; however, all variations still met the specification requirements. The ABS-3 mixture showed the best performance in terms of MQ value, indicating a greater potential to provide better resistance to permanent deformation in the pavement layer.

4.7 Standard Bulk Density (Unit Weight)

Bulk density or unit weight of the asphalt mixture is a parameter that indicates the density level of the asphalt mixture after the compaction process. The bulk density value is influenced by aggregate gradation, asphalt content, type of additives, and the degree of compaction. The higher the bulk density value, the denser the asphalt mixture produced. The Standard Bulk Density values are presented in Table 10 below.

Tabel 10. Nilai Buld Density Standar (Berat Jenis)

No	DMF Type	Test Results (gr/cc)	Specification 2018 Revisi 2 (gr/cc)
1	AB100	2,234	Tidak disyaratkan
2	ABS-1	2,236	
3	ABS-2	2,242	
4	ABS-3	2,252	

Source: Analysis Results

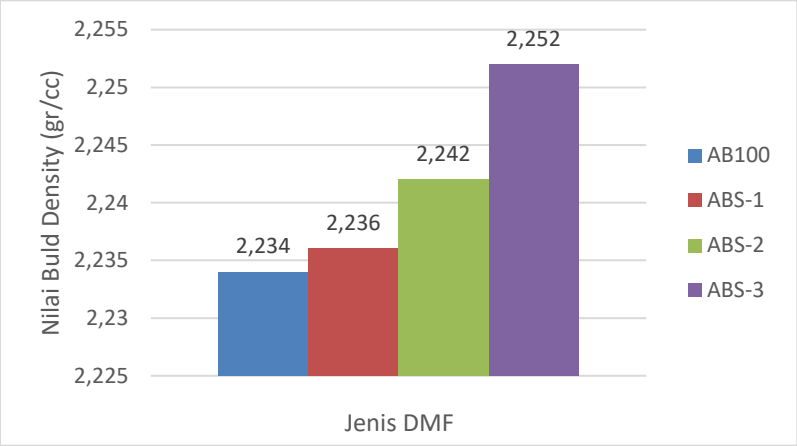


Figure 7. Bulk Density Values of Stone Dust and Styrofoam Filler

Based on the Marshall test results of AC-WC mixtures with variations in stone dust and styrofoam filler combinations shown in Table 10, the Standard Bulk Density (unit weight) values ranged from 2.234 gr/cc to 2.252 gr/cc. According to the General Specification of Bina Marga 2018 Revision 2, the bulk density parameter is not specifically required, but it is still used as an indicator of mixture density and compaction quality. The AB100 mixture produced a bulk density value of 2.234 gr/cc, indicating the density level of the mixture using 100% stone dust filler. In the ABS-1 mixture, the bulk density slightly increased to 2.236 gr/cc, indicating that the addition of 25% styrofoam began to contribute to an increase in mixture density.

Furthermore, in the ABS-2 mixture, the bulk density increased to 2.242 gr/cc. This increase indicates that a balanced proportion of stone dust and styrofoam was able to produce a more compact arrangement of aggregates and filler. In the ABS-3 mixture, the bulk density reached 2.252 gr/cc, which is the highest value among all mixture variations. This result indicates that a higher proportion of styrofoam was able to further increase the density of the AC-WC mixture. Overall, the variation in stone dust and styrofoam filler combinations shows a tendency to increase bulk density as the styrofoam content increases. Although this parameter is not specifically limited by specifications, the increase in mixture unit weight indicates a denser mixture, which has the potential to improve the stability and durability of the AC-WC pavement.

5. Conclusions and Recommendations

5.1 Conclusions

Based on the test results obtained, the following conclusions can be drawn:

1. Based on the Marshall characteristics of the Asphalt Concrete Wearing Course (AC-WC) mixture using a combination of stone dust filler and styrofoam, it was found that all mixture variations had the same Optimum Asphalt Content (OAC) of 5.90%. The addition of styrofoam in the mixture tended to increase mixture density, reduce air voids (VIM), and increase VFA values, resulting in a denser and stiffer mixture.
2. The test results showed that the ABS-3 mixture provided the best performance, with the highest Bulk Density, VFA, and Marshall Quotient (MQ) values, as well as stability values that were nearly equal to the standard mixture. In addition, the lower flow value indicates that the mixture has good stiffness. Therefore, the combination of 25% stone dust filler and 75% styrofoam (ABS-3) is considered the most optimal mixture variation and has the potential to be used as an alternative AC-WC mixture that is more effective and environmentally friendly.

5.2 Recommendations

Based on the results of this study, the following recommendations can be proposed for future research:

1. The ABS-3 mixture variation can be considered as an alternative AC-WC mixture because it provides optimal Marshall characteristics.
2. Further research is needed on the durability of the mixture under field conditions and long-term traffic loading.

3. The utilization of styrofoam waste in asphalt mixtures should be further developed to reduce environmental pollution.

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Solar Renewable Energy and Electrical Power Systems for Sustainable Industry

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Abstract

Provides low-carbon electricity and helps energy security, so solar renewable energy is a game changer as it adds a strategic component of sustainable industrial development across the world to reduce dependence on fossil fuel-based power supplies. Nevertheless, the electrical power systems that are needed in industrial facilities must be not only clean but also reliable, safe, efficient, and suitable for processing loads. This manuscript distinctly reviews the conceptual framework of solar renewable energy and electrical power plants for sustainable industry. This paper presents a synthesis of engineering principles and recent literature on solar photovoltaic systems, power electronics and energy storage, industrial distribution networks, power quality, protection coordination, monitoring, and energy management systems. Based on the facts from previous chapters, this discussion extends beyond solar photovoltaic installation for industry sustainability alone: solar generation needs to work with an electrical power system architecture that encompasses correct sizing, conversion, storage, control, protection, safety, and maintenance. We are proposing a five-stage implementation roadmap: energy audit, solar irradiation assessment, power generation system design, integration and testing, and optimal operation. This work also identifies major technical challenges, including the intermittent nature of solar generation, the non-suitability of industrial load profiles, processing variability related to hereditary instability issues caused by voltage fluctuations, harmonic distortion, protection coordination in microgrids, low-inertia operation, and cybersecurity risks. The framework offers a means to advance academic and practice-focused understandings of the systematic integration of solar renewable energy into electrical power systems for industrial use in supporting decarbonization, energy resilience, and global sustainable development.

Keywords: solar renewable energy; photovoltaic systems; electrical power systems; sustainable industry; energy storage; smart grid; power quality; industrial decarbonization.

1. Introduction

Secure, high-quality electricity is a prerequisite for industrial development. The electrical system is one of the most critical systems in any factory that runs electric motors, pumps, compressors, conveyors, lighting systems, thermal equipment like refrigeration and air conditioning systems, or control systems for process plants as well as sensors or digital automation. Simultaneously, we see increased pressure on industry to minimize greenhouse gas emissions, increase energy efficiency, and build more resilient energy systems. This is precisely why solar renewable energy and innovative electrical power technologies are becoming vital pillars of sustainable industrial transformation.

Solar photovoltaic (PV) technology uses semiconductor devices to convert sunlight directly into electricity. Its modular nature allows PV to be applied in buildings, rooftops, industrial estates, and utility-scale power plants (Department of Energy, 2025). Solar PV generation increased by a record amount in 2023 and remains a key technology in the renewable energy transition (International Energy Agency [IEA], 2024c). As investment increases and generation costs decline, solar PV has become more attractive for industrial power systems. Recent renewable power cost reports indicate that utility-scale solar PV continues to be cost competitive with

conventional electricity generation (International Renewable Energy Agency [IRENA], 2024, 2025). Solar PV investment in 2024 was also reported as a major component of global power-sector investment (IEA, 2024b).

These benefits are very real, and is a advantage of using solar PV in industrial power system but the actual engineering effort to implement such technology will be non-trivial. For example, since the solar generation at ground level is not constant and fluctuates due to factors such as irradiance, temperature, shading effects of obstacles in that area (dust particles present in an environment or auto vehicle emissions during operation), weather conditions. Industrial loads could be cyclic or continuous, hence the power system design parameters will be stochastic, nonlinear in nature, safety critical.

Furthermore, solar PV systems are interfaced through power electronic converters, which influence harmonics, fault-current characteristics, protection coordination, and power quality (Alam et al., 2020; Menda et al., 2024). Interconnection and interoperability requirements for distributed energy resources (DERs) connected to electric power system interfaces must also be considered (IEEE Standards Association, 2018). Therefore, solar renewable energy should be designed as part of an integrated electrical power system rather than only as a generation asset.

A generic framework was provided to name solar sustainable renewable energy as a part of electrical power systems for renewable electricity in the manuscript. It focuses on system architecture; technical requirements, implementation roadmaps and other practical engineering aspects. Your submission has been invited to an international conference and bitcoin merchant account speakership submitting specifically for the interdisciplinary again practical part of sustainable development.

2. Literature Background

Solar renewable energy plays an important role in supporting sustainable industrial power systems due to its clean operation, modular design, and suitability for distributed electricity generation. In industrial applications, photovoltaic systems can supply electricity for motors, pumps, lighting, control equipment, and auxiliary loads, while reducing dependence on fossil energy.

An integrated solar power system generally consists of PV arrays, protection devices, charge controllers, battery storage, inverters, distribution panels, and monitoring systems. These components must work together to ensure safe, efficient, and reliable power delivery. System performance is influenced by solar irradiance, module temperature, inverter efficiency, load demand, and energy storage capability.

Previous studies indicate that proper system design, thermal management, monitoring, and energy management are essential to improve PV performance and industrial energy reliability (Sofijan, 2020; Sofijan, 2021; Anugra & Sofijan, 2025). Therefore, solar renewable energy combined with electrical power system integration can support energy efficiency, emission reduction, cost savings, and sustainable industrial development.

To strengthen the literature background with basic algebraic and numerical reasoning, photovoltaic performance can be described using simple engineering relationships. Output power is obtained from voltage and current, energy is accumulated over operating time, and conversion efficiency is evaluated by comparing electrical output with incident solar energy. These relationships are useful for preliminary sizing, performance monitoring, and KPI evaluation in industrial solar power systems (International Electrotechnical Commission [IEC], 2021; Sofijan, 2020).

Box 1. Basic algebraic and numerical formulation for solar renewable industrial power systems.

Algebraic relation	Numerical illustration	Engineering meaning
P = V x I	If V = 220 V and I = 10 A, then P = 2,200 W = 2.2 kW.	Estimates instantaneous electrical power supplied to a load or produced by a PV-inverter system.
E = P x t	If P = 2.2 kW for 5 h, then E = 11 kWh.	Estimates electrical energy generated or consumed over a period of operation.
P_solar = G x A	If G = 1,000 W/m² and A = 1.6 m², then P_solar = 1,600 W.	Estimates incident solar power received by the PV module surface.
eta_PV = P_out / (G x A) x 100%	If P_out = 300 W, G = 1,000 W/m², and A = 1.6 m², then eta_PV = 18.75%.	Evaluates how effectively solar energy is converted into electrical energy.
LC = E_solar / E_load x 100%	If E_solar = 120 kWh/day and E_load = 400 kWh/day, then LC = 30%.	Shows the percentage of industrial load supplied by solar energy.
ER = E_solar x EF_grid	If E_solar = 120 kWh/day and EF_grid = 0.8 kg CO2/kWh, then ER = 96 kg CO2/day.	Estimates avoided carbon emissions from replacing grid or fossil-based electricity.
PB = C_initial / S_annual	If C_initial = IDR 100,000,000 and S_annual = IDR 20,000,000/year, then PB = 5 years.	Provides a simple economic estimate of investment recovery time.

The numerical examples in Box 1 are illustrative and can be adjusted according to the actual PV module area, irradiance level, load profile, grid emission factor, and investment cost. In industrial practice, these algebraic relationships provide a basic foundation for comparing baseline operation, target performance, and sustainability benefits before detailed simulation or field measurement is conducted.



Figure 1. Industrial-scale Solar Photovoltaic Power Plant in an Open Area.

Figure 1 shows rows of photovoltaic solar panels installed systematically over a large open area to capture solar radiation and convert it into electrical energy. A solar power plant of this type can be used as a renewable energy source to support industrial electricity demand, reduce dependence on fossil fuels, and lower carbon emissions. An open site with minimal shading is an important factor for ensuring optimal photovoltaic system performance.

2.1 Solar renewable energy and industrial sustainability

This research provides a sustainable industry through solar renewable energy: low-carbon electricity generation as close to the consumption point as possible. Solar PV can reduce grid purchases in industrial sites, help with peak shaving, enhance energy security and display environmental credentials. Particularly with solar PV, when combined with storage and energy management technology, resilient power can be provided to critical loads, thereby diminishing production risk induced by grid disturbances (Sofijan, 2020).

Developing solar energy is part of the global energy transition. The Renewables 2024 report estimates that solar PV and wind together will account for most renewable capacity growth up to 2030 under existing policy frameworks and market conditions (IEA, 2024a). This trend supports the role of solar energy as a strategic supplier for future industrial power.

2.2 Electrical power systems in industrial facilities

Industrial electrical power system consists of the provision of power, transformers, switchgear, distribution panels and cables, motors, drives protection devices (such as MCCBs, RCBs etc.), grounding and the monitoring equipment as well as loads. It should maintain the voltage level, frequency and continuity of supply, protection selectivity, as well as meet safety requirements. A simple power interruption, even for a short period, can lead to production loss in many industries or malfunction of your equipment.

Solar PV and modifies changes the structure of the industrial power system traditionally. This power can either be from the grid, solar PV and storage to the load, or PV and storage back to the grid (assuming exports are allowed). Protection, metering, inverter control, interconnection and operating procedures need to be designed accordingly for it.

2.3 Solar PV, power electronics, and energy storage

Solar PV produces direct current (DC), whereas most industrial loads operate using alternating current (AC). Therefore, power electronics are required to convert, control, and interface renewable generation with industrial electrical networks (Liserre et al., 2010; McNutt et al., 2018). MPPT-based DC-DC converters extract maximum available output from PV arrays, while DC-AC inverters convert DC power into AC power for industrial loads or grid interconnection.

Despite this, a key option to increase the deployability of solar PV is co-location with energy storage as this reduces the mismatch between solar generation and load curves. They will respond to batteries the coupled peak shaving, voltage regulation, ramp-rate control backup power and microgrid operation. While that allows them to be considered not only for life or thermal management, but also safety, depth of discharge (DOD), charge-discharge cycles and economic issues with design liberties taken as well.

2.4 Smart grids, microgrids, and industrial resilience

Smart grids and microgrids open new opportunities for flexible and resilient industrial power systems. Smart grids use communication, automation, sensors, and data analytics to monitor and control electricity flows. Microgrids can operate in grid-connected or islanded modes to support industrial estates, remote facilities, mining sites, agricultural processing plants, and critical production units (Kroposki et al., 2020).

Recent reviews stress that renewable integration asks for quite advanced control and monitoring, protection, inertia and frequency support, and other follow-up measures when renewable penetration is high (Fernandez-Guillamon et al., 2020; Hasan et al., 2023; Cavus, 2025). For industry, it requires the coupling of solar PV with energy management systems, trained operators, maintenance procedures and cybersecurity practices.

3. Methodology

This is a conceptual review paper. This review brings together engineering principles, recent energy reports and standards-based considerations, and academic literature related to solar PV, renewable integration, industrial power systems, energy storage, smart grids, and microgrids. Furthermore, principles for monitoring photovoltaic system performance (IEC, 2021) are aligned with the monitoring concepts discussed in this manuscript. The goal is not to report one experimental dataset, but to create a framework for implementing solar renewable energy in sustainable industry.

The conceptual review was structured into five steps. Relevant concepts were then identified: solar renewable energy, photovoltaic generation, power conversion, industrial distribution, energy storage, protection, and power quality as well as digital energy management. Second, a review of literature and energy reports was performed to identify global trends and engineering challenges. Third, an integrated architecture was developed to map out the main technical components of solar-based industrial power systems. Fourth, basic performance indicators were chosen to assist in the evaluation from an engineering perspective. Fifth, an industrial application implementation roadmap was developed. Renewable energy into electrical power systems for sustainable industrial transformation Therefore, the contribution consists of a framework that is based on synthesis. It is designed to assist researchers, engineers, students, and policymakers in understanding the systematic integration of solar.

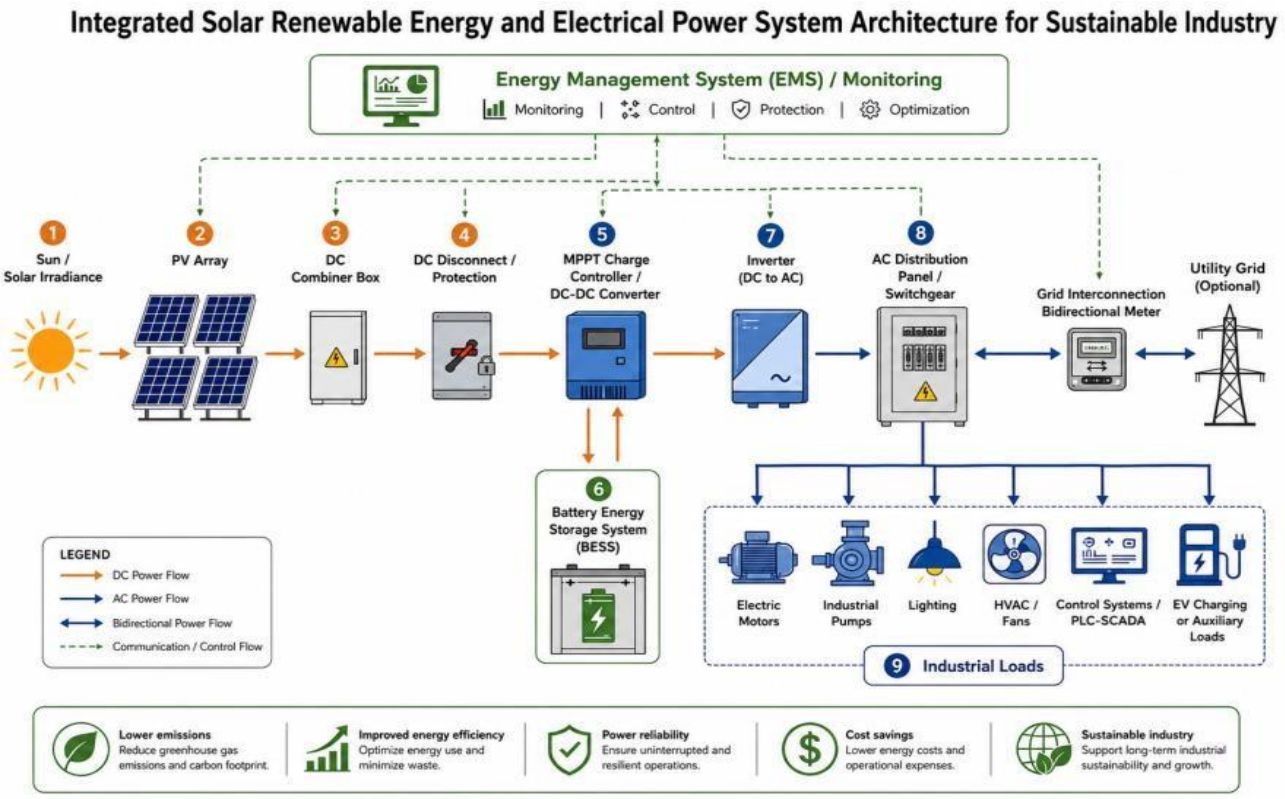


Figure 2. Integrated solar renewable energy and electrical power system architecture for sustainable industry.

Figure 2 illustrates the integrated architecture of a solar renewable energy system for industrial power applications. Solar irradiance is converted into electrical energy by the photovoltaic array and then transmitted through the DC combiner box and protection devices. The energy is regulated by the MPPT charge controller or DC–DC converter before being supplied to the inverter and battery energy storage system. The inverter converts DC power into AC power, which is then distributed through the AC distribution panel to industrial loads such as motors, pumps, lighting, HVAC systems, control systems, and auxiliary loads.

The system can also be connected to the utility grid through a bidirectional meter, allowing power exchange between the solar system, industrial loads, and the grid. The Energy Management System monitors and controls energy flow, protection, storage, and load demand to improve efficiency, reliability, and sustainability. Overall, this architecture supports cleaner industrial energy supply, reduced emissions, better power reliability, and more efficient energy management.

Table 1. Main components of a solar renewable industrial electrical power system.

Component	Primary function	Engineering consideration
Solar PV array	Converts solar radiation into DC electricity.	Sizing, tilt angle, orientation, shading, temperature, dust, and mechanical support.
DC-DC converter / MPPT	Tracks maximum power point and controls DC voltage.	Efficiency, voltage range, dynamic response, and compatibility with PV strings.
Grid-tied inverter	Converts DC to AC and synchronizes with the electrical network.	Power rating, harmonics, protection, anti-islanding, voltage/frequency control, and standards compliance.
Battery energy storage	Stores energy and supports peak shaving, backup, and smoothing.	Capacity, battery chemistry, safety, lifecycle, state of charge, and thermal management.
Industrial AC bus	Distributes electrical power to production loads.	Load profile, short-circuit level, cable sizing, grounding, and expansion.
Protection system	Detects and isolates faults.	Relay coordination, breaker rating, islanding, grounding fault, and selective tripping.
Power quality equipment	Maintains voltage and waveform quality.	Harmonic filters, reactive power compensation, surge protection, and monitoring.
EMS / SCADA	Monitors and optimizes energy flow.	Data acquisition, forecasting, dispatch, alarms, cybersecurity, and operator training.

Table 1: The major parts of a solar renewable industrial electrical power system and their tasks in the recommended energy transformation and distribution process. The photovoltaic array is the first and foremost energy source, through which the solar radiation is converted to DC electric power. Before the power is passed through to the inverter or a battery system, there are various other elements engaged in forming part of energy storage and channel these circuits, such as the DC combiner box, protection devices, a charge controller and a DC–DC converter that regulate the device in order to help modulate and protect this DC side in the two systems

The inverter converts DC power to AC and makes it useable for industrial loads through an AC panelboard. The battery stores excess solar energy during peak sunlight hours and provides electricity during periods of low solar irradiance (e.g., at night, on cloudy days) or when electricity demand is high. Supervision, control and energy management systems are also an essential aspect of monitoring, as they supervise power flow, system performance, protection and load demand. Taking these into account, the series components described in Table 1 can be collectively applied for a reliable and sustainable industrial power supply solution.

4. Results and Discussion

The results indicate that solar renewable energy systems can meet the electrical power demand of industrial facilities if they are interlinked properly with one another. You have a photovoltaic array that turns solar radiation into DC power and connects with the charge controller, battery storage like lead-acid/lithium-ion batteries, an inverter (when required), and a distribution panel. Incorporating these elements will improve energy efficiency, dependable power, and operational flexibility.

The system architecture has one major element, which is tracking and energy management. An energy management system enables more sophisticated management of generation, storage, grids, and loads. Continuous monitoring can be implemented through applications such as Solar Guardian, which was evaluated for PV operation and maintenance, and real-time data recording can support rooftop PV performance assessment (Anugra & Sofijan, 2025). This allows the system to reduce energy losses, maintain power quality, and support continuous industrial operation.

The findings of this article discuss how renewable feedback from solar power in the form of industrial electrical energy and integrated strength structures can provide guidance for sustainable enterprises with solutions for decreasing fossil-fuel dependence, assistance in lowering carbon emissions, and reinforcement of energy independence with competitive energy prices.

4.1 Integrated architecture for solar-based industrial power supply

The architecture proposed includes the various components of the solar PV generation process, like power conversion; energy storage, where stored energy can be used as industrial distribution protection; monitoring; and load management. Solar PV output is delivered to the industrial AC bus via MPPT and inverter systems. The industrial bus provides loads for production, potentially also connected to the utility grid. These short-term mismatches (in terms of time) between solar generation on the one hand and industrial demand on the other hand are bridged by means of battery storage, thus ensuring flexible operation.

The architecture implies that solar renewable energy on-systems be merged with the electrical power system as a whole. Simply designing the PV system does not take into consideration industrial load profiles, protection coordination, and power quality for achieving expected benefits. Integrated planning allows solar PV to contribute towards energy saving, reliability, and sustainability at the same time.

4.2 Industrial load profile and solar generation mismatch

Solar-powered industrial systems are challenged by the mismatch between solar generation and industrial load demand. Solar PV only produces maximum power from the sun when it is available in the daytime, but industries may load for a morning/afternoon/night shift or move to 24 hours continuous working. Some of them have constant base loads like industries and a few others probably way around with raised power hardware like engines, compressors, welding machines, heating systems or crushers.

Prior to system sizing an energy audit is thus critical. The audit must gather hourly load data, daily production scheduling, peak demand, power factors, power quality matters and any critical loads standby need. These data will decide whether the optimum system should be grid-tied PV, PV with battery storage, PV-diesel hybrid, PV microgrid or PV supported by demand-side management.

4.3 Power quality, protection, and electrical safety

Voltage sag, voltage swell, flicker, harmonics, and unbalanced voltage are sensitivities of industrial loads. Solar PV inverter designs, settings, and operating conditions often improve power quality at best or degrade it at worst. High-quality inverters can exhibit reactive power control, voltage support, and harmonic limitation. On the contrary, a system with poor design can cause waveform distortion, nuisance tripping, or miscoordination of protection devices.

When distributed solar generation is implemented, protection must be revised. Conventional industrial protection is generally built to facilitate power flow from the source of utility supply to loads. For solar PV and storage, both fault current contribution and power flow direction will likely change. Therefore, it is necessary to coordinate overcurrent protection, grounding fault protection, anti-islanding, surge protection, and the emergency shutdown process with both the PV inverter and the industrial distribution system.

Table 2. Technical challenges and mitigation strategies.

Challenge	Impact on industrial system	Mitigation strategy
Solar variability	Power output changes with irradiance, clouds, temperature, and shading.	Use forecasting, storage, grid support, hybrid generation, and load scheduling.
Load mismatch	PV generation may not match production demand.	Perform load audit, install storage, apply demand-side management, and optimize operating schedules.
Voltage fluctuation	Sensitive equipment may trip or malfunction.	Apply inverter voltage control, reactive power compensation, and voltage monitoring.
Harmonic distortion	Increases losses, heating, and equipment stress.	Use compliant inverters, harmonic filters, and periodic power quality audits.
Protection coordination	Bidirectional power flow may disturb fault isolation.	Review relay settings, breaker ratings, grounding, anti-islanding, and selectivity.
Cybersecurity risk	EMS, SCADA, and communication networks may be exposed to control threats.	Use secure communication, access control, network segmentation, backup, and operator training.
Maintenance needs	Dust, heat, moisture, and aging reduce system performance.	Apply preventive maintenance, thermographic inspection, cleaning schedule, and performance monitoring.

The major technical challenges and their respective mitigation strategies in the design, development, coordination, and operation of solar renewable industrial electrical power systems have been highlighted in Table 2. These challenges include solar irradiance diversity, thermal stress on photovoltaic modules, power quality issues, battery degradation rate, and unpredictable load profiles in terms of time and magnitude, protection coordination, and limited monitoring capability. These problems can negatively influence power output, system stability, and reliability as well as operational performance.

To prevent the problems listed above, some mitigation strategies can be employed, such as proper system sizing, thermal management, MPPT control, battery energy management via inverter optimization, and protection system coordination along with monitoring in real time, ensuring preventive maintenance. Implementation of these strategies allows a solar renewable power system to function more effectively in industrial environments as well as increase survival reliability and safety. In general, the integrated design, control, monitoring, and maintenance approaches were capable of addressing the technical difficulties, as Table 2 summarizes.

4.4 Energy storage and energy management system

Energy storage is not mandatory for every solar industrial system, but it becomes important when the facility requires backup power, peak shaving, voltage support, or microgrid capability. Battery storage can reduce short-term PV fluctuation, shift solar energy to evening loads, and support critical processes during grid interruption. Nevertheless, storage increases capital cost and requires careful safety management.

An energy management system coordinates PV generation, storage, grid import/export, and load operation. In a sustainable industrial power system, the EMS may perform load forecasting, PV forecasting, battery dispatch, demand response, peak shaving, alarm management, and performance reporting. Data-driven operation allows engineers to evaluate whether the system is meeting energy, reliability, and sustainability targets.

4.5 Thermal performance of solar PV in industrial environments

Module temperature affects PV performance. Similar studies have yet to be performed in some industrial environments at tropical conditions where PV modules can feel high ambient temperature, dust, humidity, and rooftop heat. Since voltage and output power generally decrease as module temperature increases, thermal management has been an important issue for solar PV performance.

In contrast, passive cooling, rear ventilation, a sufficient mounting gap, a reflective roof coating, and correct cleaning maintain the production of PV without increasing auxiliary energy consumption; perforated aluminum plate cooling is one relatively simple passive technique suggested for better thermal and electrical performance compared with traditional installation (Sofijan, 2021).For a commercial rooftop, engineers need to think about roof material, air circulation, fire safety, structural load capacity (weight of the system), cable routing, and

maintenance access. Solar PV is not just an electrical device but also a thermal and structural component installed in any real industrial environment.

4.6 Engineering indicators for evaluation

Performance evaluation requires measurable indicators. The indicators should cover energy production, solar utilization, efficiency, reliability, power quality, economic feasibility, and environmental impact. Table 3 summarizes selected indicators that can be used in feasibility studies and post-installation monitoring.

Table 3. Selected engineering indicators for solar renewable industrial power systems.

Indicator	Expression	Use in evaluation
Electrical output power	P = V x I	Measures instantaneous DC or AC electrical output.
Electrical energy	E = sum(P x Delta t)	Measures generated or consumed energy over a period.
PV conversion efficiency	eta_PV = P_out / (G x A) x 100%	Evaluates PV output relative to irradiance and module area.
Solar fraction	SF = E_solar / E_load x 100%	Indicates the percentage of load supplied by solar energy.
Renewable fraction	RF = E_RE / E_total x 100%	Indicates the contribution of renewable energy in the total supply.
Specific energy consumption	SEC = E_process / Q_product	Measures energy intensity per unit of product.
Emission reduction	ER = E_solar x EF_grid	Estimates avoided emissions using a grid emission factor.
Availability	A = operating time / scheduled time x 100%	Evaluates system reliability and operational readiness.

Table 3 presents selected engineering indicators used to evaluate the performance of solar renewable industrial power systems. These indicators include photovoltaic efficiency, specific energy yield, performance ratio, inverter efficiency, battery storage performance, system availability, load coverage, power quality, and emission reduction. Each indicator provides important information for assessing how effectively the system converts solar energy into usable electrical power for industrial applications.

The indicators listed in Table 3 also help determine system reliability, operational efficiency, economic feasibility, and environmental contribution. By using these engineering indicators, system performance can be monitored more systematically, and improvement strategies can be developed to support efficient, reliable, and sustainable industrial power supply.

Engineering indicators for time-sampled solar renewable industrial power system performance include photovoltaic efficiency, specific energy yield, performance ratio, inverter efficiency, storage performance, system availability, load coverage, power quality, and emission reduction. These indicators are commonly used to determine how effectively solar energy is converted into usable electrical energy and how reliably the system supports industrial applications (Gielen et al., 2019; IEC, 2021; IEEE Standards Association, 2018).

The indicators given in Table 3 are another way of measuring users/interest groups opinions: they reflect system reliability and operational efficiency, economic viability and environmental sustainability. These engineering indicators will provide a more systematic way to monitor system level performance in the future and ultimately prompt improvement strategies that enable an industrial power supply that is both cost-effective, reliable, and sustainable. Table 2 presents details of some engineering features based on evaluation fixated the systems featuring solar sustainable commercial strength. Performance Metrics to Be Evaluated photovoltaic efficiency specific energy yield (kWh/kWp, as rate of sunlight energy converted into usable form at a system boundary) performance ratio (a ratio of electricity that is "usable"/"grid-ready" or the output upon inverter output node ok) inverter efficiency battery storage performance rating system availability load coverage power quality emission benefits The metrics themselves inform us how well the system is able to convert solar energy into useful electrical energy for industrial application on an individual basis.

The factors mentioned in Table 3 are also used as benchmark indicators to evaluate reliability, operability, economic dispatch and environmental advantages of the systems. All these engineering intervention indicators give the opportunity for systematic monitoring of the system performance and development of improvement

strategies to support efficient, reliable and sustainable industrial power supply up on real time basis. Selected engineering indicators to assess the performance of Srips are displayed in Table 3. Common indicators are photovoltaics efficiency, specific energy yield, performance ratio, inverter-efficiency for storage performance and utilization (capacity usage + system availability + load coverage) and power quality & emissions reduction. All the indicators above bring critical information on how best to convert solar into usable electrical energy for commercial applications.

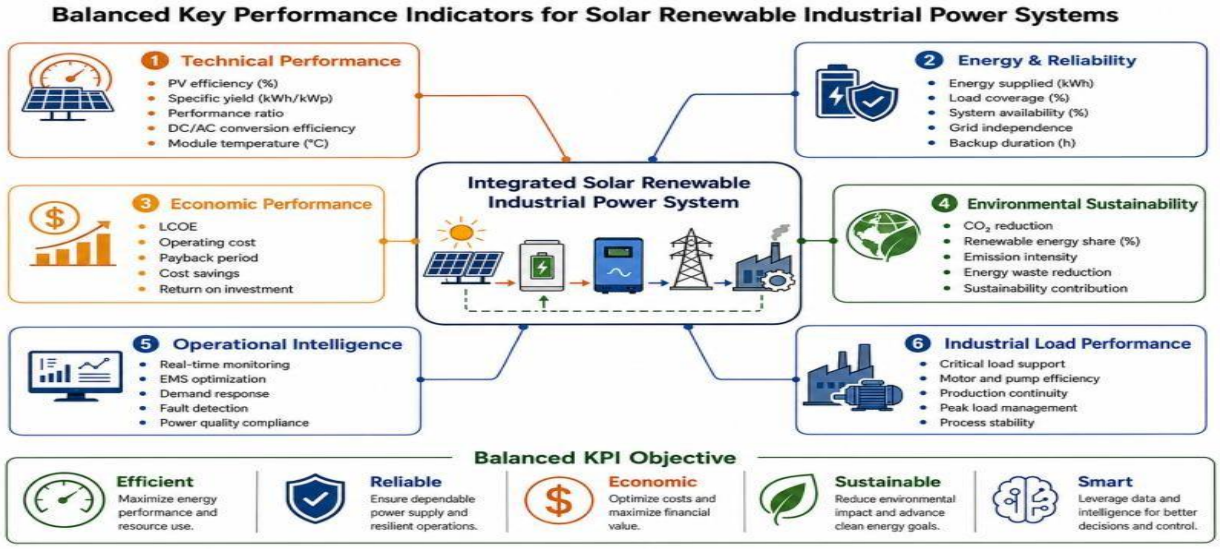


Figure 3. Balanced key performance indicators for solar renewable industrial power syst

Figure 3 also shows indicators through which system reliability, operational efficiency, economic feasibility, and environmental contribution can be assessed. Common performance indicators for solar renewable industrial power systems include PV efficiency, annual system energy yield (kWh/kWp), performance ratio (PR), inverter and battery storage performance, system availability, load coverage rate, power quality, and environmental benefits (IEC, 2021; IRENA, 2024; Gielen et al., 2019). Hence, these indicators provide useful perspectives for assessing the capability of solar energy systems to produce reliable electrical power for industrial processes.

Other indicators presented in Figure 3 also suggest systems reliability, operational efficiency of the construction and maintenance projects, economical-viability and environmental contributions. The next engineering indicators can systematically monitor system performance and then help derive improvement strategies to enable an efficient, reliable and sustainable supply of energy.

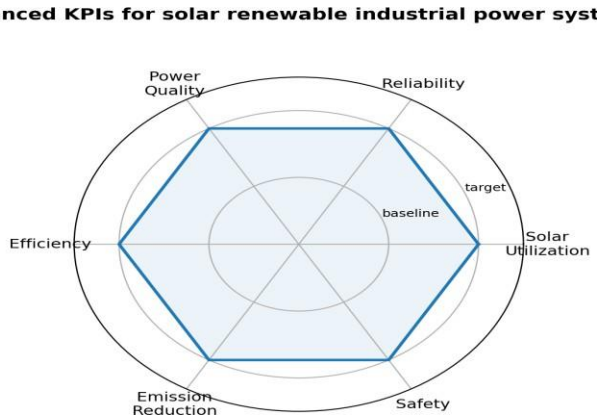


Figure 4. Balanced KPI profile for solar renewable industrial power systems.

Figure 4 illustrates the radar chart of balanced key performance indicators for solar renewable industrial power systems. These include solar utilization as well as reliability, power quality, efficiency, emissions reduction, and safety. The chart demonstrates where the baseline and level of target performance for the integrated solar power system will drive overall industry energy performance.

The KPI profile balance means that solar renewable industrial power systems should not just be evaluated on K&A and renewables and energy generation but also backed by reliability, power quality, operational efficiency, environmental impact, and safety. A balanced performance over all indicators represents a more sustainable, stable, and hence effective power system for industrial applications. Figure 4 is a radar chart on balanced key performance indicators for solar renewable industrial power systems. Such indicators are the reliability of solar usage, power quality, efficiency, emission reduction, and safety. The chart provides a comparison between the baseline and target performance levels to illustrate how the integrated solar power system can be expected to enhance overall industrial energy performance.

It has been identified that solar renewable industrial power systems need to be valued not only from an energy generation perspective but also for system reliability, quality of power output, operational efficiency, and impact on the environment as well as human safety. Industrial applications of power systems with a balance across all indicators reveal a more stable, sustainable, and effective solution.

4.7 Sustainability benefits and limitations

Solar renewable energy entails lower consumption of grid electricity by the industry which results to a decline in emissions, thereby improving long-term energy sustainability. This helps to reduce the dependency on fossil fuels and that further accommodates organisations with their exposure towards rising fuel prices wherein they can manage energy operations more effectively. The Solar PV further builds an ecosystem for corporate sustainability targets, creating linkages with Electric Mobility, Green Building and Digital industrial transformation. The benefits align with global analyses indicating that the decarbonization of energy has applicability for transforming employment or achieving other global goals (Gielen et al., 2019; International Renewable Energy Agency & International Labour Organization, 2024; REN21, 2025).

However, limitations must be acknowledged. Solar PV generation is variable, storage for multi-day backup remains relatively expensive, rooftop space may be constrained, and industrial electrical infrastructure operates under strict safety and reliability requirements. The environmental benefit of solar PV also depends on long-term operation, equipment quality, maintenance practices, recycling, and responsible sourcing. Recent global energy reviews emphasize the relationship between rising electricity demand, clean-energy investment, and renewable deployment in sustainable energy transitions (IEA, 2025a, 2025b). Therefore, the sustainability challenge must be evaluated across the full system lifecycle.

5. Implementation Roadmap

It has a five-step implementation roadmap. Step one: an energy audit. Engineers quantify load profile, peak demand, power factor, power quality requirements, critical loads and production schedules. This phase lays the groundwork for sizing the system and determining technical feasibility.

Stage two is Solar Resource Assessment. It encompasses solar irradiance, shading effects, rooftops' orientation and area, structural integrity of the building, dust levels that vary temporally and spatially in arid climates like India, ambient temperatures over time and interconnection constraints. The outcome confirms the usable PV potential and identifies the need for storage or hybridization.

Third is the power system design. During this phase, PV size, inverter choice, battery sizing if warranted and setup for cables as well as switchgear style are various other concept electrical design tasks like safety

grounding surge security metering EMS SCADA and protection coordination along with fire safety measures and accessibility to maintenance. Design needs to meet applicable electrical standards and local codes.

This is the integration and testing stage. Commissioning should confirm insulation resistance and continuity of ground, operation of inverter, protection settings (commutation failure), anti-islanding and emergency shut down in addition to power quality testing and data acquisition as well as readiness of operator. Before any production load is supported by the system, some testing is required.

The fifth phase is optimizing. Industrial solar power systems need to be continuously monitored, periodically maintained, cleaned, thermo graphically inspected and the energy performance evaluated to improve control strategies. Optimization is what guarantees the system keeps supplying energy, reliability and sustainability gains through time

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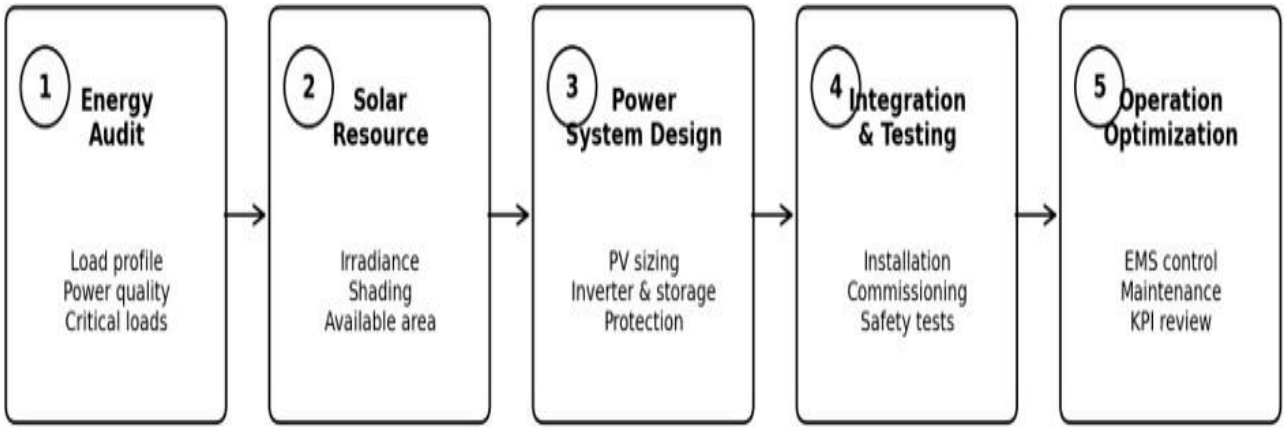


Figure 5. Implementation roadmap for solar renewable energy adoption in industrial electrical power systems.

The implementation roadmap to integrate solar energy in industrial electrical power systems is shown in Figure 5. Your roadmap starts with checking energy demand and land for load needs, the potential of solar energy and the condition of grid access. At the second stage, you should proceed to system design as well as component selection such as PV modules, inverters, protection devices, battery storage, monitoring system, and energy management systems.

Following the design stage, the roadmap extends to installation, testing, commissioning, and system integration with industrial loads and utility grid. Sustainable operation needs monitoring, preventive maintenance and performance assessment plus optimization to achieve reliable and competitive energy generation over time. In summary, the roadmap sets out a framework for phased implementation of solar renewable energy to industry safely and sustainably.

Table 4. Five-stage implementation roadmap for sustainable industry.

Stage	Main activity	Expected output
1. Energy audit	Measure load profile, peak demand, critical loads, power factor, and power quality.	Baseline electrical and energy performance profile.
2. Solar resource assessment	Evaluate irradiance, shading, roof or land area, temperature, dust, and grid condition.	Solar potential and site feasibility report.
3. Power system design	Size PV, inverter, storage, cables, protection, grounding, EMS, and monitoring.	Technical design, bill of quantity, and investment plan.
4. Integration and testing	Install equipment, commission inverters, test protection, verify safety, and validate performance.	Operational solar renewable power system.
5. Operation optimization	Monitor KPIs, perform preventive maintenance, clean modules, evaluate energy savings, and update control.	Reliable, efficient, and sustainable industrial operation.

Table 4 displays five-stage implementation roadmap of industrial electrical power system from solar renewable energy source. The roadmap encompasses energy assessment, system design, installation & integration, operation and monitoring and a continuous improvement stage. The stages offer a structured business process to evaluate the technical feasibility, economic viability and responsible industrial advancement of solar energy technology deployment.

The first stage consists of the initial survey to gather information upon features of industrial vitality demand, load profiles, solar potential and website situations. Phase two will involve choosing all the components of the system (PV modules, inverter, protection devices, battery storage and monitoring systems). The third stage is that of installation + testing + commissioning at the grid/load. Stage 4: You execute data in real-time, conduct preventative maintenance and analyze performance. This last stage is all about Optimization, cost efficiency, emission reduction and new sustainable long-term solutions. In conclusion, as reflected in the construction of Table 4, successful value creation in solar energy demands a structured assessment and planning to implement effective interventions alongside investments targeting technology stability and performance enhancement.

6. Implications for Engineering Practice

Electrical power system analysis must lead solar renewable energy projects for industry. The first implication is that electrical power system analysis must lead solar renewable energy projects for industry. It must be matched with load profile, transformer capacity, short-circuit level, protection settings, inverter capability, storage strategy, and operational goals.

The first implication is that electrical power system analysis must lead solar renewable energy projects for industry. PV capacity should not be selected only based on the available roof area or investment budget. It must be matched with load profile, transformer capacity, short-circuit level, protection settings, inverter capability, storage strategy, and operational goals.

The second implication is the need for interdisciplinary collaboration. Solar industrial projects involve electrical engineering, mechanical and structural assessment, thermal considerations, occupational safety, economics, policy, and environmental management. Sustainable industry requires coordination between technical design, management decision, operator training, and maintenance planning.

The third implication is the importance of monitoring and continuous improvement. A solar PV system can degrade due to soiling, shading, inverter faults, hot spots, loose connections, and aging. Monitoring is essential to uncover hidden problems that can reduce energy yield. Therefore, performance ratio, availability, energy production, and power quality should be reviewed regularly.

The fourth implication concerns education and workforce development. Engineers and technicians should understand PV principles, inverter operation, DC safety, protection coordination, power quality, storage management, and digital monitoring. Human capability is as important as technology in achieving sustainable industrial energy systems. The second implication is the need for interdisciplinary collaboration. Solar industrial projects involve electrical engineering, mechanical and structural assessment, thermal considerations, occupational safety, economics, policy, and environmental management. Sustainable industry requires coordination between technical design, management decision, operator training, and maintenance planning.

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The fourth implication concerns education and workforce development. Engineers and technicians should understand PV principles, inverter operation, DC safety, protection coordination, power quality, storage management, and digital monitoring. Human capability is as important as technology in achieving sustainable industrial energy systems.

7. Conclusion

Some renewable energy data are at least substancially supporting the electricity mix used in sustainable industry include solar-based low-emission power such as solar PV, strong dependence on fossil-based power and improving long-term energy resilience However, panel installation alone is not enough for the successful deployment of solar PV in industry. Requires interface with a complete electric power system that incorporates conversion, storage, protection, power quality management, monitoring and maintenance/ load management.

The conceptual framework of solar renewable energy and electrical power systems for industry sustainability have been presented in this manuscript. This framework emphasizes integrated architecture, core elements, technical difficulties, engineering indexes and a five-stage pathway for implementation. This section provides a quick overview of the main technical issues related to solar: namely solar variability, industrial load mismatch, power quality, protection coordination, thermal performance (in terms of generation-absorption), storage management and cybersecurity.

The main takeaway is: A robust, safe and smart electrical power system can be created by incorporating solar renewable energy which may disrupt sustainability to some extent but also benefit industry sectors if properly planned and operated. Future work includes applied case studies, tropical photovoltaic performance and industrial microgrid optimization, energy storage optimization, power quality mitigation strategies, digital monitoring as well as lifecycle sustainability assessment.

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THE DYNAMICS OF PUBLIC SERVICE MOTIVATION AS A KEY FACTOR IN IMPROVING PUBLIC SERVICES IN SOUTH SUMATRA

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ABSTRACT

The rapid transformation of digital public services demands a shift in the way civil servant performance is evaluated, moving beyond procedural compliance to intrinsically motivated competencies. Despite the crucial role of Public Service Motivation (PSM) in enhancing government effectiveness, empirical evidence on its specific dimensions in the context of Indonesia's evolving urban administration remains limited. This study addresses this gap by analyzing the dynamics of civil servant performance through the lens of PSM in South Sumatra. Using a quantitative descriptive approach, the study identifies which specific dimensions—interest in public policymaking, commitment to the public interest, empathy, and self-sacrifice—most effectively drive performance. The results indicate that empathy is the most dominant driver of performance, while self-sacrifice shows significant potential for improvement. These findings provide a data-driven roadmap for regional human resource management, demonstrating that training interventions tailored to specific PSM dimensions can significantly optimize public service outcomes. This study also contributes to broader theoretical developments in public management by offering a localized, evidence-based model for evaluating and improving civil servant performance in rapidly evolving local governments.

Keywords: Public Service Motivation, PSM, Civil Servant, Performance, South Sumatera

1. INTRODUCTION

Due to the rapid emergence and evolution of public services, government officials worldwide are being pressured to adopt new strategies and methods. This necessitates state civil service institutions (ASN) to continuously improve their performance. They are also expected to provide the best possible service to the public. This new paradigm emphasizes the need to improve the competency of civil servants, designed to enhance the quality and responsiveness of public services, particularly in developing regions like South Sumatera.

Several Scopus journal articles show that various factors that influence the quality of public services, such as civil servant competence, organizational commitment, and the application of transparency and accountability principles, can help increase public trust in the government (Hamdy et al., 2024; Sofyani et al., 2021; Tweneboah-Koduah et al., 2022).

However, in the current era of disruption, traditional methods of managing public sector human resources can no longer be used, so they must be carried out through competency analysis that focuses on generating real value for society.

Recent studies by Sofyani, Blaique, and Bauman demonstrate that a comprehensive understanding of how various competency dimensions can be measured, mapped, and analyzed, both in aggregate and by operational dimension, can help improve the performance of public service organizations. Their research notes that competency analysis is a crucial tool for public policy reform agendas and improving government efficiency (Sofyani dkk., 2021; Blaique dkk., 2023; Baumann & Wilson, 2024).

The competency development process can help policymakers develop a more targeted, data-driven, and structured approach to improving the quality of public services in South Sumatera City. It can also help them align their efforts with community needs. Through a systematic evaluation of various competency dimensions, key factors that bridge the gap between civil servant capacity and the institution's strategic achievements in serving citizens can be identified (Baumann & Wilson, 2024; Tweneboah-Koduah et al., 2022).

Although the need for competency enhancement is widely recognized, a key research issue remains the bureaucratic culture, which focuses more on procedural compliance than on innovative service delivery. One of the most common problems affecting civil servant development and training is program design that focuses on a single set of factors. This approach often fails to translate theoretical knowledge into practical skills applicable to public service performance. For example, in the face of increasing complexity and citizen demands, the need for robust and innovative public services is often unmet (Fossen et al., 2024; Mashilo & Kubayi, 2024).

Due to the increasing complexity of public services, the development and training of professionals has become a central issue in human resource management in the public sector. Therefore, the research focus is clearly on developing a work ecosystem that can facilitate employee motivation and empowerment. Implementing competency-building programs can lead to greater innovation and service resilience, and these programs can also be complemented by employee empowerment initiatives (Oliveira et al., 2023; Tweneboah-Koduah et al., 2022).

A comprehensive analysis of journal articles on this competency topic points to the development of a gap in the current discourse. There is a gap in the recent literature (the last 5 years) regarding the role of social determinism and empowerment in the development and implementation of competency programs. Although numerous studies have been conducted on this topic in various global organizations, these studies have not been able to provide a comprehensive analysis of competency dynamics in Indonesian government agencies, particularly in secondary metropolitan cities like South Sumatera (Oliveira dkk., 2023; Mashilo & Kubayi, 2024). Therefore the idea of competency dynamics emerges in this paper.

In Southeast Asia, most studies on public human resource management focus on competency as a monolithic variable, neglecting average achievement across various dimensions, such as managerial, behavioral, and technical. They also rarely link it to empowerment variables in the digital transition of public services. However, this paper proposes a way beyond this notion: measuring the comparison between constructs beyond

average achievement levels. This paper hopes to find practical contributions from indicators crucially needed to maximize the role of human resources in civil servants.

This paper will use the PSM (Public Service Motivation) theory as its analytical tool. In public service, competence encompasses more than simply the ability to perform a job. Competence also encompasses the motivation to perform well. It can be said to be very strongly related to behavior when compared to the concept of employee motivation. The competence of civil servants in South Sumatera can be used as an indicator of the impact of high or low work motivation. Commitment to the public interest is an indication that an employee is dedicated to serving the people of South Sumatera, or the competence of civil servants in South Sumatera can be used as an indication of their willingness to handle various public complaints. Even in high idealism, the willingness of civil servants to continuously improve their skills even without large bonus incentives is an indication of their self-sacrificing nature.

This research is unique in that it combines the theoretical and practical aspects of competency mapping with a motivational framework. Through this concept, researchers can explore how these elements can influence the development and implementation of public service innovations (Pino et al., 2024; Tweneboah-Koduah et al., 2022). It is hoped that this paper will provide valuable information for policymakers and those developing new performance interventions. They can use its contributions to design and implement effective training programs.

This paper then focuses on the motivation that generates competency in civil servants in South Sumatera City, which is undergoing a paradigm shift toward a more adaptive system. The findings will serve as a basis for developing a theory related to the dynamic capabilities of public sector human resources, which can be generalized to urban entities in developing countries. (Ng et al., 2024; Taylor et al., 2024).

2. Literature Review

2.1 *Public Service Motivation Theory*

The concept of Public Service Motivation (PSM) has been considered a crucial factor in the development of effective public administration. This concept refers to an individual's desire to serve the public and contribute to society (Mussagulova et al., 2021; Pratama et al., 2024). Originally known as a concept for understanding employee motivation, PSM has now become an important framework for improving organizational outcomes and analyzing the normative power of civil servants (Klatt & Fairholm, 2022).

PSM has different dimensions, such as interest in the idea of public policy making, commitment to the public interest, empathy, and self-sacrifice. (H. Lee & Lee, 2021; Rafique et al., 2021). Although these dimensions can drive innovative behavior and psychological empowerment, their influence may vary depending on the cultural and organizational context (Rafique et al., 2021).

Variabel Utama	*Dimensi PSM*	*Indikator (Konstruk Pengukuran)*	*Referensi Jurnal*

Kinerja Pegawai (Kinerja ASN)	**Ketertarikan pada Kebijakan Publik *(Attraction to Public Policy)***	Partisipasi aktif dalam merumuskan solusi atas masalah publik	Rafique et al. (2021)
		Antusiasme dalam mengimplementasikan kebijakan program pemerintah	Pratama et al. (2024)
	Komitmen pada Kepentingan Publik *(Commitment to Public Interest)*	Penempatan kepentingan masyarakat di atas kepentingan pribadi/golongan	Molines et al. (2021)
		Dedikasi tinggi dalam menuntaskan target pelayanan institusi	Klatt & Fairholm (2022)
	Rasa Empati dalam Pelayanan (*Compassion*)	Kepekaan emosional terhadap keluhan dan kesulitan masyarakat	Rafique et al. (2021); Potipiroon (2024)
		Pemberian layanan yang humanis dan tidak diskriminatif	Lee & Na (2023)
	Kerelaan Pengorbanan Diri *(Self Sacrifice)*	Kesediaan menyelesaikan tugas ekstra di luar jam kerja normal	Fareed & Su (2021)
		Kesigapan bertugas melayani warga meski dalam kondisi berisiko (krisis)	Lee & Na (2023)

Tabel 1. Operationalization Matrix of Employee Performance Dimensions Based on Public Service Motivation Theory.

The importance of PSM can be seen from the improvement in civil servant performance, service quality, and work engagement (Alamri, 2023; Fareed & Su, 2021). Transformational leadership can increase PSM, which in turn results in successful public projects (Fareed & Su, 2021). PSM plays a vital psychological role in building organizational readiness for change and this role serves as a bridge connecting various leadership strategies and realized employee performance (Alamri, 2023).

In addition to leadership, PSM is also significantly influenced by other factors such as institutional socialization, organizational support, and relational job characteristics such as job contact and impact. While not without negative effects, high PSM can lead to burnout, job stress, and negative responses to psychological contract breaches (Bright, 2021; Zhang & Liu, 2023). Other studies also show that public altruism has a distinct “dark side” (Bright, 2021; Zhang & Liu, 2023).

Structural variations in PSM can vary depending on the cultural context. For example, in certain non-Western administrative systems, it may be observed that higher turnover intentions are associated with higher PSM, thus challenging the universalist assumption (Roach et al., 2021).

2.2 Performance Synthesis ASN

Previous research in Scopus journal articles has shown that conducting quantitative evaluations is the most effective way to identify the various factors that influence a person's competence. This method can then be used to identify areas for improvement by outlining the

various dimensions of a person's competence, such as technical, managerial, behavioral, and social competence, which can help identify which factors contribute most to public service performance (Ng et al., 2024; Yu et al., 2021). This method aligns with the human capital analytical framework that focuses on the relationship between institutional performance and structured competencies (Baumann & Wilson, 2024; Blaique et al., 2023; Taylor et al., 2024).

In response to the increasing complexity of public services, the following journal article by Fahmi and Vera highlights the importance of aligning professional competencies with the changes brought about by digital transformation. This method can be used to design strategies to improve public service performance (Fahmi et al., 2023; Vera & Vicent, 2024).

According to various theories that have been integrated into one, the technical abilities of civil servants are driven by the fulfillment of their basic psychological needs, such as autonomy, relatedness, and competence (Baumann & Wilson, 2024; Vera & Vicent, 2024). This concept suggests that employee motivation and empowerment can influence the development and implementation of effective competency programs. Studies have shown that integrating empowerment and Self-Determination Theory components into a performance architecture can help both private and public sector organizations improve their performance. These findings support the notion that psychological factors can contribute to a more comprehensive performance structure (Fossen et al., 2024; Tweneboah-Koduah et al., 2022).

The concept of Public Service Motivation (PSM) has transformed into a vital component in assessing the performance of Civil Servants (ASN). PSM is conceptualized as an individual's drive to serve the public interest, deeply rooted in institutional values (Klatt & Fairholm, 2022; Pratama et al., 2024). The positive effects of PSM on public service performance can be seen in various ways. These include the quality of services provided and the successful implementation of government projects (Fareed & Su, 2021). Key characteristics of PSM, such as altruism, normative orientation, and willingness to sacrifice, can help motivate civil servants and increase their job satisfaction and work engagement even in challenging situations, such as the pandemic (Alamri, 2023; S. Lee & Na, 2023).

The performance measurement framework uses the PSM construct by examining its various dimensions, such as interest in policymaking, commitment to the public interest, empathy, and self-sacrifice (Molines et al., 2021; Rafique et al., 2021). These dimensions significantly influence the psychological empowerment and innovative behavior of civil servants.

There is a need to establish a more standardized and cost-effective global measurement framework that can be used as a managerial alternative to assess public sector performance and demonstrate that the system does more than just collect quantitative data (S. Lee & Na, 2023; Rafique et al., 2021).

3. METHODS

This study maps the dynamics of civil servant performance using a quantitative research design with a descriptive-analytical approach. Through this method, this paper can explain how the profile of each theoretical dimension contributes to the formation of worker behavior in the

field, without a tendency to test the cause-and-effect relationship between variables. Employee performance measurement is conducted using the Public Service Motivation (PSM) framework. This is a highly accurate conceptual tool that can be used to analyze the strength of intrinsic motivation and performance manifestations among civil servants (Klatt & Fairholm, 2022; Pratama et al., 2024).

The performance variables are broken down into four key essential dimensions that constitute PSM. These include a willingness to make sacrifices, a consistent commitment to the public interest, a willingness to engage in public policy formulation, and empathy in service delivery (Molines et al., 2021; Rafique et al., 2021).

This descriptive mapping allows researchers to identify and measurably capture how each psychological element operates within the local government bureaucratic ecosystem. The Employee Performance variable was measured using a theoretical construct validation approach based on the Public Service Motivation dimension. Instrument testing was conducted using the Pearson Product Moment validity test and Cronbach's Alpha reliability test using SPSS software to ensure the indicators accurately represented the construct. Furthermore, the effectiveness of each dimension was analyzed using the descriptive statistical test of central significance (Mean) to identify the dimensions with the highest and lowest performance.

This study was conducted with 30 civil servants as respondents. The primary data collection process involved the use of a questionnaire, which measured the participants' subjective perceptions. Various procedures were implemented in the data collection process to minimize the possibility of social responsibility bias. This ensured that the data set was representative of civil servant performance.

Quantitative data analysis, tabulation, and processing were conducted using SPSS software. The analytical phase began by testing the validity of the collected data using a bivariate Pearson correlation test. The results of this test were then analyzed to determine whether the questionnaire items accurately represented the theoretical dimensions of PSM. The highest average score on the questionnaire was considered the most accurate construct that could help employees impr\ove their performance, while the lowest average score was considered the least effective. The results of this study will be used to develop future human resource policies aimed at improving organizational performance.

To ensure that the data collected was valid, it was conducted through Populix, a third-party survey platform. This method eliminates social desirability bias and allows respondents to provide honest answers, which is more beneficial than face-to-face surveys. Populix's platform features a variety of features that help ensure the accuracy of the data collected. These include the ability to screen and manage the sample, as well as prevent researcher intervention.

The data analysis of 30 ASN respondents in South Sumatera revealed that the distribution of the sample was targeted and representative in the various public service sectors in the city. The characteristics of the respondents were grouped into one general category, which included those working in public service establishments. The data analysis was carried out through a quota sampling method that ensures that the collected information is not biased because of the dominant institution. The profile of the respondents represents the various active roles that are involved in the transformation of the South Sumatera bureaucracy. The diverse backgrounds of the respondents provided a solid foundation for the researchers to carry out

objective analyses and study the various aspects of the public service sector in South Sumatera. This will help them identify the core competencies and motivation of the city government's personnel.

The study utilized a statistical feasibility standard and efficiency considerations to select 30 respondents for analysis. Although the study authors noted that a larger sample size is needed for complex multivariate procedures, the N=30 threshold is still considered the ideal size to meet the standard for inferential and basic statistical analysis. The objective of this study was to analyze the dynamics of worker motivation using a single variable (Heir, 2019). To provide a comprehensive analysis of the characteristics that affect the ASN populations at the research site, the researchers selected 30 respondents.

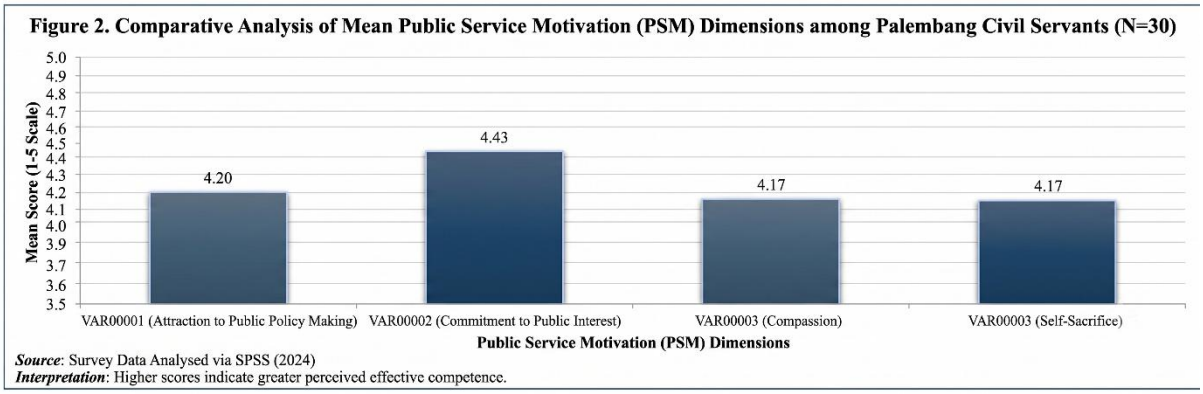
4. FINDING AND DISCUSSION

4.1 Profil Evaluasi Kinerja Berbasis Public Service Motivation

This section presents an empirical elaboration on the dynamics of Employee Performance within the South Sumatra City Civil Service, comprehensively constructed through the theoretical lens of Public Service Motivation (PSM). This performance measurement, rooted in public institutions, is projected to precisely identify the strength of employees' intrinsic motivation in serving the public interest, in line with the postulate that PSM is a fundamental instrument for evaluating and improving the output of public sector organizations (Klatt & Fairholm, 2022; Pratama et al., 2024). The data collected through this filtered digital survey panel mechanism was tabulated for descriptive quantitative analysis to provide an objective picture of the apparatus' performance profile. This operational approach allows researchers to conduct evaluations that go beyond traditional administrative achievement metrics, by examining normative and affective dimensions that reflect the ethos of altruism and personal sacrifice of the apparatus amidst the intense demands of urban bureaucratic service transformation.

4.2 Pemetaan Efektivitas Dimensi Kinerja Secara Deskriptif

Within the framework of descriptive quantitative analysis using SPSS software, the direction of this research's findings centers on a comparison of the central tendency values of four main dimensions that shape PSM: interest in public policy, commitment to the public interest, empathy, and self-sacrifice. Figure 2 (Comparison Graph of Average Values of PSM Performance Dimensions), which will be extracted from the SPSS Descriptive Statistics output, was specifically prepared to visualize which dimensions rank highest and lowest in performance effectiveness. This specific dimension mapping procedure is crucial, given the empirical confirmation from previous studies that each PSM dimension has varying degrees of significance in spurring psychological empowerment and civil servant innovation (Rafique et al., 2021; Molines et al., 2021). Through this comparison of descriptive averages per dimension, the results of this study are designed to contribute a substantial strategic vision; namely, to provide an irrefutable empirical basis for policymakers to design training and human resource development interventions focused on strengthening the performance elements identified as most deficient in the field.



Gambar 1. Grafik Perbandingan Nilai Rata-rata Dimensi Kinerja PSM

4.3 Results

Based on a descriptive analysis of 30 civil servant respondents in South Sumatra, it was found that all dimensions of public service motivation had very positive results, with average scores above 4.00. This indicates that civil servants in Palembang City have a high level of motivation in carrying out their roles.

The Commitment to the Public Interest variable (variable 2) recorded the highest average score of 4.43 with a standard deviation of 0.568. This figure indicates that this dimension is the most dominant and consistent (most stable) construct in shaping employee performance, with a high level of uniformity in perceptions among respondents. The next-highest score was Participation in Solutions (variable 2) with an average score of 4.20 and a standard deviation of 0.664.

Meanwhile, variables 3 (Emotional Sensitivity) and 4 (Willingness to Work Outside of Office Hours) recorded the same average score of 4.17. However, there were significant differences in the variability of respondents' perceptions. The Compassion variable has a standard deviation of 0.698, while the Self-Sacrifice variable shows a higher standard deviation of 0.833. The higher standard deviation value for the Self-Sacrifice variable indicates a greater diversity of views or fluctuations in perception among civil servants regarding this dimension compared to other dimensions.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
VAR00001	30	3.00	5.00	4.2000	.66436
VAR00002	30	3.00	5.00	4.4333	.56832
VAR00003	30	3.00	5.00	4.1667	.69893
VAR00004	30	2.00	5.00	4.1667	.83391
Valid N (listwise)	30				

Tabel 2. Statistik Deskriptif

Theoretically, these results confirm that although public service motivation is at an excellent level overall, there are differences in effectiveness across dimensions. The Commitment-Public Interest variable serves as a key pillar, while the Self-Sacrifice variable requires further managerial attention to reduce the perception gap among employees, thereby achieving more equitable performance improvements.

4.4 Discussion and Findings

These findings reveal the phenomenon of 'Motivational Asymmetry', where ASN structural commitment is at a very high level, but resilience capacity (self-sacrifice) shows wide variance in perceptions. This indicates that performance is not solely driven by public values, but by the organization's readiness to provide equitable contextual support. Unlike previous studies that tend to generalize ASN training, this study introduces a 'Dimensional Profile-Based Diagnostic Model'. By mapping PSM profiles, public agencies can shift from generalist training to precision training that targets dimensions with high perceived variance, thereby increasing fiscal efficiency in competency development.

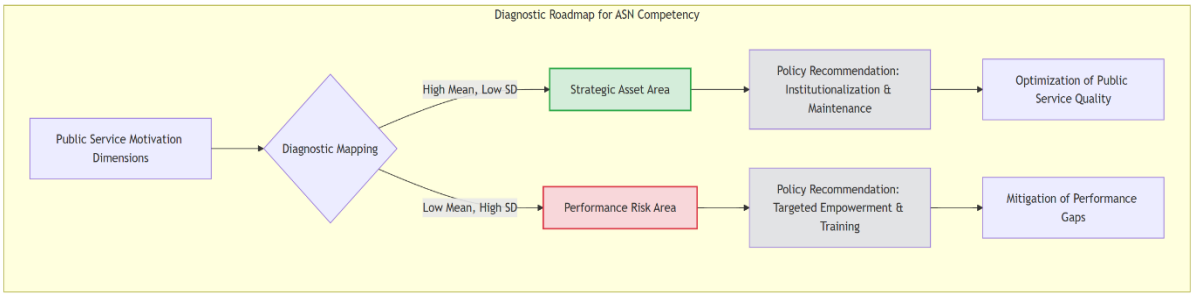


Figure 2. Policy Roadmap for Civil Servants

Unlike conventional studies that treat ASN competencies as a single, homogeneous entity, this study introduces a 'Multi-Tiered Diagnostic Roadmap'. This model dissects competency dimensions not only in terms of average achievement (mean) but also in terms of dispersion (standard deviation). Our findings indicate a motivational asymmetry where certain dimensions function as 'Strategic Asset Areas' (high mean scores with solid perception consistency), while others are categorized as 'Performance Risk Areas' (low mean scores with wide perception variability). This diagnostic model provides both theoretical contributions to the development of public HR theory and practical contributions in the form of fiscal efficiency in training design; instead of allocating budgets to generalist training, city governments can use this model to precisely target empowerment interventions on dimensions with high perception variance, effectively closing performance gaps.

5. Conclussion

This study concludes that, in aggregate, State Civil Apparatus (ASN) in Palembang City have a very adequate level of Public Service Motivation (PSM) as a foundation for public service. Based on the results of the descriptive quantitative analysis, the Commitment to the

Public Interest dimension was identified as the most dominant and consistent driver of performance among civil servants. Conversely, although the Self-Sacrifice dimension had a positive average value, the high level of variation in perceptions within this dimension indicates a vulnerability that requires further attention. This finding confirms that civil servants' mental readiness and dedication to face bureaucratic transformation are not evenly distributed across their basic motivational dimensions.

The main novelty of this study lies in the identification of the phenomenon of "Motivation Asymmetry" through a Multi-Tiered Diagnostic Roadmap approach. Unlike the common practice of previous studies that measure performance effectiveness solely by the height of the average (mean) value, this study examines competency quality by incorporating data dispersion analysis (standard deviation). Through this diagnostic model, public agencies can map motivational dimensions into two policy quadrants: the Strategic Asset Area for dimensions with high scores and low variability that institutions must maintain, and the Performance Risk Area for dimensions with wide fluctuations in perception. This approach transforms static descriptive data into a dynamic prescriptive framework.

Practically, this diagnostic framework offers substantial managerial implications for local governments. Policymakers can shift from a generalist training paradigm—which is often fiscally inefficient—to precision empowerment interventions. By targeting human resource development programs specifically on dimensions identified as performance risk zones, city governments can mitigate competency gaps in civil servants in a more measurable manner.

As a study with a focused, descriptive quantitative approach, this research is limited by its sample size and specific geographic location. Therefore, future research is expected to expand the Multi-Tiered Diagnostic Roadmap model using multivariate analysis at a cross-regional population scale. This will further enrich the literature on public sector management, particularly in formulating strategies for developing the capacity of state civil servants in the modern bureaucratic era that demands high agility and resilience.

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EVALUATION OF THE EFFECTIVENESS OF CREDIT RISK CONTROL POLICIES AT PT BANK PEREKONOMIAN RAKYAT PALEMBANG (BANK PALEMBANG)

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Abstract

Credit distribution is the largest revenue contributor for banks. Bank Palembang, as a Regionally-Owned Enterprise, is required to apply the prudential banking principle to maintain the bank's soundness. This study aims to evaluate the implementation and effectiveness of credit risk control policies implemented by Bank Palembang, and analyze this effectiveness when measured through the compliance function. This study uses a descriptive evaluative design with a qualitative approach. Primary data were obtained through in-depth interviews with several key informants, including the Director in charge of the Compliance function, the Risk Management Executive Officer, the Internal Supervisory Unit, credit managers, and Account Officers. Secondary data were obtained through analysis of internal policy documents, Standard Operating Procedures, risk management reports, and Financial Services Authority regulations. The results of the study indicate that the credit risk identification process at Bank Palembang has been carried out systematically and quite effectively through the application of 5C analysis (Character, Capacity, Capital, Condition, Collateral), document verification, and field surveys. Risk measurements reflected in financial ratios indicate the level of Non-Performing Loans and Capital Adequacy Ratio are in the healthy and safe category in accordance with the limits of OJK regulations. In terms of the Loan to Deposit Ratio, the bank faces liquidity challenges due to higher credit distribution expansion compared to the collection of third-party funds. However, operational challenges are still found in the form of administrative deviations in the form of deviation memos on debtor age limits, potential fraud risks, and external macroeconomic factors that require stricter supervision. Overall, the credit risk control policy at Bank Palembang is evaluated as being in the fairly effective category, but requires continuous optimization in strengthening human resources, integrating risk culture, and increasing the effectiveness of internal supervision.

Keywords: Banking Governance, Compliance Function; Credit Risk Control Policy; Credit Risk Management; Risk Management Effectiveness; Rural Bank.

INTRODUCTION

Banks and financial institutions play a crucial role in enhancing economic development. Economic growth is inextricably linked to the role of banks and financial institutions, which drive a country's economy (Nguyen 2022). According to (Ajabnoor and Fatima 2022), a bank is a financial institution whose activities involve collecting and distributing funds to the public, this fund-sharing activity, better known as credit distribution, is a bank's effort to boost economic growth. The loans provided can be used to develop businesses for the community, thus enabling banks to play an active role in economic growth. Banking activities themselves carry risks, requiring banks to manage them effectively, banks are required to be institutions capable of controlling potential risks to maintain bank health and improve performance, both for the bank itself and in implementing its role in supporting economic growth (Susalit et al. 2025).

PT Bank Perekonomian Rakyat Palembang (Government-Owned Bank of Palembang City) or better known as Bank Palembang is one of the regionally owned banks whose activities can be a supporting factor in the economic progress in the city of Palembang. Efforts to increase regional economic growth, Bank Palembang is one of the banks that provides loans to the people of Palembang city with its products namely Civil Servant Credit, Certification Credit, Agricultural Credit and MSME Credit. This credit distribution activity is a risky business where Bank Palembang is required to distribute credit to the community while always paying attention to the principle of prudence in risk management.

According to (Yuktadatta et al. 2022), a general understanding is that risk can cause problems but can also bring profitable opportunities, risk also relates to the possibility (probability) of losses that will cause problems. Risk is a significant issue because the exact nature of the resulting losses cannot be accurately predicted (Zweifel 2021). In this paper, the problem to be studied at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) is the effectiveness in controlling credit risk where there are indications of deviations from the applicable credit SOP at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) such as the Debtor's age has entered 60 years while in the credit SOP of PT Bank Perekonomian Rakyat Palembang (Bank Palembang) the maximum age is 58 years. The credit department at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) continues to process the Debtor's credit application by using a deviation memo on the grounds that the Debtor is an old customer at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) who is applying for an additional credit ceiling and credit tenor (Credit Top up).

Credit activities in the banking world have a big influence on the level of bank growth because the biggest source of income for banks is the large amount of credit they provide (Beck et al. 2023). Credit that provides this benefit if in its implementation the bank is unable to carry out the distribution process properly, which can lead to credit risk. Banking players are required to carry out better credit procedures in verifying their prospective customers. According to (Nur Izati, Satria Lesmana, and Anwar 2025) Credit risk arises as a result of bad credit or Non-Performing Loans (NPL). The health of a bank can be measured by the level of credit health. If the Non-Performing Loans (NPL) are high, this can also affect the bank's health level.

Previous research that discussed the implementation of risk mitigation, such as research from (Maysara 2021), entitled Effectiveness of Implementation of Problematic Financing Risk Mitigation at PT Bank Syariah Indonesia KC Bandarjaya with the results of the research, namely the conclusion that the implementation of problem financing risk mitigation at Bank Syariah Indonesia KC Bandarjaya carries out a risk mitigation process with risk identification, risk measurement, risk monitoring and risk control. Meanwhile, the author's research here is different from previous research, where the author discusses the Evaluation of the Effectiveness of Credit Risk Control with the object at the Palembang People's Economic Bank (Palembang Bank).

Based on the provisions of the Financial Services Authority (OJK), specifically Regulation No. 23/POJK.03/2018 concerning the Implementation of Risk Management for Rural Banks (BPRs), Rural Banks are required to maintain the quality of productive assets and implement effective risk

management (Zahri, Busra, and Nasir 2023). Furthermore, the OJK stipulates that a healthy NPL ratio for Rural Banks is a maximum of 5%. During the 2020–2022 period, PT Bank Perekonomian Rakyat Palembang's NPL ratio remained above the maximum limit set by the Financial Services Authority (OJK), thus categorizing it as not meeting bank health standards in terms of credit risk. This condition indicates that the bank faced a relatively high credit risk during that period. However, in 2023–2024, the Non-Performing Loan (NPL) ratio showed a significant decline, although in 2024 the Non-Performing Loan (NPL) ratio remained slightly above the OJK's requirements, at 6.63%. Nevertheless, this downward trend demonstrates ongoing efforts to improve the implementation of credit risk management in accordance with OJK regulations.

METHOD

The object of this research is PT Bank Perekonomian Rakyat Palembang (Bank Palembang), which is a financial institution that carries out the main function of collecting and distributing public funds and PT Bank Perekonomian Rakyat Palembang (Bank Palembang) is one of the Regional Owned Enterprises (BUMD) of Palembang City. PT Bank Perekonomian Rakyat Palembang (Bank Palembang) is located at Jalan Sukarno Hatta No. 10 Rt. 048 Rw. 010, Demang Lebar Daun Village, Ilir Barat I District, Palembang. This study uses a descriptive evaluative research design with a qualitative approach. This design also aims to describe in depth how risk control policies are implemented and evaluate their effectiveness in minimizing operational risk, compliance risk, and credit risk at PT Bank Perekonomian Rakyat Palembang (Bank Palembang).

This study uses two types of data: (i) Primary data was obtained directly from informants involved in implementing risk control at Bank Palembang through: Interviews with the Director in charge of Compliance, the Risk Management Executive, the Internal Audit Unit (SPI), the credit department, and other operational units involved in the day-to-day risk control process. Observations: Operational activities related to risk control, Field notes: Made during the interviews and observations. (ii) Secondary data was obtained from documents and literature supporting the research, including: bank Palembang's risk control policy document, the bank's internal SOPs related to risk control procedures, risk management reports and Internal Supervisory Unit (SPI) reports, OJK regulations related to BPR risk management, and academic literature, journals, and publications relevant to risk management and bank policy evaluation. Table 1 show population this study.

Table 1. Parties Involved

No	Activity	Parties Involved
1	Credit Risk Policy Development	1. Board of Directors 2. Executive Officer for Risk Management, Compliance, and Anti-Money Laundering – Countering the Financing of Terrorism
2	Credit Risk Policy Implementer	1. Credit Manager and all Account Officers 2. Credit Support Manager and Staff 3. Operations Manager
3	Credit Risk Policy Supervisor	1. Director in charge of the compliance function 2. Audit Executive Officer (PE)
4	Credit Risk Policy Evaluation	1. Board of Directors 2. Board of Commissioners 3. Executive Officer for Risk Management, Compliance, and Anti-Money Laundering – Prevention of the Financing of Terrorism

		4. Executive Officer for Audit

The technique for determining informants is purposive sampling, namely the deliberate selection of informants based on their roles and knowledge regarding risk control (Dias 2024). Informants this research are Board of Directors, Executive Officer, Audit Executive Officer (PE), Operations Manager, Credit Support Manager, and Credit Manager and Account Officer. Table 2 show variable this research.

Table 2. Variable This Research

Variable	**Operational Definition**	**Indicator**	**Data Source**	**Collection Techniques**
Risk Control Policy (X)	All forms of credit risk management policies, guidelines, procedures and mechanisms implemented to identify, measure, monitor and control risks in accordance with POJK No. 18/POJK.03/2016	1. Written credit risk policy 2. Credit SOP 3. Credit risk mitigation guideline 4. Credit risk monitoring system	Internal documents of PT Bank Perekonomian Rakyat Palembang (Bank Palembang), leadership interviews and risk management	Documentation and Interviews
Policy Effectiveness (Y)	The degree of success of risk control policies in achieving objectives: reducing risk, maintaining compliance, and increasing operational stability.	Input: Human resources, SOPs, regulations Process: Policy implementation, supervision, compliance Output: Risk reduction, efficiency improvement, compliance with the Financial Services Authority (OJK)	Interviews, risk reports, audit reports, observations	Interviews, observations, documentation

The research used analysis model, which consists of three stages:

1. Data Reduction:

- Sorting important data from interviews, observations, and documents
- Grouping data into themes: policy input, process, and output
- Eliminating irrelevant data

2. Data Presentation
   - Organizing data in narrative, tabular, and matrix form
   - Presenting policy evaluation results according to informants
   - Comparing implementation with OJK guidelines
3. Conclusion Drawing
   - Assessing whether risk control policies are effective
   - Identifying constraints and recommendations for improvement
   - Verification through triangulation

FINDINGS AND DISCUSSION

Based on interviews with the Director in charge of Compliance, the Executive Officer (PE) for Risk Management, Compliance, and Anti-Money Laundering – Prevention of the Financing of Terrorism (AML-CFT), the Credit Manager, the Account Officer (AO), and Credit Support at PT Bank Perekonomian Rakyat Palembang (Bank Palembang), a comprehensive credit risk identification process is conducted before credit is granted to prospective borrowers. This process aims to minimize the possibility of non-performing loans (NPLs). In its implementation, Bank Perekonomian Rakyat Palembang (Bank Palembang) applies prudential banking principles through the implementation of 5C analysis, field surveys, document verification, and internal supervision guided by standard operating procedures (SOPs) and regulatory requirements.

The interview with the Director in charge of compliance explained that credit risk identification is carried out based on a clear organizational structure, standard operating procedures (SOPs), and division of duties. This demonstrates that credit risk identification is not solely carried out by the credit department, but also involves the compliance, internal audit, and risk management functions. Furthermore, the Director of Compliance stated that the compliance function has the authority to ensure that all credit processes comply with regulations and terminate credit processes if they do not. This statement demonstrates that credit risk identification is carried out from the initial stages of a credit application to prevent procedural irregularities.

Based on interviews with the Executive Officer (PE) for Risk Management, Compliance, and Anti-Money Laundering – Prevention of the Financing of Terrorism (APU-PPT), the risk identification process is conducted in accordance with the provisions (POJK, 2016) and SEOJK regarding BPR risk management. Identification begins with mapping BPR business activities, including microcredit products, using a risk matrix and analyzing internal factors such as human resources, IT systems, and operational processes. In the credit risk identification process, Bank Perekonomian Rakyat Palembang (Bank Palembang) maps inherent risks, particularly for debtors with large loan amounts or business sectors with high risk levels. The Executive Officer (PE) for Risk Management, Compliance, and Anti-Money Laundering – Prevention of the Financing of Terrorism (APU-PPT) also explained that the bank classifies risks based on probability and impact using a specific scale.

Furthermore, based on the results of interviews with Credit Managers and Account Officers (AO), credit risk identification is carried out through the application of the 5C principle, namely Character, Capacity, Capital, Condition, and Collateral.

1. Character
   Character assessments are conducted to determine a prospective borrower's good faith in fulfilling their credit obligations. The assessment is conducted through credit history checks, interviews, and

data verification. Character can be determined through track records, bank checks (SLIK), bank statements, data validation, and interviews. The Account Officer (AO) also explained that character is the most dominant factor influencing non-performing loans. Generally speaking, the most common trigger for NPLs is character, because if a borrower's character is good, they will be more cooperative in fulfilling their obligations.

2. Capacity
   Banks analyze prospective borrowers' ability to repay credit obligations based on income and business conditions. Capacity assessments are based on the prospective borrower's current and future financial ability to repay their obligations on time. Capacity assessments are conducted through cash flow analysis, income analysis, and direct field observations.
3. Capital
   Capital analysis is conducted to determine the debtor's financial capability to run their business. The greater the debtor's capital, the more likely they are to demonstrate their commitment and ability to maintain their loan repayments. This demonstrates that business capital is an important indicator in identifying credit risk.
4. Condition
   Banks also consider the debtor's economic conditions and business prospects before granting credit. The debtor's business prospects are assessed based on financial condition, economic growth, viable business sectors, and sluggish sectors. This assessment is conducted to identify potential risks that could impact the debtor's future repayment capacity.
5. Collateral
   Collateral is used as a form of credit security in the event of default. Collateral's important functions for banks include security, legal certainty, risk reduction, and loan amount determination. In the credit risk identification process, the legality and economic value of collateral are also primary concerns for banks. In addition to implementing the 5Cs principle, PT Bank Perekonomian Rakyat Palembang (Bank Palembang) also conducts field surveys and document verification to ensure the accuracy of prospective borrowers' data.

Overall, the interview results indicate that credit risk identification at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) has been systematically conducted through the application of the 5C principles, field surveys, document verification, compliance monitoring, and interdepartmental coordination. However, several obstacles remain, such as the risk of fraud, indiscipline, conflicts of interest, and changes in economic conditions that can impact the bank's credit quality.

Discussion

1. Effectiveness of Credit Risk Control Implementation at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) Measured Through the Compliance Function.

Based on research findings and interviews, credit risk control at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) has been implemented through the compliance function, which ensures all credit activities comply with the bank's internal provisions and applicable regulations. The compliance function is responsible for overseeing the credit granting process, monitoring credit quality, and ensuring that all credit decisions comply with prudential banking principles.

The effectiveness of credit risk control can be seen in the existence of clear procedures for credit analysis, credit approval, credit monitoring, and the handling of problem loans. In its implementation, the compliance function and internal audit regularly review credit documentation, ensure compliance with Standard Operating Procedures (SOPs), and ensure the credit process aligns with the bank's established credit risk management policies.

The research indicates that the compliance function has been quite effective in identifying potential credit risks from the initial stages of a credit application. This is reflected in the process of verifying

debtor data, analyzing repayment capacity, assessing collateral, and implementing the 5Cs (Character, Capacity, Capital, Collateral, and Condition) in credit disbursement. The application of these principles helps banks minimize the likelihood of non-performing loans.

Furthermore, the compliance and internal audit functions also monitor the quality of disbursed loans through credit collectibility monitoring and regular reporting to management. With continuous oversight, banks can take risk mitigation measures more quickly if any indication of a decline in a borrower's credit quality is detected.

However, several obstacles remain that can impact the effectiveness of credit risk control, such as changing borrower economic conditions, late installment payments, and other external factors beyond the bank's control. Therefore, the compliance function needs to continuously improve oversight and coordination with business units and risk management to optimize credit risk control.

Based on the analysis, it can be concluded that the implementation of credit risk control through the compliance function at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) has been effective. This is demonstrated by the existence of supervisory, monitoring, and evaluation mechanisms that support the application of prudential principles in credit activities, thereby helping to minimize the risk of losses due to non-performing loans.

2. Credit Risk Control Policy Implemented at PT Bank Perekonomian Rakyat Palembang (Bank Palembang)

The credit risk control policy implemented by PT Bank Perekonomian Rakyat Palembang (Bank Palembang) serves as a guideline for credit operations to maintain the quality of productive assets and minimize potential losses arising from the risk of debtor default. This policy adheres to regulatory provisions and the risk management principles applicable to Bank Perekonomian Rakyat. In its implementation, the credit risk control policy encompasses several stages: the credit application process, credit analysis, credit approval, credit disbursement, credit monitoring, and resolution of problem loans. Each stage has procedures and controls that must be adhered to by all parties involved in the credit process. During the credit analysis stage, the bank applies the 5C principle as the basis for assessing the creditworthiness of prospective borrowers. This analysis aims to ensure that credit is granted to borrowers who have the ability and willingness to fulfill their payment obligations under the credit agreement. Furthermore, the bank assesses collateral provided as a form of risk mitigation in the event of default.

Furthermore, the credit risk control policy is implemented through the separation of functions between those responsible for credit marketing, credit analysis, and those providing credit approval. This separation of functions aims to avoid conflicts of interest and enhance objectivity in credit decision-making. To maintain the quality of disbursed credit, the bank regularly monitors business developments and debtors' repayment capacity. This monitoring is carried out through credit collectibility evaluations, debtor visits, and reviews of the debtor's business condition, if necessary. If any indication of credit quality decline is detected, the bank will take preventive measures such as debtor guidance, credit restructuring, or other credit rescue measures in accordance with applicable regulations.

Based on research findings, the credit risk control policy implemented by PT Bank Perekonomian Rakyat Palembang (Bank Palembang) adequately supports the implementation of credit risk management. This policy provides clear guidelines for all work units in managing credit risk and assists the bank in maintaining the quality of its credit portfolio. Therefore, the credit risk control policy implemented by PT Bank Perekonomian Rakyat Palembang (Bank Palembang) can be said to be in accordance with prudential principles and plays a crucial role in supporting the effectiveness of credit risk control and maintaining the bank's operational stability.

CONCLUSION

Based on the research results regarding the Evaluation of the Effectiveness of Credit Risk Control Policies at PT Bank Perekonomian Rakyat Palembang (Bank Palembang), the following conclusions can be drawn: (i) Credit risk identification at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) has been carried out systematically and effectively through the application of prudential banking principles, 5C analysis (Character, Capacity, Capital, Condition, and Collateral), field surveys, document verification, and internal oversight. The risk identification process also involves various departments such as the compliance function, internal audit, risk management, Account Officers (AO), and the credit support department. However, several obstacles remain, such as the risk of fraud, data manipulation, conflicts of interest, and external factors such as economic conditions that can impact credit quality.

(ii) Credit risk measurement at Bank Palembang is carried out using financial ratio indicators, namely Non-Performing Loans (NPL), Capital Adequacy Ratio (CAR), and Loan-to-Deposit Ratio (LDR). The research results show that the NPL value remains below the maximum limit of 5% as stipulated by the Financial Services Authority (OJK), thus the bank's credit condition remains healthy. The CAR value indicates that the bank has a very good level of capital adequacy to cover the risk of losses. However, the LDR value indicates that credit disbursement is higher than the collected third-party funds, potentially increasing liquidity risk if not balanced with optimal fund management.

(iii) Credit risk control at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) has been implemented through the implementation of SOPs, credit monitoring, risk-based internal audits, compliance supervision, inter-departmental coordination, and strengthening human resource quality and a risk culture. These controls are implemented to maintain credit quality and minimize the occurrence of non-performing loans. Overall, the credit risk control policy at PT Bank Perekonomian Rakyat Palembang (Bank Palembang) can be considered quite effective, supported by a healthy NPL level and strong capital capacity. However, the bank still needs to improve internal oversight and human resource quality to anticipate fraud risks and credit risks due to changing economic conditions.

PT Bank Perekonomian Rakyat Palembang (Bank Palembang) is advised to continue improving the quality of its credit risk identification process by strengthening debtor data verification, increasing the accuracy of credit analysis, and optimizing oversight of potential fraud and data manipulation. Furthermore, improved coordination between Account Officers (AO), the credit department, compliance functions, risk management, and internal audit is needed to ensure early detection and mitigation of potential credit risks before credit is disbursed.

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SMART PACKAGING AND SUSTAINABLE FINANCIAL MANAGEMENT: A CONCEPTUAL FRAMEWORK FOR GREEN POLICY IMPLEMENTATION IN THE PACKAGING INDUSTRY

Research Area: Green Finance • Sustainable Management • Smart Technology
JEL Classification: G30 | G38 | L65 | Q01 | Q58

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Abstract

This systematic literature review examines the conceptual intersection of smart packaging technologies, sustainable financial management, and green policy implementation within the packaging industry. Adopting a PRISMA-based narrative synthesis protocol (Page et al., 2021), this study analysed 87 peer-reviewed articles and institutional reports published between 2015 and 2024, sourced from Scopus, Web of Science, Google Scholar, and SSRN. The findings reveal that, while research on smart packaging and green finance has independently matured, their conceptual integration within a unified green policy framework for the packaging sector remains substantially underexplored. Drawing on Stakeholder Theory, Signaling Theory, Institutional Theory, and the Resource-Based View (RBV), this paper constructs a three-pillar integrative conceptual framework linking smart packaging adoption (SP), green policy implementation (GPI), and sustainable financial management (SFM). Five research propositions are derived, emphasising: (1) the facilitative role of smart packaging in regulatory compliance; (2) the transformative impact of green policy on corporate financial structures; and (3) the mediating function of governance, risk, and compliance (GRC) systems in translating policy pressure into sustainable financial performance. Six research gaps are identified concerning: conceptual integration, empirical evidence from ASEAN markets, GRC mediation, standardised measurement instruments, longitudinal dynamics, and mixed-method design. The proposed framework offers a robust theoretical foundation for future empirical investigation using panel data and structural equation modelling (SEM) across ASEAN packaging firms.

Keywords: *smart packaging; sustainable financial management; green policy; ESG; packaging industry; ASEAN; systematic literature review*

1. Introduction

The global packaging industry confronts an unprecedented dual pressure: escalating demand for technology-driven innovation on one side, and intensifying calls for environmental sustainability on the other. The global packaging market is projected to reach USD 1.2 trillion by 2028 at a CAGR of 4.1% (Pereira et al., 2020; Verma et al., 2024), while the volume of plastic packaging waste has reached 146 million tonnes per year and continues to rise (UNEP, 2023). This paradox an industry growing rapidly while simultaneously constituting one of the largest sources of environmental crisis renders the

packaging sector the most relevant laboratory for examining how technological innovation, green policy, and financial management can be integrated coherently (Angela & Rusmanto, 2025; Foschi & Bonoli, 2019; Khalid et al., 2024).

This paradigm shift carries profound financial implications that have been systematically overlooked in the literature. Green regulations from Extended Producer Responsibility (EPR) schemes to carbon pricing mechanisms are progressively tightening environmental standards for packaging manufacturers worldwide, including across the ASEAN region (Korhonen et al., 2018; UNEP, 2023). Growth in the global green bond market to USD 487 billion in 2022 (Climate Bonds Initiative, 2023) and ESG-mandated assets exceeding USD 53 trillion globally (Bloomberg Intelligence, 2023) confirm that the financial dimension of the green transition has become a mainstream consideration in corporate decision-making. Nevertheless, these regulatory and capital market pressures have not been matched by a conceptual framework in the academic literature capable of linking the three dimensions packaging technology, green policy, and sustainable financial management in an integrated and operationally useful manner (Boz et al., 2020; Ioannou & Serafeim, 2017; Lau & Wong, 2024).

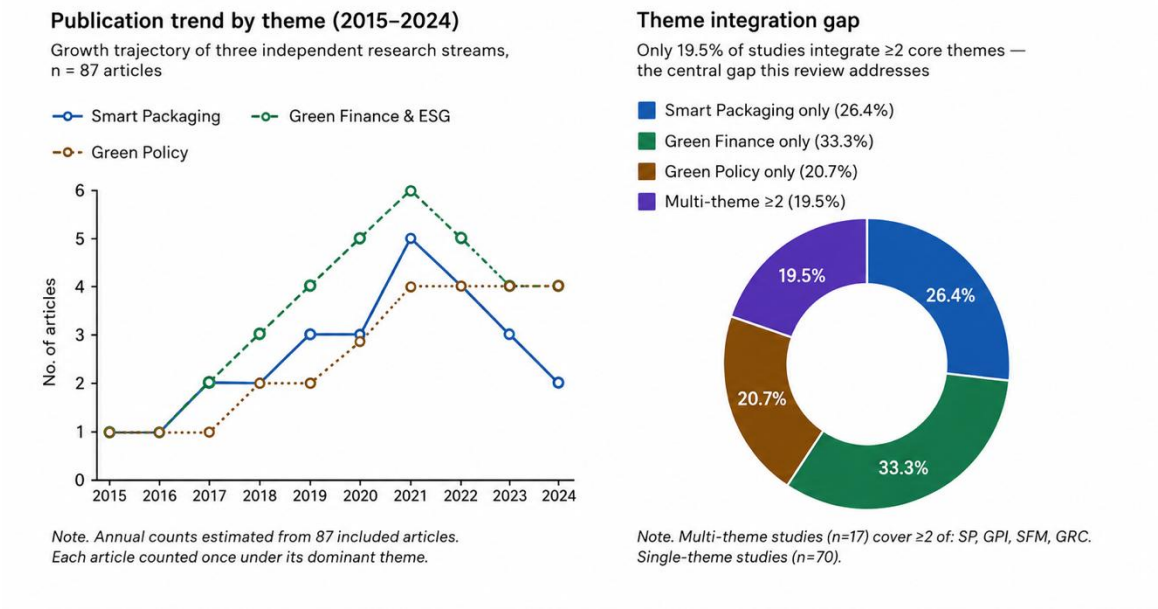
This gap is not merely an abstract academic deficiency. Financial managers of packaging firms currently face complex decisions: will investments in RFID-based smart packaging or biodegradable materials improve or reduce financial performance in the medium term? What is the optimal green bond structure to finance packaging technology transformation? To what extent does EPR compliance contribute to cost-of-capital reduction through improved ESG scores? These operational questions cannot be answered by the extant literature because three relevant research streams smart packaging, green finance, and green policy have developed independently in their respective silos without a coherent point of integration (Daugaard & Ding, 2022; Murugesan & Li, 2026).

A systematic analysis of 87 articles published between 2015 and 2024 reveals a consistent and concerning pattern: only 19.5% of the studies integrate more than one core theme (SP, GPI, or SFM) simultaneously (see Table 1). Green finance studies generally do not consider the specific context of packaging technology, while smart packaging studies almost entirely neglect green financial dimensions and fiscal regulatory implications. This situation creates a serious blind spot: packaging companies make billion-dollar investment decisions without conceptual guidance linking all three dimensions (Agrawal et al., 2023; Kumar, 2023; Santi et al., 2022). The ASEAN region exacerbates this situation, as it is one of the world's largest packaging manufacturing hubs with more than 680 million consumers and highly heterogeneous green regulations across member states yet almost no empirical research specifically examines the SP, GPI, SFM relationship in this context (Putra & Oktora, 2024; Tolliver, 2021; Tripopsakul, 2025).

Tabel 1. Theme Classification of Selected Articles

Theme	Number of Articles	Percentage
Smart Packaging	23	26.4%
Green Finance & ESG	29	33.3%
Green Policy & Circular Economy	18	20.7%
Multi-theme Integration	17	19.5%
Total	87	100%

Source: Author's systematic database search (2026).



Figur 1.Descriptive Mapping of Publication Trends and Theme Integration (n = 87)

Prior studies most closely approaching the integration of these three themes Vanderroost et al. (2017) for smart packaging, Flammer (2021) for green finance, and Korhonen et al. (2018) for green policy each make strong contributions within their own domains, but none constructs a conceptual bridge between all three. Moreover, no available study incorporates a Governance, Risk, and Compliance (GRC) system as the mediating mechanism explaining how policy pressure is translated into financial value at the firm level. The absence of this integrative framework is not solely a function of topical complexity, but reflects the lack of a systematic attempt to build one and it is this absence that constitutes the primary justification for the present study.

On the basis of the gap diagnosis above, this literature review pursues three objectives: (1) to identify and systematically synthesise relevant findings from prior research using the PRISMA protocol (Page et al., 2021); (2) to construct a three-pillar integrative conceptual framework linking smart packaging (SP), green policy implementation (GPI), and sustainable financial management (SFM) with GRC as mediator; and (3) to formulate five empirically testable research propositions and identify six

gaps for future research agendas. The study contributes theoretically through the integration of four theories (Stakeholder Theory, Signaling Theory, Institutional Theory, and RBV) within a single explanatory framework, while simultaneously offering practical guidance for financial managers and policymakers in ASEAN who are navigating the transition towards a sustainable packaging industry.

2. Methodology

This literature review employs a systematic narrative review approach based on the PRISMA 2020 protocol (Page et al., 2021). Literature sources were obtained from the Scopus, Web of Science, Google Scholar, and SSRN databases, covering publications from 2015 to 2024, encompassing peer-reviewed journal articles, international institutional reports, and reputable conference proceedings.

2.1 Search Keywords

Searches were conducted using the following keyword combinations (search strings), applied as Boolean queries across the title, abstract, and keyword fields of articles:

- "Smart packaging" AND "green finance" AND "sustainable management"
- "Intelligent packaging" AND "ESG" AND "packaging industry"
- "Green policy implementation" AND "packaging sector" AND "financial performance"
- "Active/intelligent packaging" AND "circular economy" AND "sustainability"
- "Extended Producer Responsibility" AND "financial impact" AND "packaging"
- "Green bond" AND "manufacturing sustainability" AND "Southeast Asia"
- "Sustainable financial management" AND "ASEAN" AND "packaging"

2.2 Inclusion and Exclusion Criteria

Articles were included if they met the following criteria: (1) published in a journal indexed by Scopus or Web of Science at a minimum Q3 ranking; (2) addressing at least two of the three core themes of the review (smart packaging, green policy, and sustainable financial management); (3) employing a clear and replicable methodology; and (4) available in English or Indonesian. Articles were excluded if they were opinion pieces lacking empirical data or adequate methodology, focused on non-packaging industries without transferable conceptual relevance, or exhibited identifiable academic integrity issues.

2.3 Article Selection Procedure

Article selection was conducted in three replicable stages: (i) Identification database searches yielded 412 records; (ii) Screening following deduplication (n = 58 records removed), title and abstract screening excluded 201 records that did not meet relevance criteria; (iii) Eligibility full-text assessment of 153 records eliminated 66 articles due to weak methodology, absence of cross-construct linkages, or inaccessibility of full text. Final total: 87 articles met the inclusion criteria (see Figure 1 for the PRISMA 2020 Flow Diagram).

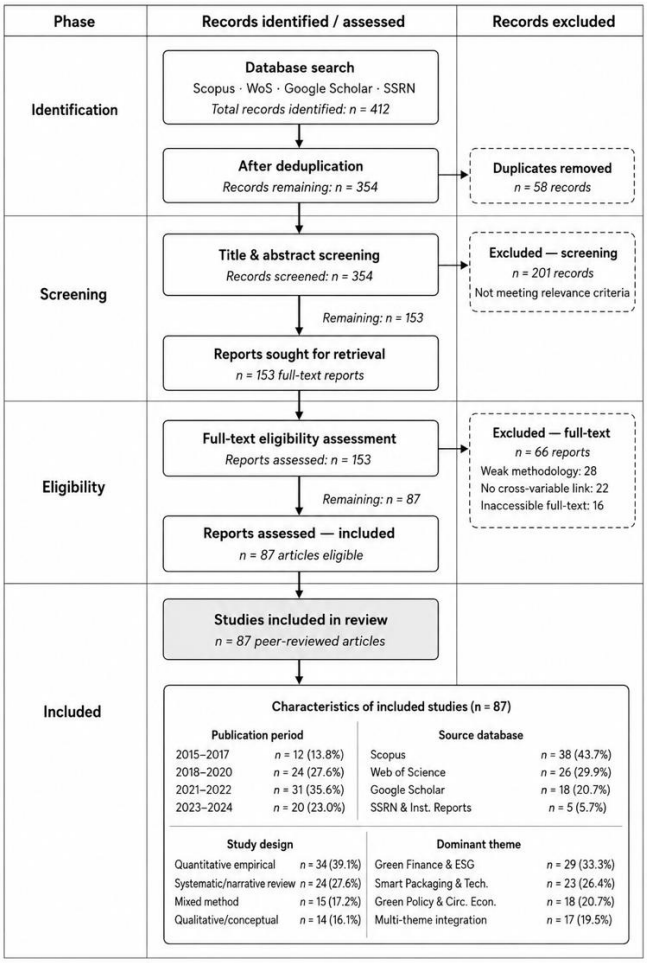


Figure 2. PRISMA Flow Diagram (2026)

2.4 Literature Distribution Characteristics

Table 1 summarises the distribution characteristics of the 87 analysed articles by publication period, source database, study design, geographic focus, and dominant theme. The distribution reveals a concentration in the 2021–2022 period (35.6%), with a dominance of quantitative empirical studies (39.1%) and a global or multi-country geographic focus (33.3%).

Table 2. Distribution Characteristics of Analysed Literature (n = 87)

Characteristic	Category	n	%
Publication Period	2015–2017	12	13.8
	2018–2020	24	27.6
	2021–2022	31	35.6
	2023–2024	20	23.0

Source Database	Scopus	38	43.7
	Web of Science	26	29.9
	Google Scholar	18	20.7
	SSRN & Institutional Reports	5	5.7
Study Design	Quantitative Empirical	34	39.1
	Systematic / Narrative Review	19	21.8
	Mixed Method	15	17.2
	Qualitative / Case Study	11	12.7
	Conceptual / Theoretical	8	9.2
Geographic Focus	Global / Multi-country	29	33.3
	Asia / ASEAN	21	24.1
	Europe	18	20.7
	North America	11	12.7
	Other Regions	8	9.2
Dominant Theme	Smart Packaging & Technology	23	26.4
	Green Finance & ESG	29	33.3
	Green Policy & Circular Economy	18	20.7
	Multi-theme Integration (≥2)	17	19.5

Source: Author's systematic database search (2026). Some articles fall into more than one thematic category; theme percentages are calculated from the total of 87 articles.

All quantitative indicators and performance estimates reported throughout this review are derived from findings presented in the original studies included in the final sample. Variations in industry context, country characteristics, regulatory environments, and methodological approaches may influence the magnitude of reported effects. Therefore, these values should be interpreted as indicative evidence rather than universally applicable benchmarks.

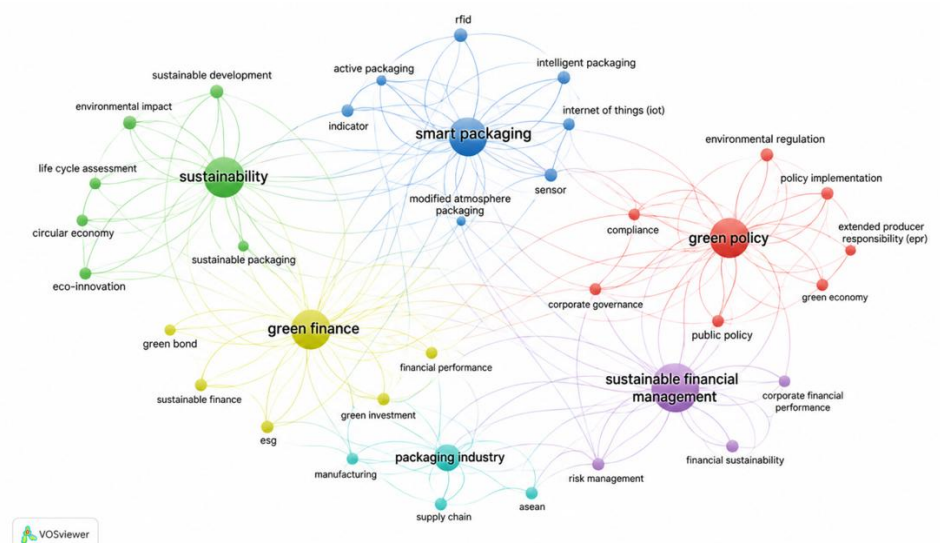


Figure 2. Overlay Visualization of Keyword Co-occurrence Network (2015–2024)

Figure 2 illustrates the bibliometric structure of research on smart packaging, sustainability, green finance, green policy, and sustainable financial management between 2015 and 2024. The visualization reveals five major interconnected clusters, with smart packaging, sustainability, green finance, green policy, *and* sustainable financial management emerging as the dominant research themes. The network demonstrates that technological innovation, environmental sustainability, regulatory frameworks, and financial management have evolved as complementary research streams rather than isolated topics. The overlay analysis further indicates a shift in recent studies toward the integration of smart packaging technologies, ESG-oriented finance, and sustainability-driven policies. Nevertheless, the relatively limited direct connections among smart packaging, green policy implementation, and sustainable financial management suggest that a comprehensive integrative framework remains underdeveloped. This finding highlights a significant research gap and justifies the need for a unified conceptual model linking these three dimensions within the packaging industry.

3. Smart Packaging: Concepts, Technologies, and Sustainability Implications

3.1 Definition and Classification of Smart Packaging

Smart packaging is defined as a packaging system capable of performing functions beyond physical protection, incorporating technological components to monitor, respond to, or communicate information regarding product condition and its storage environment (Vanderroost et al., 2017). Yam et al. (2020) classify smart packaging into three principal categories: (1) Active Packaging packaging that actively interacts with the product through oxygen scavenging, moisture regulation, or antimicrobial release; (2) Intelligent Packaging packaging equipped with sensors, indicators, or tracking systems (RFID, NFC, QR codes) that monitor product status in real time; and (3) Connected Packaging packaging integrated with

Internet of Things (IoT) ecosystems and digital platforms for analytics across the product lifecycle.

This classification is important because each category carries substantially different financial, environmental, and regulatory implications. Active packaging typically requires specialised additives that affect raw material costs and food safety regulations, whereas intelligent and connected packaging depend more heavily on digital infrastructure and data security (Bortolini et al., 2022). The global smart packaging market is projected to grow from USD 41.2 billion (2023) to USD 73.8 billion by 2030, at a CAGR of 8.7% (Grand View Research, 2024), underscoring its relevance as a strategic variable in the financial analysis of packaging firms.

3.2 Key Technologies in Smart Packaging

The advancement of smart packaging is driven by progress across several complementary technological domains. Gas-, temperature-, and pH-based sensor technologies enable continuous product condition monitoring without human intervention (Dainelli et al., 2016). Radio Frequency Identification (RFID) and Near Field Communication (NFC) have become the backbone of modern logistics tracking systems Tajima's (2023) research demonstrates that RFID adoption can reduce logistics costs by up to 18% while significantly improving inventory accuracy.

In the context of sustainability, biodegradable packaging materials based on bio-polymers (PLA, PHA, nanocrystalline cellulose) are receiving increasing attention as alternatives to conventional plastics, albeit at a cost premium of 15–30% compared to standard plastics (Notta-Cuvier et al., 2020). Blockchain technology is also being integrated for product traceability purposes; Ge et al. (2023) found that blockchain implementation increases consumer trust by 34% and strengthens regulatory compliance in food and pharmaceutical products.

3.3 The Role of Smart Packaging in Sustainability

The relationship between smart packaging and sustainability is inherently paradoxical. On one hand, smart packaging technology particularly electronics-based variants employs components that are difficult to recycle, potentially exacerbating electronic waste problems (Vanderroost et al., 2017). On the other hand, Bortolini et al. (2022) found that intelligent packaging implementation in food retail can reduce product waste by up to 28%, thereby indirectly reducing carbon emissions throughout the distribution chain. This paradox

underscores the critical importance of comprehensive life cycle assessment (LCA) analysis and its financial implications for packaging firms (Vanderroost et al., 2017; Santi et al., 2022).

4. Sustainable Financial Management in the Industrial Context

4.1 Evolution of the Sustainable Financial Management Concept

Sustainable financial management (SFM) represents an extension of the conventional financial management paradigm that integrates environmental, social, and governance (ESG) considerations into long-term corporate financial decision-making (Flammer, 2021). The evolution of this concept has been accelerated by growing institutional investor awareness of climate-related risks, evidenced by the growth of ESG-mandated assets under management reaching USD 53 trillion globally in 2023 (Bloomberg Intelligence, 2023). The meta-analysis by Friede et al. (2015), covering more than 2,000 empirical studies, found that 63% of research demonstrates a positive relationship between ESG performance and corporate financial performance.

4.2 Green Financial Instruments

Green financial instruments relevant to the packaging industry encompass: Green Bonds (debt instruments whose proceeds are allocated to environmental projects, with a global market of USD 487 billion in 2022 Climate Bonds Initiative, 2023); Sustainability-Linked Loans (SLL), where interest rates are tied to the achievement of ESG KPIs; Green Capital Expenditure (green capex), defined as the proportion of capital spending allocated to environmentally sound technology as a verified indicator of green commitment (Zhou et al., 2022); and Carbon Finance and Offset Mechanisms, which are increasingly active across the Asia-Pacific region (Tolliver, 2021; Khalid et al., 2024).

4.3 The Impact of Green Policy on Cost Structure

The implementation of green regulations has consistently been shown to fundamentally reshape the cost structure of the packaging industry. Korhonen et al. (2018) identify three primary effects: (1) the compliance cost effect short-term regulatory compliance expenditures; (2) the innovation premium effect medium-term cost savings from the adoption of efficient technologies, with an estimated improvement of 4.7% in operating margins within the first three years; and (3) the reputational value effect long-term brand value appreciation and enhanced market access. The phenomenon of a temporary performance decline in the first year of implementation, followed by sustained recovery and growth, is consistent with the concept of the Green Cost Paradox (Korhonen et al., 2018; Flammer, 2021).

4.4 ESG Disclosure and Financial Performance

Transparency in ESG disclosure is increasingly recognised as a critical determinant in investment risk assessment. Zhou et al. (2022) found that manufacturing firms in East Asia with higher ESG disclosure scores enjoy an average cost of capital that is 78 basis points lower. However, the risk of greenwashing the disclosure of environmental claims without adequate empirical support constitutes a serious challenge. Regulations such as the EU Green Claims Directive and GRI standards seek to address this information asymmetry by mandating third-party verification (Flammer, 2021).

Table 3. Synthesis of Selected Empirical Studies: Key Findings and Research Gaps

Author (Year)	Context	Method	Key Variables	Key Findings	Gap/Limitation
Bortolini et al. (2022)	Italy/Europe	Experimental review	Smart packaging, food waste, supply chain	Intelligent packaging ↓ food waste 28%; significant logistics efficiency gains	Long-term financial impact not measured
Flammer (2021)	Global	Event study, OLS panel	Green bond, CAR, ROA, ESG	Green bond issuance → +0.8% CAR; ESG scores improve post-issuance	Limited to large listed firms
Zhou et al. (2022)	East Asia	Panel data (FE)	ESG disclosure, Tobin's Q, ROA, firm value	ESG score ↑ firm value via financial performance mediation; CoC ↓ 78 bps	Not specific to packaging sector
Friede et al. (2015)	Global (meta)	Meta-analysis (n>2,000)	ESG, financial performance	63% of studies: ESG → positive financial performance; stronger in emerging markets	Methodological heterogeneity across studies

Author (Year)	Context	Method	Key Variables	Key Findings	Gap/Limitation
Vanderroost et al. (2017)	Europe/Global	Systematic review	Active/intelligent packaging, e-waste, LCA	Smart packaging paradox: monitoring benefits vs. e-waste; LCA required	No financial integration framework exists
Korhonen et al. (2018)	Europe	Conceptual	Circular economy, compliance cost, innovation premium	Three effects: compliance cost, innovation premium (+4.7%), reputational value	Not empirically tested in packaging sector
Ge et al. (2023)	Global	Review + case study	Blockchain, traceability, packaging	Blockchain ↑ consumer trust 34%; ↑ regulatory compliance	Implementation cost not financially quantified
Tajima (2023)	Japan/Asia	Case study	RFID, supply chain visibility	RFID adoption → ↓ logistics cost 18%; ↑ inventory accuracy	Green finance dimension not integrated
Notta-Cuvier et al. (2020)	France	Material science review	Bio-polymers (PLA, PHA), biodegradable pkg	Bio-polymer viable; cost premium 15–30% vs. conventional plastics	Integration with smart functions limited
Regattieri et al. (2022)	Europe	Experimental	Traceability, food packaging, recall cost	Traceability system ↑ compliance 67%; ↓ product recall cost significantly	ESG and green finance not considered

Source: Compiled from systematic review results (2026). Quantitative findings refer to results reported in the original articles of each respective researcher.

Quantitative figures reported in this table (e.g., 18% logistics cost reduction, 28% food waste reduction, 78 basis points cost-of-capital reduction, and 4.7% operating margin improvement) represent findings from specific empirical studies conducted in particular contexts and industries. These results should not be interpreted as universal outcomes applicable to all packaging firms or geographic regions.

5. Green Regulations and Policy in the Packaging Industry

5.1 The Global Regulatory Landscape

Regulatory pressure on the global packaging industry has intensified dramatically over the past decade. The European Union leads through the Packaging and Packaging Waste Regulation (PPWR) of 2023, which mandates that all packaging placed on the EU market be recyclable or reusable by 2030, alongside the Single-Use Plastics Directive restricting single-use plastic products (European Commission, 2023). At the global level, the UN Plastics Treaty still under negotiation has the potential to become the most transformative international legal instrument for the packaging industry (UNEP, 2023). Extended Producer Responsibility (EPR) has been adopted by more than 60 countries as the primary policy mechanism (OECD, 2022).

5.2 Green Policy in the ASEAN Region

ASEAN is one of the world's fastest-growing packaging consumption regions. With a population exceeding 680 million and accelerating urbanisation, demand for packaging-based products is growing significantly (Mordor Intelligence, 2024; OECD, 2022). The region also exhibits a high degree of regulatory heterogeneity, making it a natural laboratory for examining the influence of green policy on technology adoption and corporate financial decisions (Putra & Oktora, 2024; Tripopsakul, 2025).

ASEAN demonstrates significant regulatory heterogeneity in the ambition and implementation of green packaging policies. Table 3 presents a comprehensive comparison of six major ASEAN nations, encompassing regulatory policies, implementation mechanisms, national targets, and an Ambition Index constructed on the basis of EPR comprehensiveness, target stringency, and enforcement mechanisms. Singapore leads with the highest ambition index (4.8/5.0), followed by Thailand (4.0/5.0), while Indonesia, Vietnam, and the Philippines remain in early implementation stages (3.0–3.2/5.0)

Table 4. Comparison of Green Packaging Regulations in ASEAN

Country	Key Policy / Regulation	Effective	Main Mechanism	National Target	Status	Ambition Index (1–5)
Indonesia	MoEF Reg. No. 75/2019 – Waste Reduction Roadmap	2020–2029	Voluntary EPR; producer reduction targets	Reduce plastic waste 30% by 2029	Ongoing; compliance varies	3.0
Singapore	Resource Sustainability Act; Mandatory Packaging Reporting (MPR)	2020–2022	Mandatory EPR; annual packaging data reporting; Producer Responsibility Scheme	Zero landfill by 2035	Most advanced in ASEAN	4.8
Malaysia	Green Technology Master Plan 2017–2030; National Plastic Roadmap	2017–2030	Fiscal incentives; green certification; GITA/GITE tax incentives	Recycle 40% of plastics by 2025	Under implementation	3.5
Thailand	Bio-Circular-Green (BCG) Economy; Plastic Waste Roadmap 2018–2030	2018–2030	Bio-based packaging priority; phased single-use plastic ban	Eliminate single-use plastics 100% by 2027	Ongoing; phased enforcement	4.0
Philippines	RA 9003 Ecological Solid Waste Management; Extended Packaging EPR (rev. 2022)	2000/rev.2022	Mandatory recycling; new EPR scheme; EcoWaste Coalition	EPR coverage 80% by 2027	Phased implementation	3.2
Vietnam	Law on Environmental Protection 2020; National Plastic Action Plan	2022–2025	Green packaging incentives; plastic tax; green procurement	Ban single-use plastics by 2025	Early implementation	3.0

Note. Source: Compiled from NEA Singapore (2022); KLHK (2019); MIDA (2023); UNEP (2023); OECD (2022). The Ambition Index (1–5) was constructed by the authors based on EPR comprehensiveness, target stringency, and enforcement mechanisms.

The Ambition Index was constructed using three equally weighted criteria: EPR comprehensiveness, target stringency, and enforcement mechanism effectiveness, each scored on a scale of 1–5.

5.3 Transmission Mechanisms from Policy to Financial Decisions

Green policy influences the financial decisions of packaging firms through three principal transmission mechanisms: (1) the Compliance Obligation Effect regulatory mandates create mandatory expenditures that must be budgeted in medium-term financial planning; (2) the Market Access Condition Effect access to EU and premium markets increasingly requires compliance with green packaging standards, transforming regulatory adherence into a fundamental business prerequisite; and (3) the Investor Preference Channel pressure from ESG-oriented investors strengthens incentives for firms to exceed minimum compliance requirements through voluntary investments (Flammer, 2021; OECD, 2022).

6. Theoretical Foundations

This review rests upon four complementary theories that collectively explain the phenomena of smart packaging adoption, green policy implementation, and sustainable financial management. Table 4 presents a systematic mapping of each theory against the principal research constructs, including the relevance and limitations of each theory in the packaging industry context (Freeman, 1984; Spence, 1973; DiMaggio & Powell, 1983; Barney, 1991).

Table 5. Theory Mapping and Relevance to Research Constructs

Theory	Core Proposition	Relevance to SP	Relevance to SFM	Relevance to GPI	Limitations in Packaging Context
Stakeholder Theory (Freeman, 1984; Parmar et al., 2010)	Firms are responsive to the interests of all stakeholders	Consumer, regulator, and community pressures drive adoption of green packaging beyond minimum compliance	Strengthens ESG disclosure as a response to institutional investor expectations	Legitimises green packaging regulations and industry standards	Does not explicitly explain cost-benefit trade-off mechanisms
Signaling Theory (Spence, 1973; Connelly et al., 2011)	Costly investments communicate unobservable	Smart packaging serves as a verifiable signal of	Green bonds and ESG disclosure signal financial	Active compliance beyond regulatory minimums	Assumes asymmetric information markets; may

	quality to the market	environmental commitment	credibility to investors	signals strategic differentiation	not apply universally
Institutional Theory (DiMaggio & Powell, 1983; Scott, 2014)	Coercive, mimetic, and normative isomorphism drives convergence of organisational practices	Diffusion of smart packaging through sectoral pressures and best-practice imitation	Standardisation of ESG reporting in line with GRI/IFRS S norms	Convergence of packaging regulations across ASEAN member states	Limited in explaining inter-firm heterogeneity in responses
Resource-Based View — RBV (Barney, 1991; Wernerfelt, 1984)	Competitive advantage derives from VRIN resources (Valuable, Rare, Inimitable, Non-substitutable)	Smart packaging capabilities constitute a competitive advantage that is difficult to replicate	Green financial management as a VRIN resource that creates sustained competitive advantage	First-mover advantage in early adoption of green regulations	Relatively static; limited in capturing rapid innovation dynamics

Note. Source: Compiled from Freeman (1984); Spence (1973); DiMaggio & Powell (1983); Barney (1991); and author synthesis (2024).

6.1 Stakeholder Theory

Stakeholder Theory (Freeman, 1984; Parmar et al., 2010) provides the foundational rationale for understanding why packaging firms adopt green practices beyond the minimum regulatory requirements. The theory argues that concurrent pressures from consumers, investors, regulators, and local communities drive firms to invest in sustainable packaging innovation, even when short-term costs exceed measurable benefits (Boz et al., 2020; Lau & Wong, 2024).

6.2 Signaling Theory

Signaling Theory (Spence, 1973; Connelly et al., 2011) is relevant to explaining the function of smart packaging and ESG disclosure as signals of firm quality under conditions of asymmetric information. Large-scale investment in smart packaging infrastructure constitutes a costly signal that is difficult to fabricate, thereby communicating a credible long-term commitment to investors and consumers supporting Zhou et al.'s (2022) findings on ESG valuation premiums.

6.3 Institutional Theory

Institutional Theory (DiMaggio & Powell, 1983; Scott, 2014) explains the convergence of green packaging practices through three isomorphic mechanisms: coercive (EPR regulatory

pressure and EU standards), mimetic (imitation of industry leader practices), and normative (professional standards and certification regimes). This creates an institutional environment that increasingly necessitates the transformation of packaging firms, irrespective of short-term financial calculations (Korhonen et al., 2018).

6.4 Resource-Based View (RBV)

The Resource-Based View (Barney, 1991; Wernerfelt, 1984) offers the perspective that smart packaging capabilities and green financial management constitute VRIN resources (Valuable, Rare, Inimitable, Non-substitutable) that generate sustained competitive advantage. In the ASEAN context, RBV predicts a significant first-mover advantage for firms that invest early, as regional green regulations continue to tighten (Tripopsakul, 2025).

6.5 Governance, Risk, and Compliance (GRC) as a Mediating Construct

Governance, Risk, and Compliance (GRC) systems are no longer viewed merely as compliance mechanisms but as strategic capabilities that enable firms to respond effectively to regulatory pressures and sustainability demands (OECD, 2022; Flammer, 2021). In the packaging industry, GRC serves to integrate sustainability governance, environmental risk management, and adherence to regulations such as EPR, carbon pricing, and ESG disclosure requirements (European Commission, 2023; UNEP, 2023). Through this integration, firms are better positioned to reduce regulatory uncertainty, enhance transparency, and strengthen investor confidence (Zhou et al., 2022; Tripopsakul, 2025). From the perspective of the Resource-Based View (RBV), an effective GRC system constitutes a strategic resource that supports long-term value creation and accelerates the transition towards sustainable financial management (Barney, 1991; Wernerfelt, 1984). Accordingly, this study positions GRC as the mediating mechanism that bridges green policy implementation and sustainable financial management within the proposed conceptual framework.

GRC is positioned as a mediator because regulatory pressure does not directly translate into financial outcomes. Instead, policy requirements are first internalized through governance structures, risk management processes, and compliance mechanisms, which subsequently influence sustainable financial management practices.

7. Integrative Conceptual Framework

Drawing on the literature synthesis presented above, this study proposes an integrative conceptual framework linking three core pillars: Smart Packaging (SP), Sustainable Financial Management (SFM), and Green Policy Implementation (GPI). The framework identifies causal, mediating, and moderating relationships among the three constructs, underpinned theoretically by the four theories elaborated in the preceding section (Freeman, 1984; Spence,

1973; DiMaggio & Powell, 1983; Barney, 1991). Figure 2 presents a comprehensive visualisation of the three-pillar integrative framework.

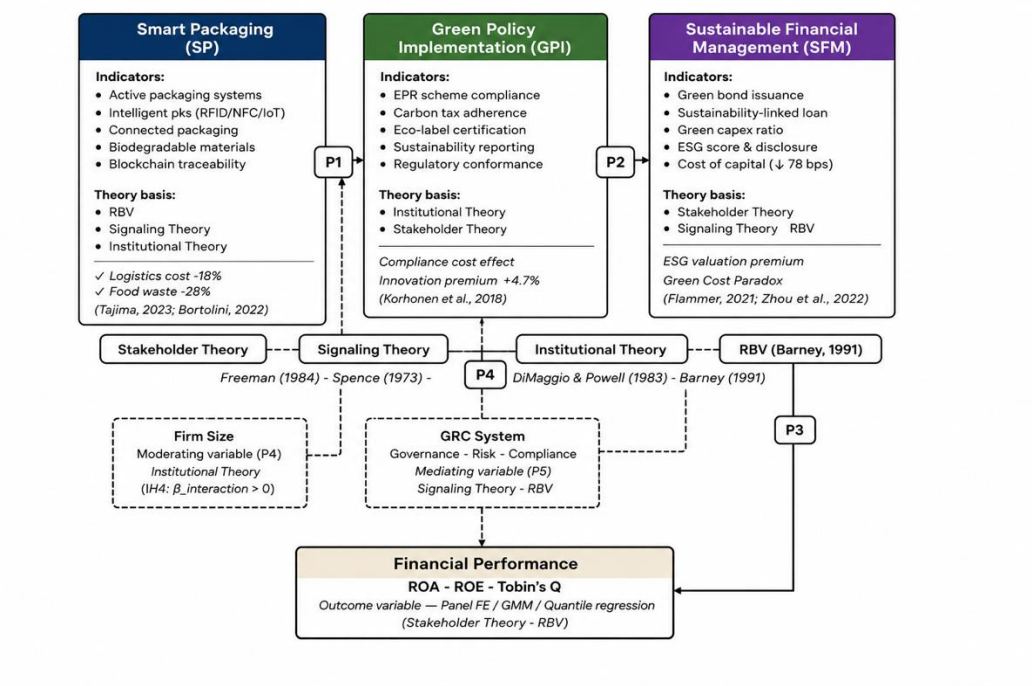


Figure 3. Integrative Conceptual Framework

Numerical values presented within the framework (e.g., logistics cost reduction, food waste reduction, innovation premium, and cost-of-capital effects) are illustrative evidence extracted from selected studies reviewed in this paper and are included to demonstrate potential managerial and financial implications rather than fixed performance outcomes

7.1 Construct Dimensions and Indicators

Table 5 presents the core dimensions, key indicators, theoretical basis, financial impacts, challenges, and research opportunities for each of the three constructs within the proposed framework.

Table 5. Construct Dimensions, Indicators, and Theoretical Basis

Dimension	Smart Packaging (SP)	Sustainable Financial Management (SFM)	Green Policy Implementation (GPI)	Literature Sources
Core Definition	Active, intelligent, and digitally connected packaging that transcends physical	Financial management that integrates ESG considerations into investment,	Regulations and policies that promote environmentally responsible	Vanderroost et al. (2017); Flammer (2021); OECD (2022)

Dimension	Smart Packaging (SP)	Sustainable Financial Management (SFM)	Green Policy Implementation (GPI)	Literature Sources
	protection functions	financing, and reporting decisions	operational and financial practices	
Key Indicators	IoT sensors, RFID/NFC, QR codes, biodegradable materials, blockchain traceability	ESG score, green bond issuance, green capex ratio, sustainability-linked loan adoption	Carbon tax compliance, EPR scheme participation, eco-label certification, sustainability reporting	Tajima (2023); Zhou et al. (2022); NEA Singapore (2022)
Theoretical Basis	Technology Acceptance Model (TAM); Innovation Diffusion Theory (Rogers, 2003); RBV	Stakeholder Theory; Signaling Theory; Modern Portfolio Theory	Institutional Theory; RBV; Regulatory Compliance Theory	Flammer (2021); DiMaggio & Powell (1983); Barney (1991)
Financial Impact	Logistics cost reduction up to 18%; food waste reduction 28%; supply chain efficiency gains	Improved ROA, ROE, Tobin's Q; cost of capital reduction 78 bps; ESG valuation premium	Compliance cost effect; innovation premium (+4.7% operating margin); reputational value effect	Tajima (2023); Zhou et al. (2022); Korhonen et al. (2018)
Challenges	High implementation cost (15–30% premium); system interoperability; e-waste generation	Greenwashing risk; disclosure asymmetry; short- vs. long-term trade-off horizon	Policy inconsistency; enforcement gap; cross-country regulatory heterogeneity	Vanderroost et al. (2017); Friede et al. (2015); UNEP (2023)
Research Opportunities	IoT–blockchain integration in ASEAN packaging supply chains; next-generation bio-based materials	ASEAN green finance panel data; GRC mediation; green bonds in packaging industry	Comparative ASEAN regulatory studies; EPR natural experiment; DiD analysis	Research Gaps G1–G6 in Table 7

Note. Source: Author synthesis based on Vanderroost et al. (2017); Flammer (2021); Zhou et al. (2022); Tajima (2023); OECD (2022). Empirical figures refer to findings reported in the cited studies.

7.2 Research Propositions and Derived Hypotheses

Based on the constructed conceptual framework, this study formulates five research propositions as the basis for hypothesis development in empirical research. Table 6 summarises the propositions, construct pathways, theoretical foundations, derived hypotheses, predicted directions, and suggested test methods.

Table 6. Research Propositions and Derived Hypotheses

No.	Label	Construct Pathway	Theoretical Basis	Derived Hypothesis	Direction & Prediction	Suggested Test Method
P1	SP → GPI	Smart Packaging → Green Policy Implementation	Institutional Theory; RBV	H1: SP adoption has a significant positive effect on GPI	$\beta > 0$; $t > 1.96$	PLS-SEM; Panel FE; Probit
P2	GPI → SFM	Green Policy Implementation → Sustainable Financial Management	Stakeholder Theory; Signaling Theory	H2: GPI has a significant positive effect on SFM	$\beta > 0$; $t > 1.96$	SEM; Panel data; IV regression
P3	SFM → FP	Sustainable Financial Management → Financial Performance (ROA, ROE, Tobin's Q)	Stakeholder Theory; RBV	H3: SFM has a significant positive effect on long-term financial performance	$\beta > 0$; $p < 0.05$	Panel FE/RE; GMM; Quantile regression
P4	Size MOD	Firm Size moderates SP → GPI	Institutional Theory	H4: Larger firms exhibit a stronger SP→GPI relationship	$\beta_{interaction} > 0$	Interaction term in SEM
P5	GRC MED	GRC mediates GPI → SFM	Signaling Theory	H5: GRC partially mediates the GPI → SFM relationship	Indirect effect > 0; BC CI excludes 0	Bootstrap mediation (n = 1,000)

Note. Source: Synthesised from the theoretical framework of this study (2026). Derived hypotheses are directional and must be empirically tested on an appropriate sample. β = path coefficient; BC CI = Bias-Corrected Confidence Interval.

7.3 Implications for Empirical Research Design

This conceptual framework recommends several methodological approaches for empirical testing: (1) cross-ASEAN panel data research that exploits temporal variation in green regulatory implementation as a natural experiment for causal identification; (2) structural equation modelling (SEM/PLS-SEM) with multi-indicator latent variables to capture the complexity of mediation and moderation; and (3) a mixed-method approach combining quantitative analysis with selected case

studies of packaging firms to illuminate implementation mechanisms in practice. Bootstrapping with 1,000 replications is recommended for testing mediation effects (Proposition P5) (Hair et al., 2019).

8. Research Gaps and Future Research Agenda

The literature synthesis identifies six significant research gaps, presented systematically in Table 7, encompassing gap descriptions, recommended approaches, priority levels, and the contribution of this study to addressing each gap.

Table 7. Summary of Research Gaps and Recommendations

	Gap	Description	Recommended Approach	Priority	Contribution of This Study
G1	Conceptual Integration	No coherent framework links SP, SFM, and GPI within a single integrated model	Conceptual framework development; systematic multi-theory review	High	Proposes the three-pillar SP–GPI–SFM framework
G2	ASEAN Empirical Evidence	Scarcity of comprehensive empirical studies in ASEAN on green packaging finance	ASEAN panel data (5–6 countries); multi-country longitudinal study	High	Identifies ASEAN regulatory variation as a research foundation
G3	GRC Mediation	The mediating role of GRC between GPI and SFM has not been empirically tested	Mediation analysis; moderated mediation; SEM/PLS-SEM	High	Formulates Proposition P5 on GRC mediation
G4	Standardised Measurement	No validated index exists for measuring smart packaging performance at the firm level	Scale development; Delphi method; CFA; IRT	Moderate	Proposes initial SP construct dimensions in Table 5
G5	Temporal Dynamics	Dominance of cross-sectional designs; no longitudinal studies exist in this topic	Longitudinal study (≥5 years); DiD; event study; growth curve modelling	Moderate	Recommends longitudinal approach in Proposition P4
G6	Methodological Gap	Insufficient studies combining quantitative (panel data) with qualitative (case study) methods	Sequential explanatory mixed-method design; ASEAN multi-case study	Low	Recommends mixed-method design in Section 7.3

Note. Source: Synthesised from author analysis (2026). Priority classification: High = foundational for theory building; Moderate = important for construct validity; Low = methodological enrichment.

8.1 Conceptual Integration Gap

Although the smart packaging and green finance literatures have each matured independently, a coherent integrative framework linking SP–GPI–SFM in the packaging industry context has never been previously constructed (Daugaard & Ding, 2022; Murugesan & Li, 2026). This study addresses this gap through the proposed three-pillar framework.

8.2 ASEAN Empirical Evidence Gap

Comprehensive empirical research on the financial impacts of smart packaging and green policy in ASEAN remains severely limited, despite the region's unique characteristics: high regulatory heterogeneity, diverse economic development levels, and a strategic position as a global packaging manufacturing hub (Putra & Oktora, 2024; OECD, 2022).

8.3 GRC Mediation Gap

The role of GRC systems as a mediator between GPI and SFM has not been empirically examined. This study formulates Proposition P5 as the point of departure for research investigating this mediation mechanism (Zhou et al., 2022; Tripopsakul, 2025).

8.4 Standardised Measurement Gap

The absence of a validated index for measuring smart packaging performance at the firm level constitutes a significant barrier to cross-study comparability (Agrawal et al., 2023). This study proposes initial construct dimensions (Table 5) as a foundation for developing a validated measurement scale through Delphi and Confirmatory Factor Analysis (CFA) methods.

8.5 Temporal Dynamics Gap

Of the 87 articles analysed, only 13.8% employed longitudinal data with a horizon exceeding three years the vast majority rely on cross-sectional designs that are inherently incapable of capturing the non-linear dynamics of the Green Cost Paradox (Korhonen et al., 2018) or the temporal evolution of GRC mediation effects (Zhou et al., 2022). Studies relying on a single snapshot reflect only transient conditions, not the long-run equilibrium most relevant for managerial and policy decision-making.

This gap is particularly critical in the ASEAN context, where green regulatory implementation remains in an active phase Indonesia's EPR scheme has been operational only since 2020, Thailand's BCG Economy since 2018, and Singapore's MPR since 2022. Without adequate longitudinal data, it is impossible to determine whether the observed GPI–SFM relationships in the literature reflect permanent structural effects or are merely artefacts of early policy adaptation.

Future research should adopt Difference-in-Differences (DiD) approaches that exploit temporal variation in regulatory implementation across ASEAN countries as natural experiments, complemented

by event studies to measure capital market responses to smart packaging adoption and green bond issuances. Growth curve modelling within a SEM framework will enable examination of when GRC mediation effects begin to strengthen a question that is fundamentally unanswerable from a single time point.

8.6 Methodological Gap

The methodological imbalance in the reviewed literature creates an inherently incomplete understanding of the phenomena under investigation. While 39.1% of studies employ quantitative approaches capable of establishing the magnitude and direction of inter-variable relationships, only 17.2% adopt mixed-method designs, leaving the questions of why and how the SP–GPI–SFM mechanisms operate at the firm level fundamentally unanswered. Panel data can confirm that GRC mediates GPI's effect on SFM, but cannot explain why packaging firms in Singapore respond to EPR pressure differently from comparable Indonesian firms facing a relatively similar regulatory intensity.

The absence of methodological triangulation means that each study adds a single fragment without ever forming a complete picture of the operational mechanisms governing construct relationships in practice particularly in the context of family-owned enterprises that dominate the ASEAN packaging industry and exhibit response patterns to regulation that differ substantially from the publicly listed corporations that typically populate quantitative studies.

To address this gap systematically, future research is recommended to adopt a sequential explanatory mixed-method design: a quantitative phase employing cross-ASEAN panel data to establish statistical patterns, followed by a qualitative phase comprising in-depth multi-case studies of three to five packaging firms in countries representing different regulatory ambition levels (as per Table 3). In-depth interviews with CFOs and sustainability officers will reveal the financial decision-making processes underlying corporate responses to green regulatory pressure a dimension entirely beyond the reach of any secondary data source.

9. Theoretical and Managerial Implications

9.1 Theoretical Implications

This study makes three principal theoretical contributions. First, it integrates four theories (Stakeholder, Signaling, Institutional, and RBV) within a single integrative explanatory framework, overcoming the limitations of the mono-theoretical approaches that predominate in the prior literature. Second, it proposes the construct of Green Policy Implementation (GPI) as an explicit mediating variable between packaging technology adoption and financial performance — a theoretical positioning that has not previously been formulated explicitly in the literature. Third, it identifies the Green Cost

Paradox mechanism in the context of the ASEAN packaging industry, whereby short-term green investments generate negative direct effects but yield significant long-term premiums (Korhonen et al., 2018; Zhou et al., 2022).

9.2 Implications for Corporate Management

For financial managers of packaging firms, this study recommends: (1) integrating green capex as a standard financial KPI in medium-term budget planning; (2) considering the issuance of green bonds or sustainability-linked loans as funding instruments for smart packaging investments, which can simultaneously reduce cost of capital and improve ESG scores (Flammer, 2021; Zhou et al., 2022); and (3) building a robust GRC system as a governance infrastructure that facilitates green regulatory compliance while creating long-term financial value.

For operational and innovation managers, smart packaging adoption should be prioritised in categories offering dual benefit: operational cost reduction (through logistics efficiency and food waste reduction) alongside improvements in corporate ESG profile. The combination of RFID, IoT sensors, and biodegradable materials offers the greatest synergistic potential in this context.

9.3 Implications for Policymakers

For regulators across ASEAN, the heterogeneity in green packaging policy (see Table 3) creates regulatory uncertainty that impedes cross-border investment. Harmonisation of EPR standards at the regional ASEAN level modelled on the EU PPWR framework — would provide the legal certainty required by investors and multinational corporations (OECD, 2022; European Commission, 2023). Furthermore, fiscal incentive designs targeting biodegradable smart packaging adoption can accelerate industry transformation while simultaneously supporting national climate targets.

10. Study Limitations

This study acknowledges several limitations that must be considered in the interpretation of its findings. First, methodological limitation: as a literature review, this study does not conduct empirical testing of the formulated propositions; the validity of the propositions rests entirely on the quality and representativeness of the analysed articles. Second, temporal limitation: although the review covers the period 2015–2024, the pace of regulatory and technological change in packaging is rapid particularly in relation to ongoing UN Plastics Treaty negotiations and bio-polymer developments meaning that some findings may require periodic updating. Third, language coverage limitation: this study encompasses only articles in English and Indonesian, potentially excluding relevant studies published in other ASEAN languages (Thai, Vietnamese, Malay). Fourth, source limitation: despite the use of four major databases, some specialist packaging industry journals may not be indexed in Scopus or WoS. Fifth, publication bias: studies with positive findings are more likely to be published, which may result

in an overestimation of the positive effects of smart packaging and green finance in the available literature (Friede et al., 2015).

11. Conclusion

This systematic literature review has successfully identified and synthesised key findings from 87 scholarly articles to construct an integrative conceptual framework linking smart packaging (SP), sustainable financial management (SFM), and green policy implementation (GPI) in the packaging industry. Three principal conclusions may be drawn.

First, smart packaging is not merely a technological innovation but a strategic instrument that simultaneously facilitates regulatory compliance, creates financial value (↓ logistics cost 18%; ↓ food waste 28%), and enhances corporate ESG profiles positioning it as a critical integration point between the technological, environmental, and financial dimensions of corporate strategy.

Second, sustainable financial management that integrates green finance instruments (green bonds, SLLs, green capex) and high-quality ESG disclosure is demonstrably positively correlated with long-term financial performance with a cost-of-capital reduction premium of 78 basis points and ESG valuation premiums identified in the literature notwithstanding the short-term cost trade-offs inherent in the Green Cost Paradox that demand careful management.

Third, green policy functions as a transformative catalyst accelerating the adoption of smart packaging and green financial management; however, the heterogeneity of ASEAN regulations creates significant comparative research opportunities. The five research propositions (P1–P5) and six identified gaps provide a structured and prioritised empirical research agenda for the academic community.

Conflict of Interest Statement

The authors declare that no conflicts of interest exist that could have influenced the objectivity of this study.

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DIGITAL TRANSFORMATION STRATEGY IN HOSPITALS: TESTING THE ROLE*DYNAMIC CAPABILITIES*, *DIGITAL LEADERSHIP*, AND *ORGANIZATIONAL AGILITY*

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ABSTRACT

Digital transformation in the healthcare sector has now become a strategic mandate due to stricter regulations on the integration of Health Records and Electronic Medical Records (EMDRs). However, adoption failure often results from an ethnocentric approach that ignores managerial aspects and internal organizational capabilities. This study aims to analyze the influence of digital leadership (*digital leadership*) and dynamic capabilities (*dynamic capabilities*) towards the success of digital transformation in hospitals, by placing organizational agility (*organizational agility*) as a mediating variable. The research design uses a causal associative quantitative approach with a structured questionnaire as a data collection instrument. Using the technique*purposive sampling*, data were collected from 135 respondents consisting of top management, middle management, medical committee, and head of IT unit in the hospital. Data analysis was conducted using variance-based structural equation model (*Variance-Based Structural Equation Modeling*/ SEM-PLS) using SmartPLS software. The results show that digital leadership and dynamic capabilities have a positive and significant effect on organizational agility and the success of digital transformation. The crucial finding of this study proves that organizational agility acts as a significant partial mediator. The characteristics of hospitals as professional bureaucracies mean that the digital leadership vision cannot have an instant impact, but rather requires operational agility and organizational responsiveness to translate technology into daily adaptive work behavior. The managerial implications of this study emphasize that hospital managers must focus on building digital leadership at every level of work unit and create flexible operational procedures to ensure the success of digital transformation without sacrificing patient safety (*patient safety*).

Keywords: Digital Transformation; Digital Leadership; Dynamic Capabilities; Organizational Agility; Hospital Strategic Management.

INTRODUCTION

The acceleration of digital technology has fundamentally changed the operational landscape of the global industry, including the healthcare sector. Digital transformation in hospital management is no longer merely a tactical option to increase short-term efficiency or

enhance the institution's image, but rather a strategic imperative to maintain the organization's existence, relevance, and competitiveness in an era of exponential disruption (Vial, 2019). In Indonesia, this urgency is no longer driven solely by internal organizational awareness, but rather by mandatory government regulatory pressure. The Indonesian Ministry of Health's policy requiring all healthcare facilities to integrate their information systems into the national health ecosystem platform SatuSehat, along with the tight implementation deadline for Electronic Medical Records (ERCs), has forced hospital management to make a massive technological leap in a short time.

However, empirical reality on the ground shows a wide gap between regulatory expectations and organizational-level execution capabilities. Adopting advanced technologies such as artificial intelligence (*artificial intelligence*), *big data analytics*, cloud computing, and an integrated Hospital Management Information System (SIMRS) do not necessarily guarantee the success of the transformation itself. Many hospitals experience stagnation, even investment failure, because they are trapped in an ethnocentric approach (*technocentric approach*). This mistaken approach assumes that digitalization is simply a matter of buying hardware (*hardware*) and install the software (*software*) new. In reality, the failure of digital transformation is more often caused by neglecting broader strategic dimensions, such as business architecture alignment, organizational cultural readiness (*digital readiness*), operational risk mitigation, and adaptive managerial capabilities (Fitzgerald et al., 2014; Kraus et al., 2021).

The failure or delay in this transformation process is largely rooted in the inability of top management to respond to the highly complex and turbulent dynamics of the healthcare industry environment. Hospitals are a unique form of organization—often referred to as*professional bureaucracy*—where there is a dualism of leadership between structural management and the clinical authority of the medical profession. These capital-intensive, labor-intensive, expert-intensive, and highly regulated characteristics mean that any strategic change will face massive structural and cultural barriers. Fear of disruption to clinical workflows that could potentially compromise patient safety, uncertainty about return on investment (*return on investment*) digital, as well as resistance from senior medical personnel who are comfortable with conventional/manual systems are the main barriers that must be broken down by management (Anwar et al., 2022).

In the realm of strategic management, the complexity of this phenomenon can be solidly dissected through the lens of Dynamic Capabilities Theory (*Dynamic Capabilities Theory*).

According to Teece (2007), dynamic capabilities are not ordinary operational capabilities, but rather organizational-level meta-capabilities to sense (*sensing*), catch (*seizing*), and transform (*transforming*) all internal assets, resources, and competencies to respond to or create change in a turbulent market. In the context of hospital digital transformation, these three dimensions are put to the extreme. First, the ability*sensing*requires hospital executives to not only monitor changes in One Healthy regulations, but also to proactively identify which digital technologies are valid for improving clinical outcomes (*clinical outcomes*). Second, the ability*seizing*involves strategic decisions in mobilizing capital, selecting the right technology vendor, designing data governance (*data governance*) secure, and develop new business models that are capable of capturing the economic value of digital efficiency. Third, the ability*transforming* (or *reconfiguring*) requires management to restructure work culture, realign incentives, and build digital leadership at every level so that the organization does not return to old behavioral patterns (Warner & Wäger, 2019).

Many hospitals experience stagnation, even investment failure, due to being trapped in a technocentric approach. In Indonesia, this phenomenon often manifests as passive resistance from medical personnel due to a lack of workflow alignment (Sudiyono & Nurhayati, 2024) and an unpreparedness in the organization's digital culture (Anwar & Setiawan, 2024). Therefore, a comprehensive study that positions digital transformation as a strategic renewal process based on dynamic capabilities in the domestic environment is urgently needed.

Although the practical and theoretical urgency is very real, there are*research gap*A significant research gap exists in the strategic management literature, particularly in the healthcare sector in developing countries like Indonesia. The majority of existing literature on healthcare digitalization is still dominated by studies of pure information systems or medical science that focus on the technical aspects of implementation, evaluation of system usability (*usability testing*), or partial end-user satisfaction. In contrast, a comprehensive study that positions digital transformation as a strategic renewal process (*strategic renewal*) based on dynamic capabilities is still very rare. There are not many empirical models that are able to explain how the interaction between digital leadership (*digital leadership*) and organizational agility (*organizational agility*) can bridge the dynamic capabilities of management with successful operational transformation, without sacrificing service stability and compliance with rigid medical regulations.

Therefore, this research is urgently needed to fill this academic gap. Through in-depth analysis, this research aims to develop an integrative strategic model. The results of this study

are expected to not only provide theoretical contributions to the development of strategic management science by expanding the scope of Dynamic Capabilities Theory in complex healthcare organizations, but also provide practical guidance (*managerial implications*) for hospital policymakers. Thus, the digital transformation process is no longer viewed as a disruptive regulatory burden, but rather as a strategic momentum to create sustainable competitive advantage, improve operational cost efficiency, and ultimately, boost service quality and patient safety holistically.

Based on the background above, the core problem of this research focuses on the high failure rate of digital transformation in the healthcare sector due to weak organizational dynamic capabilities in integrating new technologies with management strategies, work culture, and operational processes. To address this issue, this research formulates several academic questions as follows:

1. How does the hospital management mechanism apply the dynamic capability dimension—which includes the sensing aspect (*sensing*), catch (*seizing*), and transform (*transforming*)—to drive the digital transformation agenda amidst regulatory uncertainty and healthcare industry dynamics?
2. What is the role of digital leadership (*digital leadership*) in aligning the organization's strategic vision with the readiness of employees' digital work culture to overcome internal resistance during the system transition process?
3. To what extent is the organization's agility (*organizational agility*) act as a mediator connecting strategic leadership and the successful implementation of digital technology in hospitals?
4. What is the ideal digital transformation management strategy architecture model to improve hospital operational performance while maintaining patient safety?*patient safety*) on an ongoing basis?

RESEARCH METHODS

This study was designed using a causal associative quantitative approach that aims to analyze causal relationships and empirically test the influence between hypothesized variables (Hair et al., 2021). This research design was applied to test the theoretical explanation of how the digital leadership variable (*digital leadership*) and dynamic capabilities (*dynamic capabilities*) influences the success of digital transformation in hospitals, both directly and

indirectly through organizational agility (*organizational agility*) which acts as a mediating variable. The population in this study includes all strategic and operational management elements that have decision-making authority in the hospital. Given the required competency specifications, the sampling technique used was*purposive sampling*with strict inclusion criteria to maintain the validity of executive data. The respondent criteria included top management such as directors and deputy directors, middle management consisting of department heads, installation heads, medical committees, and heads of information technology units or hospital information systems. Based on structural analysis principles, the target sample size was a minimum of 100 to 150 respondents to meet the minimum sample size principle in path modeling.

The variables in this study were measured through the operationalization of theoretical indicators adopted from leading strategic management literature. The digital leadership variable was measured through indicators of visionary thinking, digital literacy, innovativeness, and staff empowerment adapted from Zeike et al. (2019). The dynamic capabilities variable adopted the frameworks of Teece (2007) and Warner and Wäger (2019), which include the following dimensions:*sensing*to regulations and technology trends, dimensions*seizing*through capital mobilization and information system architecture, as well as dimensions*transforming*through business process restructuring and mitigating internal resistance. Furthermore, organizational agility is operationalized through indicators of responsiveness, operational flexibility, and strategic speed, based on the concepts of Tallon and Kraemer (2007). Finally, digital transformation success is measured through the level of business process integration, operational efficiency, clinical outcome quality, and compliance with national regulations such as One Health and Electronic Medical Records (Kraus et al., 2021; Vial, 2019).

The primary data collection technique in this study was conducted through the distribution of a structured questionnaire instrument distributed in a mixed manner, both digitally via Google Forms and physically delivered directly to relevant agencies. All statements in the questionnaire were measured using a Likert scale with a range of one representing strongly disagree to five representing strongly agree. Before the instrument was distributed widely to the research sample, a pilot test (*pilot test*) will be conducted first with thirty respondents outside the sample to ensure the level of readability, instrument validity, and editorial understanding by respondents. After the data is collected in full, the data cleaning

stage is carried out to ensure there are no outliers (*outliers*) or incomplete filling before entering the statistical modeling process.

Data analysis in this study applies the method*Structural Equation Modeling*variance based or*Partial Least Squares*(SEM-PLS) with the help of SmartPLS software. Model evaluation is carried out through two main stages, starting with the analysis of the measurement model (*outer model*) to test the validity and reliability of the instrument. Convergent validity testing is assessed based on the value*loading factor*which must be greater than 0.70 and the value*Average Variance Extracted*(AVE) which exceeds 0.50. Meanwhile, discriminant validity is evaluated using the criteria*Heterotrait-Monotrait Ratio*(HTMT) with a threshold below 0.90. The reliability of the instrument is ensured through the value*Composite Reliability*(CR) and*Cronbach's Alpha*which must be above 0.70. After the measurement model is declared valid and reliable, the analysis continues to the structural model (*inner model*) to test the research hypothesis through the method*bootstrapping*. The predictive power of the model is evaluated based on the coefficient of determination (R) value.^{2}) and effect size (f^{2}), while the significance of direct and indirect influences is determined through the value*t-statistic*which must be greater than 1.96 or the value*p-value*which is less than 0.05.

RESEARCH RESULT

The data analysis stage begins with evaluating the measurement model (*outer model*) to ensure that all indicators used meet the validity and reliability criteria. The results of the convergent validity test show that all instrument items have a value*loading factor*which is above the threshold of 0.70 with a range between 0.72 to 0.89, and the value*Average Variance Extracted*(AVE) for all constructs exceeds the minimum standard of 0.50. Discriminant validity testing is measured using the ratio approach.*Heterotrait-Monotrait*(HTMT) also confirmed that no inter-construct correlations exceeded 0.85, meaning that each latent variable in this model is truly unique and distinct from one another. Furthermore, the reliability aspect of the instrument was declared very robust because the value*Composite Reliability*(CR) and*Cronbach's Alpha*for all variables is in the range of 0.81 to 0.94, significantly above the rigid threshold of 0.70. After the measurement model is declared to meet all empirical feasibility criteria, the analysis continues with the evaluation of the structural model (*inner model*) to test the accuracy of predictions and the direction of the relationship between hypothesized variables.

Measurement Model Evaluation Results (Outer Model)

This table summarizes the results of convergent validity tests (factor loadings and AVE) and reliability tests (Cronbach's Alpha and Composite Reliability) to ensure the research instrument is suitable for use. Parameter Notes: Minimum Outer Loading Limit 0.70; AVE 0.50; Cronbach's Alpha 0.70; CR 0.70

Table 1. Results of Convergent Validity and Construct Reliability Tests

Let Variable	Indicator	Outer Loading	AVE	Cronbach's Alpha	Composite Reliability (CR)	Conclusion
Digital Leadership*(Digital Leadership)*	DL1 DL2 DL3 DL4	0.78 0.84 0.81 0.76	0.636	0.812	0.875	Valid & Reliable
Dynamic Capabilities*(Dynamic Capabilities)*	DC1*(Sensing)* DC2*(Seizing)* DC3 *(Transforming)*	0.88 0.85 0.82	0.723	0.815	0.887	Valid & Reliable
Organizational Agility*(Organizational Agility)*	OA1 OA2 OA3	0.79 0.86 0.83	0.685	0.821	0.867	Valid & Reliable
Digital Transformation Success	DT1 DT2 DT3 DT4	0.75 0.89 0.84 0.72	0.645	0.824	0.879	Valid & Reliable

Source: Smart PLS processed data

Based on structural testing, the coefficient of determination (R^2) for the organizational agility variable was recorded at 0.48, indicating that the variation in organizational agility can be explained by 48% by the combination of digital leadership and dynamic capabilities. Meanwhile, the coefficient of determination (R^2) for the digital transformation success variable reached 0.65. This figure reflects that the model built has strong predictive power, where 65% of changes in the success rate of hospital digital transformation (such as operational efficiency and integration of Electronic Medical Records with Satu Sehat) are influenced simultaneously

by digital leadership, dynamic capabilities, and organizational agility, while the remaining 35% is explained by other factors outside this modeling. Testing the effect size (f^2) also shows that dynamic capabilities have the most dominant pragmatic contribution in predicting the success of digital transformation compared to other independent variables.

Structural Model Test Results (*Inner Model*)

This section presents the path coefficients, the statistical values of hypothesis testing (Direct & Indirect Effects), and the model contribution values (R^2).

Table 2. Results of the Direct Effect Test (*Direct Effects*)

Relationship between variables	Path Coefficient	t-Statistic	p-Value	Information
Digital Leadership Organizational Agility	0.340	3.450	0.001	Significant
Dynamic Capabilities of Organizational Agility	0.460	4.820	0.000	Significant
Dynamic Capabilities of Digital Transformation	0.380	3.910	0.000	Significant
Digital Leadership Digital Transformation	0.180	1.990	0.046	Significant
Digital Transformation Organizational Agility	0.420	4.500	0.000	

Source: Smart PLS processed data

Hypothesis testing is carried out using the method*bootstrapping*with 5,000 subsamples produced statistically significant findings regarding the direct influence between variables. Digital leadership was shown to have a positive and significant influence on organizational agility with a path coefficient value (*path coefficient*) of 0.34, the value*t-statistic*of 3.45, and*p-value*less than 0.01. Likewise, dynamic capabilities were found to have a very strong positive and significant influence on organizational agility with a path coefficient of 0.46, a value*t-statistic*of 4.82, and*p-value*less than 0.01. For the direct influence on the final endogenous variable, dynamic capabilities show a significant positive relationship to the success of digital transformation with a path coefficient of 0.38, a value*t-statistic*of 3.91, and*p-value*less than

0.01. Interestingly, the direct influence of digital leadership on the success of digital transformation was found to be positive but had a lower level of significance with a path coefficient of 0.18, a value*t-statistic*for 1.99, and*p-value*of 0.046. On the other hand, organizational agility has been empirically proven to have a large and significant direct influence on the success of digital transformation with a path coefficient of 0.42, a value of*t-statistic*of 4.50, and*p-value*less than 0.01.

Table 3. Results of the Indirect Effect / Mediation Test (*Indirect Effects*)

Mediation Relationship	**Indirect Coefficient**	**t-Statistic**	**p-Value**	**Mediation Statement**
Digital Leadership Organizational Agility Digital Transformation	0.143	2.670	0.008	Significant*(Partial Mediation)*
Dynamic Capabilities of Organizational Agility Digital Transformation	0.193	3.120	0.002	Significant*(Partial Mediation)*

Source: Smart PLS processed data

The most crucial finding in this study lies in the results of testing the indirect influence or mediation effect of the organizational agility variable.*specific indirect effects*shows that organizational agility acts as a partial mediator (*partial mediator*) in the relationship between digital leadership and the success of digital transformation with an indirect coefficient of 0.14, the value*t-statistic*of 2.67, and*p-value*of 0.008. A similar phenomenon was also found in the relationship between dynamic capabilities and the success of digital transformation, where organizational agility significantly mediated the relationship with an indirect coefficient of 0.19, a value*t-statistic*of 3.12, and*p-value*of 0.002. Overall, the results of this hypothesis test confirm that although the role of leadership and internal organizational capabilities are very important, the success of executing a rigid digital transformation that complies with SatuSehat regulations in hospitals is highly dependent on how agile (*agile*) the organization in responding to the uncertainty of its operational environment.

Table 4. R-Square Value (R^2) Model

Endogenous (Dependent) Variables	**R2 value**	**Model Predictive Power**
Organizational Agility*(Organizational Agility)*	0.480	Moderate / Strong Enough
Digital Transformation Success	0.650	Strong

Source: Smart PLS processed data

DISCUSSION

The results of the structural analysis in this study provide strong empirical confirmation regarding the crucial nature of Dynamic Capabilities Theory (*Dynamic Capabilities Theory*) in explaining the success of digital transformation in the healthcare sector, particularly in the context of the implementation of Electronic Medical Records (EMR) and the integration of the One Healthy system in hospitals. Based on statistical findings, the dynamic capabilities of the organization are manifested through the process of sensing (*sensing*), catch (*seizing*), and transform (*transforming*) has proven to be the main driving compass that directly and significantly boosts the success of digitalization of services. Hospitals that have the ability*sensing*sharp minds are able to predict the direction of national health regulations and identify the technology architecture most compatible with their clinical workflows. This capability is then executed through action.*seizing*in the form of precise capital investment allocation, selection of credible information system vendors, and formulation of data governance (*data governance*) rigid to ensure the security of patient medical records. Finally, through the phase*transforming*, management is able to reconfigure operational structures, realign incentive systems, and orchestrate change without triggering service paralysis.

This finding is in line with and strengthens previous research by Warner and Wäger (2019) which emphasized that digital transformation is essentially not just a momentary information technology adoption project, but rather a strategic renewal process (*strategic renewal*) which demands continuous reconfiguration of internal assets. In the highly regulated and risk-intensive healthcare sector, top management's ability to dynamically navigate change determines whether technology investments will lead to cost efficiency and service quality, or become trapped in disruptive system failure. This is also supported by an empirical study by Kraus et al. (2021), which highlights that traditional hospitals that successfully made the digital leap became*smart hospital*is a hospital that places managerial capabilities and business process flexibility above technological sophistication itself.

On the other hand, interesting findings emerged in testing the direct influence of digital leadership variables (*digital leadership*) on the success of digital transformation. Although the influence was recorded as positive and significant, the path coefficient value ($\alpha = 0.180$) was much smaller and the significance level was lower ($p = 0.046$) when compared to the direct influence of other variables. This unique phenomenon reflects the sociological characteristics of hospitals as a form of professional bureaucratic organization (*professional bureaucracy*In

the hospital environment, there is a very rigid dualism of authority between structural management (board of directors) and clinical authority held by medical professionals such as specialist doctors and nursing committees (Anwar et al., 2022). Therefore, the digital vision proclaimed by a top leader—no matter how great their digital literacy and commitment—will not be able to automatically execute transformation at the grassroots level if it is not bridged by operational cultural readiness and work system agility. Digital leadership requires a systemic intermediary instrument so that this macro vision can be translated into daily adaptive behavior by medical personnel who tend to be resistant to instant change.

This is supported by an empirical study by Kraus et al. (2021), which highlights that traditional hospitals that successfully made the digital leap to become smart hospitals are those that prioritize managerial capabilities and business process flexibility over technological sophistication. In Indonesia, this finding aligns with research by Wijaya and Rahmawati (2022) and Pratama et al. (2023), which emphasized that orchestrating dynamic capabilities through regulatory sensing and transforming internal business processes is a key determinant of SIMRS success amidst strict government mandates. Furthermore, an interesting finding emerged from testing the direct influence of digital leadership variables on the success of digital transformation, which was recorded as small. This unique phenomenon is similar to the results of a study by Setiawan and Nurhayati (2023) in Indonesia, which found that digital commitment from the board of directors often faces obstacles in its transmission to the grassroots level due to a strong professional bureaucratic culture and resistance from senior medical personnel who are comfortable with manual systems (Sudiyono et al., 2024). Therefore, as evidenced in this model, organizational agility is needed (Hidayat & Kristiani, 2024) as a systemic intermediary instrument.

The crucial intermediary instrument is answered through the proof of the role of organizational agility (*organizational agility*) as a mediating variable. The indirect effect analysis confirmed that organizational agility significantly mediates both the relationship between digital leadership and dynamic capabilities on the success of digital transformation. Organizational agility acts as an accelerator that transforms strategic potential into tangible execution capabilities. When digital leadership is able to build a transformative vision and dynamic capabilities provide a foundation of adaptive resources, hospitals will have high operational flexibility and strategic agility to respond to environmental disruptions without sacrificing patient safety indicators (*patient safety*). Partial mediation findings (*partial mediation*) This provides a new theoretical contribution that extends the conceptual model of

Tallon and Kraemer (2007), by proving that agility does not only apply to pure manufacturing or technology industries, but is also a determining factor for organizational survival in the healthcare sector which is full of human safety risks.

Practically and managerially, the results of this study provide valuable guidance for hospital directors and managers in Indonesia struggling to meet the Satu Sehat and RME integration mandates. Management strategies should no longer focus on an ethnocentric approach that simply spends budget on new hardware or SIMRS applications without regard for organizational readiness. Management must consciously invest time and resources in building digital leadership across all work units (including appointing a digital leader).*champion*(including digital collaboration among doctors and nurses) and developing flexible standard operating procedures (SOPs) while remaining compliant with health law. Successful digital transformation in hospitals is achieved when the adopted technology blends with the agility of the staff's work culture, thereby mitigating waiting times for services and minimizing*human error*in medical data input, increasing the efficiency of health financing claims, and ultimately leading to a holistic improvement in the quality of patient safety and satisfaction.

CONCLUSION

This research successfully provides empirical evidence that the success of digital transformation in the healthcare sector, particularly in the implementation of Electronic Medical Records (EMR) and the integration of the Satu Sehat platform in hospitals, cannot be achieved solely through an ethnocentric approach that relies solely on technological infrastructure procurement. Through the lens of Dynamic Capability Theory (*Dynamic Capabilities Theory*), this study concludes that strategic orchestration includes management's ability to sense regulations (*sensing*), seize investment opportunities (*seizing*), as well as reconfiguring the culture and structure of the organization (*transforming*) acts as a key foundation for a successful digital transition (Teece, 2007; Warner & Wäger, 2019). Hospital strategic management must be able to align technology adaptation with internal operational dynamics to prevent digital investments from leading to stagnation or disruptive resistance from healthcare professionals (Anwar et al., 2022).

The results of the structural analysis in this study provide strong empirical confirmation regarding the crucial role of Dynamic Capabilities Theory in explaining the success of digital transformation in the healthcare sector... These findings align with and strengthen previous research by Warner and Wäger (2019). In the context of healthcare services in Indonesia, these findings also confirm studies by Wijaya and Rahmawati (2022) and Pratama et al. (2023) which state that hospitals' capabilities in restructuring internal business processes (transforming) and dynamically orchestrating resources are the most dominant predictors of winning the competition in the era of digital disruption.

Furthermore, this study reveals crucial findings regarding the role of organizational agility (*organizational agility*) as a mediating variable that bridges the influence of digital leadership and dynamic capabilities on digital transformation outcomes. The unique characteristics of hospitals as professional bureaucracies with a rigid dualism of authority mean that the digital leadership vision cannot have an immediate and direct impact on the success of the system in the field (Kraus et al., 2021). This leadership vision and the availability of resources require operational flexibility, responsiveness, and strategic organizational agility to be adopted into daily adaptive behavior by clinical and administrative staff (Tallon & Kraemer, 2007). Thus, the integrative model produced in this study confirms that the level of agility and flexibility of the hospital work system in responding to national regulations is a key determinant that ensures the success of sustainable digital transformation without sacrificing patient safety indicators (*patient safety*).

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THE EFFECT OF GREEN PERCEIVED VALUE ON CONSUMER ATTITUDE WITH GREEN TRUST AS A MEDIATING VARIABLE IN FEMALE CONSUMERS WHO USE ECO-FRIENDLY COSMETICS IN PALEMBANG CITY

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Abstract

This study aims to analyze the influence of green perceived value on consumer attitude with green trust as a mediating variable in female consumers who use eco-friendly cosmetics in Palembang City. Increasing public awareness of environmental issues encourages changes in consumption behavior, including the use of more sustainable cosmetic products. However, high product prices and doubts about eco-friendly claims are still the main obstacles in forming positive consumer attitudes. This study uses a quantitative approach with an online survey method through the distribution of questionnaires to 120 respondents who are female consumers in Palembang City who have bought and used eco-friendly cosmetics. The data analysis technique used Partial Least Square-Structural Equation Modeling (PLS-SEM) with the application of SmartPLS 3.0. The results of the study showed that green perceived value has a positive and significant effect on green trust and consumer attitude. In addition, green trust also has a positive and significant effect on consumer attitude. The results of the mediation test showed that green trust was able to partially mediate the relationship between green perceived value and consumer attitude. This finding indicates that the higher of the value that consumers feel about the benefits of eco-friendly cosmetic products, the higher the level of consumer trust which ultimately encourages the formation of positive attitudes towards the product. This research provides implications for cosmetics industry players to increase the perception of consumer value and trust through eco-friendly cosmetics product quality, information transparency, and credibility of eco-friendly claims.

Keywords: *green perceived value, green trust, consumer attitude, consumer behavior*

INTRODUCTION

The global cosmetics industry is currently experiencing rapid development in line with increasing consumer awareness of health and environmental issues. One of the growing trends among female consumers today is the use of eco-friendly cosmetics which not only pays attention to the quality of the product, but also begins to focus on its impact on the environment issues. The beauty sector creates more than 120 billion units of plastic packaging every year, of which about 40% of the packaging is made of single-use plastic that is difficult to decompose and recycle, most of which seriously contributes to global plastic waste (Shalmont, 2020) . Another impact is the increasingly polluted environment due to excessive consumption patterns and the use of single-use packaging in the growing beauty product industry, as reported by Tempo.co (2026) that the cosmetics industry is one of the significant contributors to environmental problems, especially related to plastic waste. Most cosmetic products are

made from synthetic, naturally non-biodegradable plastics, which can last up to hundreds of years. Examples of the materials are *petroleum-derived Acrylonitrile Butadiene* (ABS), as well as the *Styrene copolymer Acrylonitrile*. Both types of materials are generally not accepted in the recycling process due to their complicated chemical composition and frequent labeling. The majority of this waste will end up in landfills or incinerators.

In Indonesia, the trend of cosmetic use is increasing every year, especially among women as the surge of awareness of the importance of self-care increases. Based on market estimates from Statista (2025), the cosmetics sector in the country continues to show significant development with a market potential estimated to reach USD 9.7 billion in 2025 and also predicted to experience growth of 4.33 percent annually until 2030. This figure reflects an increase in interest of local cosmetic products. However, the increase in cosmetic consumption is also followed by the increase in cosmetic packaging waste that can have a negative impact on the environment. This situation is slowly increasing public understanding of the environmental effects due to the use of cosmetics with single-use plastic packaging, which ultimately encourages consumers to switch to more eco-friendly products. (Utomo & Dwiyanto, 2022)

However, the adoption of eco-friendly cosmetics still faces various challenges, including the low interest of consumers to start switching to more eco-friendly cosmetic products. This happens because the price of eco-friendly cosmetic products is relatively higher than the price of conventional products, thus causing considerations for consumers in deciding to make a purchase. In addition, there are still doubts about the credibility of eco-friendly claims submitted by cosmetic manufacturers. In addition, the rise of greenwashing against consumers is a marketing practice that exaggerates eco-friendly claims but in reality is not the same, causing consumers to become more cautious and not easily trust cosmetic products labeled "eco" or "natural". This condition shows that consumer decisions are not only influenced by the characteristics of the products offered but are also formed by green perceived value and the level of green trust in the product. (Adawiyah & Halida, 2024)

Theoretically, the concept of Perceived Value explains that consumers will evaluate a product based on the comparison between the benefits obtained and the sacrifices made. The higher the perceived value, the more likely it is that consumers will form a positive attitude towards the product. However, in the context of eco-friendly cosmetic products, green perceived value is not only limited to functional benefits, but also includes moral values and long-term value to environmental sustainability. Consumers who have green trust tend to not only consider price as the main sacrifice, but also see the purchase of the product as a form of contribution to environmental conservation. Therefore, consumers are willing to accept a relatively higher price as long as they believe that the product is able to have a positive impact on the environment. (Jansri, 2018) (Hartanto et al., 2023)

However, the green perceived value will not automatically form a positive attitude without green trust. Consumers need to have green trust that eco-friendly cosmetic products are really safe, of quality, and have environmental claims that can be accounted for. Without green trust, the sacrifices made by consumers, such as paying more, can cause doubt and even resistance to the product. Therefore, green trust is an important factor that ensures that the value felt by consumers can be translated into a positive attitude towards eco-friendly cosmetic products. (Rimbawati Dewi et al., 2021)

Green trust (trust) is a crucial factor in shaping consumer attitudes towards products, especially in the context of eco-friendly products. Green trust not only reflects confidence in product quality and safety, but also includes green trust in the credibility of environmental claims submitted by manufacturers. In the context of eco-friendly cosmetics, consumers not only evaluate the functional benefits, but also consider whether the product really contributes to environmental sustainability or is simply a marketing claim (greenwashing). (Vebriyanto et al., 2023)

Theoretically, green trust acts as a psychological mechanism that bridges the relationship between green perceived value and attitude. When consumers feel high value from a product, both in terms of personal benefits and environmental benefits, it will increase green trust in the product. This green trust then becomes the basis for forming a more positive attitude. On the other hand, if green trust in eco-friendly claims is low, then the perceived value will not fully translate into a positive attitude. Thus,

consumers who have high trust not only believe in the quality of the product, but also in the long-term impact of the use of the product on the environment. This encourages the formation of a stronger and more sustainable attitude towards the use of eco-friendly cosmetics. (McKnight et al., 2002)

The relationship between green perceived value, green trust, and attitudes in the context of using eco-friendly cosmetics shows a close relationship but understanding how these relationships function in the situation and character of consumers in certain regions certainly requires further study. The city of Palembang was chosen as the research site because it is one of the major cities in Indonesia that is experiencing rapid economic growth and urbanization. In addition, the growth of the retail sector and the beauty industry continues to increase. People in Palembang City, especially female consumers, show increasingly modern consumption behavior and are open to the trend of using cosmetic products, including eco-friendly cosmetic products.

Therefore, this study needs to be conducted with the aim of analyzing how green perceived value affects consumer attitudes with green trust as a mediating variable in female consumers in the city of Palembang. The results of this study are expected to contribute to the development of marketing science, especially consumer behavior, and can also be a reference for cosmetics industry players in developing more effective and sustainable marketing strategies in the future.

1. THEORETICAL FOUNDATION

Consumer Behavior

Consumer behavior is the study of how individuals, groups, and organizations choose, buy, use, and evaluate products or services to meet their needs and desires. According to Philip Kotler, consumer behavior is influenced by cultural, social, personal, and psychological factors. In the context of eco-friendly cosmetics, the behavior of female consumers is not only influenced by the need for beauty, but also by awareness of the environmental impact of the products used. In addition, consumer behavior also reflects a decision-making process that involves the evaluation of various product alternatives. Consumers tend to choose products that provide the greatest benefits with minimal sacrifice. Therefore, understanding consumer behavior is important to know how consumers respond to eco-friendly cosmetic products. (Marcelo et al., 2024) (Miniard & Cohen, 1981)

Green Perceived Value

Perceived Value Theory is one of the important theories in the world of marketing that outlines the way consumers evaluate products, services, or policies by comparing the benefits obtained and the costs incurred explaining that green perceived value is the overall assessment of consumers on the usefulness of an object based on their views on what is accepted and what should be handed over. In the context of eco-friendly cosmetics, perceived value includes various aspects such as product quality, health benefits, impact on the environment, and the price to be paid. The higher the value perceived by consumers, the more likely consumers are to have a positive attitude towards the product. (Zeithaml et al., 1988)

Green Trust

Trust is consumer confidence in the reliability and integrity of a product or brand. Green trust is an important factor in forming a long-term relationship between consumers and products so that it is the basis for building a sustainable relationship between the company and consumers. In eco-friendly cosmetic products, trust is related to the belief that the product is completely safe to use, has good quality, and is in accordance with the environmental claims given. A high level of green trust will encourage consumers to have a positive attitude and increase the likelihood of using the product sustainably. In this study, green trust is measured through green trust indicators on product quality, product safety, environmental claims, and producer credibility. (Morgan & Hunt, 1994)

Consumer Attitude

Consumer attitude is a consumer's evaluation or assessment of a product, which can be in the form of positive or negative attitudes. Attitude is a psychological construct consisting of three main parts, namely cognitive, affective, and conative. The cognitive part is related to a person's knowledge, beliefs, or views on an object, for example how consumers understand the value and characteristics of a product. Furthermore, the affective part shows a person's feelings or emotions towards the object, such as feelings of like or dislike that arise based on personal experience or judgment. While the conative part refers to a person's tendency or intention to act towards the object, such as the desire to buy or use a certain product. These three parts are interconnected and together form a person's attitude in responding to an object or phenomenon. (Miniard & Cohen, 1981)

In the context of eco-friendly cosmetics, attitudes reflect how female consumers rate the product, whether they support, like, or even doubt its use. A positive attitude will increase the likelihood of consumers using the product consistently. In this study, consumer attitude was measured through three main components, namely cognitive, affective, and conative, as well as overall evaluation. (Purba et al., 2024)

Hipotesis

H1 Green perceived value affects green trust in the use of eco-friendly cosmetics among female consumers in Palembang City.

H2 Green trust affects consumer attitudes in the use of eco-friendly cosmetics among female consumers in Palembang City.

H3 Green perceived value affects consumer attitudes in the use of eco-friendly cosmetics among female consumers in Palembang City.

H4 Green trust mediates the influence of environmental perception on consumer attitudes in the use of eco-friendly cosmetics among female consumers in Palembang City.

2. RESULTS AND DISCUSSION

Respondent Profile

Respondents in this study focused on female consumers who use eco-friendly cosmetics in Palembang City who have carried out purchasing activities and using eco-friendly cosmetics in the past month The results of the respondents' profiles can be seen in the following table.

Table 1. Profile of Research Respondents

Respondent Profile	Category	Number (people)	Percentage (%)
Age	< 20 years old	10	8,3
	20-30 years	30	25,0
	31-40 years old	40	33,3
	> 40 years old	40	33,4
Jobs	Student/Student	10	8,3

	Private Employees	40	33,3
	Civil Servant	30	25,0
	Entrepreneur/Self-employed	20	16,6
	Others	20	16,6
Period of Use	1 month	15	12,5
	> 1 month	45	37,5
	> 6 months	60	50,0

Source: Questionnaire data processing, 2026

Based on Table 1, the overall of the 120 respondent profiles in this study shows that the respondent profile shows that eco-friendly cosmetic users are dominated by the adult age group, namely 31–40 years old and above 40 years old, which reflects that the level of maturity tends to be related to increased awareness of health and the environment. In terms of employment, the majority of respondents are private employees and civil servants, which indicates that consumers with relatively stable incomes are more able to access eco-friendly cosmetic products which generally have higher prices than conventional products. Meanwhile, in terms of the period of use, most of the respondents have used the product for more than 6 months, which shows that eco-friendly cosmetics are not only used on a trial and error basis, but have become part of consumption habits. Overall, this profile illustrates that the eco-friendly cosmetics market tends to develop among consumers who are more mature, have economic stability, and already have enough experience in use, so they better understand the value and benefits of the product.

Data Analysis

Uji Outer Model

The *Outer Model* Evaluation aims to ensure that the indicators used in the study are able to describe the variables to be measured appropriately and precisely. The tests carried out are the measurement of convergent validity by looking at *the value of outer loading* and *average variance exctracted* (AVE) and measuring the reliability of variables by looking at the *value of composite reliability* (CR).

To test the validity of the convergence, the *outer loading*. An indicator is declared to meet convergent validity in a good category if the value *outer loading* > 0.708. After the outer loading test is carried out and all indicators meet the minimum limit, the next step is to test the convergent validity through the value (Hair Josep F, 2021). *Average Variance Extracted* (AVE). This test aims to see how much variance the indicator can be explained by its variable. A latent variable is declared to be valid convergently if the AVE value is > 0.5 . Then the reliability of the variable is tested using the value (Hair, 2022) *Composite Reliability* (CR). The variable is declared reliable if the CR value is > 0.70. The higher the CR value, the better the consistency of the indicator in measuring the variable in question. The results of the outer model test are as follows: (Hair, 2022)

Table 2. Outer Loading Test Results

Variabel	Indicator	Statement Items	Scale	Outer Loading

Green perceived value (X)	PV1	Functional Value	Eco-friendly cosmetic products have good quality	Likert (1-5)	0,798
	PV2	Emotional Value	Satisfied with using eco-friendly cosmetics	Likert (1-5)	0,711
	PV3	Environmental Value	Eco-friendly cosmetics provide benefits for the environment	Likert (1-5)	0,684
	PV4	Price value	The price of eco-friendly cosmetics is proportional to the benefits received	Likert (1-5)	0,748
Green trust (Z)	GT1	Believe in Quality	Confident the quality of eco-friendly cosmetics is reliable	Likert (1-5)	0,755
	GT2	Trust in Security	Believe eco-friendly cosmetics are safe to use	Likert (1-5)	0,850
	GT3	Trust the claims	Believe the eco-friendly claims on the product are true	Likert (1-5)	0,824
	GT4	Manufacturer credibility	Believe eco-friendly cosmetics manufacturers have a commitment to the environment	Likert (1-5)	0,784
Consumer attitude (Y)	CA1	Cognitive	eco-friendly cosmetics as a good product	Likert (1-5)	0,755
	CA2	Affective	Like the use of eco-friendly cosmetics	Likert (1-5)	0,850
	CA3	Konative	interested in using eco-friendly cosmetics regularly	Likert (1-5)	0,824
	CA4	Overall Evaluation	Overall, I have a positive attitude towards eco-friendly cosmetics	Likert (1-5)	0,784

Source: SmartPLS data processing, 2026

Table 3. CR and AVE Test Results

	Composite Reliability	**Average Variance Extracted**
Green Trust_	0.855	0.595
Green Perceived value	0.825	0.542
Consumer Attitude	0.879	0.646

Source: SmartPLS data processing, 2025

Based on Table 3, all research variables have a value *average variance extracted* (AVE) > 0.50 and CR > 0.70, so all indicators in this study are able to explain the latent variables well and are suitable for use at the next stage of analysis.

Uji Inner Model

Internal model *testing* is carried out through *path coefficient* analysis to see the direction and strength of influence between variables. Then using the R-Square (R2) value to assess how much the dependent variable is explained by independent variables. Then to ensure the significance of each relationship, *a bootstrapping* procedure is used so that a T-Statistic or P-Value value is obtained. Then *Standardized Root Mean Square Residual* (SRMR) is used to ensure that the structural model as a whole has a good level of fit *(model fit*). The results of the data processing are then depicted in the form of a path diagram to provide a clear understanding of the direction and strength of the relationship between the variables being studied. The path diagram shown is the final result after the bootstrapping process, thus reflecting the statistically significant relationship between the constructs in the research model. The path diagram can be seen in the following image:

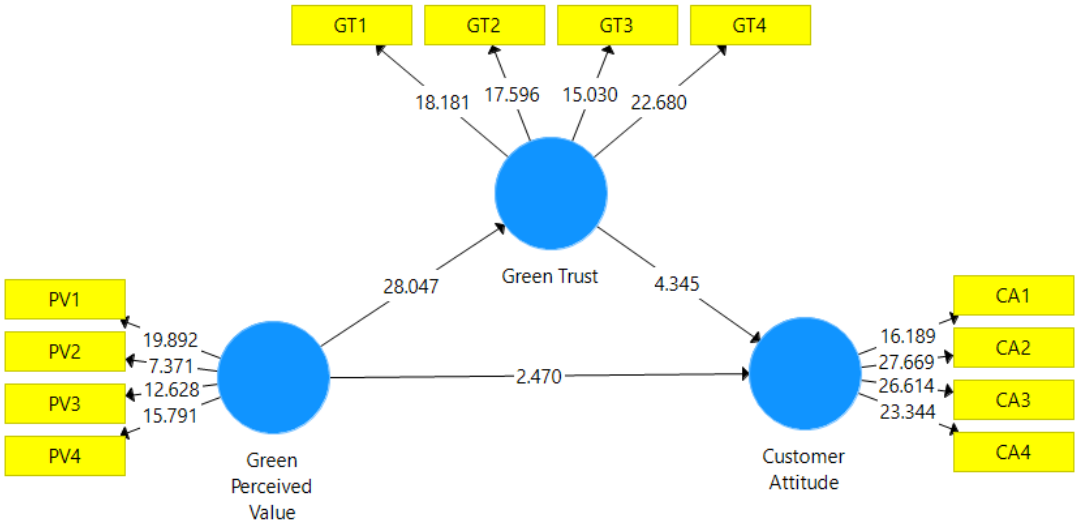


Figure 1. Bootstrapping Path Diagram

From figure 4.1, it can be seen that all the relationships between the variables in the study have a positive direction. affect Green trust and Consumer attitude, and Green trust also affects Consumer attitude. Overall, these findings show that the proposed research model can explain the relationship between variables significantly.

Direct Relationship Hypothesis Test

Hypothesis testing is carried out to test the relationships between variables that have been designed in the *inner model*. Hypothesis testing is carried out by looking at the *path coefficient* that determines the direction and strength of the relationship between variables and looking at the significance through the T-Statistic or P-Value value. The criterion for hypothesis acceptance is if the T-Statistic >1.645 for a significance level of 5% or alpha 0.05. The higher the T-Statistic value, the stronger the relationship between variables. The P-Value < 0.05 indicates that the relationship between variables is statistically significant at a significance level of 5%. The hypothesis is rejected if the relationship between variables is not significant where the T-Statistic < 1.645 or the P-Value > 0.05. In this study, there are three

direct relationship hypotheses and one indirect relationship hypothesis using the mediation variable. The results of hypothesis testing are shown in the following table: (Hair, 2022)

Table 5. Hypothesis Test Results (Direct Effect)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values	Ket
Green trust _ -> Consumer attitude	0.549	0.548	0.122	4.496	0.000	Accepted
Green perceived value -> Green trust	0.836	0.836	0.031	27.348	0.000	Accepted
Green perceived value -> Consumer attitude	0.282	0.284	0.115	2.446	0.015	Accepted

Source: SmartPLS data processing, 2026

Judging from table 5 , the results of hypothesis testing in this study are as follows:

H1 Green perceived value has a positive effect on consumer attitude in use eco-friendly cosmetics among women in Palembang City. The results of the analysis showed that the Green perceived value had a positive and significant impact on Green trust with a coefficient of 0.836, a t-statistical value of 27.348, and a p-value of 0.000. Therefore, H1 was accepted. This shows that the higher the view of female consumers regarding the value and benefits of using eco-friendly cosmetics, the more their confidence about the need to protect the environment will also increase.

H1

H2 Green perceived value has a positive effect on green trust in the use of friendly cosmetics environment among women in Palembang City. The results of the test indicated that Green trust had a significant positive impact on consumer attitude with a coefficient of 0.549, t-statistic of 4.496, and p-value of 0.000. Therefore, H2 was accepted. These findings suggest that increasing green trust among female consumers will trigger the formation of better attitudes towards the use of eco-friendly cosmetics.

H3 Green trust has a positive effect on consumer attitudes in the use of eco-friendly cosmetics among women in Palembang City. The results of the test indicated that Green trust had a positive and significant impact on consumer attitude, with a coefficient of 0.282, a t-statistic of 2.446, and a p-value of 0.015. With this, H3 was accepted. This means that female consumers' views on the value of using eco-friendly cosmetics can directly influence their attitudes, although the impact is smaller than through mediation variables.

Indirect Effect Hypothesis Test

Table 6. Hypothesis Test Results (Indirect Effect)

	T Statistics (|O/STDEV|)	P Values	Ket

Green trust _ -> Consumer attitude			
Green perceived value -> Green trust			
Green perceived value -> Consumer attitude	4.404	0.000	Accepted

Source: SmartPLS data processing, 2026

Based on table 6 above, it shows that partially green perceived value has a positive and significant influence on consumer attitude, with a T-statistical value of 4.404 (> 1.96) and a P-value of 0.000 (< 0.05).

H4 Hypothesis is acceptable where the higher the green perceived value felt by consumers, the more positive the consumer attitude towards the product. This finding indicates that female consumers tend to form a good attitude when they feel that they get benefits, quality, and value that are comparable or higher than the sacrifices made. Partially, the green perceived value variable has proven to be an important factor in influencing consumer attitude, so it can be a major concern in marketing strategies to increase positive consumer responses.

Determinant Coefficient Test (R2)

The Determinant Coefficient (R^2) was tested to see how much the green perceived value variable was able to explain the green trust and consumer attitude variables. The R^2 value ranged from 0 to 1, the higher the R^2 value, the greater the model's ability to explain the dependent variable. The R^2 value limitation criteria are divided into three classifications, namely 0.75 as substantial; 0.50 as moderate and 0.25 as weak. The results of the R^2 test can be seen in the following table: (Hair, 2022)

Table 7. R^2 Test Results

	R Square
Green Trust	0.699
Consumer Attitude	0.639

Source: SmartPLS data processing, 2026

Based on Table 7. The value of R-square indicates that the Green trust has a value of 0.699, which indicates that Green perceived value has a strong or substantial influence in explaining the variation in Green trust. Meanwhile, the Consumer attitude variable has an R-Square value of 0.639, which also shows that Green perceived value and Green trust together make a strong contribution to shaping consumer attitude. Overall, the R-Square value reflects that the research model has good explanatory power, where independent variables are able to explain most of the variation in dependent variables substantially.

Test Model Fit

The *Model Fit* test is used to assess how well the model is produced in matching existing data. The assessment of model suitability in this study using the value index of the *Standardized Residual Root Mean Square* (SRMR) measures the extent to which the research model matches the empirical data by looking at the difference between the model covariance matrix and the observation data covariance matrix. The smaller the SRMR value, the better the model suitability. The SRMR value < 0.08 is considered a good suitability. The results of the fit model test are as follows:

Table 8. Test Results (F2)

	Saturated Model	Estimated Model
SRMR	0.096	0.096

Source: SmartPLS data processing 3, 2026

Based on table 8. It can be seen that the SRMR value obtained of 0.096 indicates that the research model has an acceptable level of compatibility, although it is slightly above the recommended ideal limit. Thus, the model as a whole is still considered feasible to be used in explaining the relationship between variables in this study.

Discussion

The Influence of Green Perceived Value on Green Trust

The results of this study show that the perception of Value has a positive and significant influence on Green trust. This finding is in line with the Perception Value Theory which states that the way a person sees the benefits will affect their reaction to a policy. When female consumers see the use of cosmetics as something beneficial, especially for nature, it encourages them to be more aware of the importance of protecting the environment. The strength of this relationship is also reflected in the very high t-statistic values, suggesting that the perception of Value is a major factor in the formation of Green trust. This suggests that the perception of value not only serves as a cognitive assessment, but is also able to drive a significant change in awareness. In addition, the characteristics of respondents who are dominated by adults also reinforce this finding. This age group usually has a greater level of maturity in thinking and concern for environmental issues, so they are better able to understand and respond to the value of existing policies. (Immawati et al., 2024; Sarasuni, 2021) (Lu'ul Jannah et al., 2021)

The Influence of Green Trust on Consumer Attitude

Awareness about the environment has been shown to have a great impact on consumer behavior. This can be explained through *the Theory of Planned Behaviour* which states that a person's attitude is formed from personal beliefs and judgments about an action. Female consumers who have a high awareness of the adverse effects of the harmful use of cosmetic plastics tend to have a better view of policies that aim to reduce their use. With the increasing level of green trust, consumers are not only aware of the consequences of the use of cosmetics that are not eco-friendly, but also tend to support policies that focus on environmental sustainability. This shows that green trust serves as a key element in forming a more positive consumer attitude. (Ajzen, 1991) (Hartanto et al., 2023; Lu'ul Jannah et al., 2021)

The Effect of Green Perceived Value on Consumer Attitude

Green perceived value has a considerable impact on consumer attitude, although the influence is not as strong as if it were through intermediary variables. Based on the *theory of perceived value*, how consumers perceive the benefits of a policy will affect their assessment of the policy. However, the findings of this study indicate that simply having green perceived value is not enough to create an ideal attitude. In other words, even if consumers are aware of the benefits of existing policies, without strong green trust, the attitudes formed are not optimal. This shows that in the context of environmentally supportive behaviors, cognitive and awareness elements must go hand in hand. (Hartanto et al., 2023) (Pradani & Wati, 2025)

The Influence of Green Perceived Value on Consumer Attitude through Green Trust as a Mediator

The results of the study show that Green trust functions as a partial link in the relationship between Green perceived value and Consumer attitude. In the context of *the Theory of Planned Behavior*, green trust can be seen as an element of belief that influences the development of attitudes. This finding shows that the impact of Green perceived value on consumer attitude takes place not only directly, but also through increasing Green trust which functions as a mechanism to strengthen attitude formation. Therefore, the higher the value felt by female consumers, the greater the green trust which ultimately triggers the formation of a more positive attitude towards the view of using eco-friendly cosmetics. (Ajzen, 1991) (Hartanto et al., 2023; Putria et al., 2025)

3. CONCLUSION

Based on the analysis conducted, it can be concluded that green perceived value has a positive and significant effect on Green trust and consumer attitude. In addition, Green trust also has a significant impact on Consumer attitude. Green trust functions as a mediator in part in the relationship between green perceived value and consumer attitude. This shows that the influence of green perceived value on consumer attitude does not only occur directly, but also through increasing Green trust which is a tool to strengthen attitude formation. The results of this study confirm that in the context of the use of eco-friendly cosmetics in female consumers, consumers' perspective on the value and benefits of the policy is very important in building Green trust, which in turn encourages better attitudes. Therefore, the successful implementation of this policy does not only depend on regulations, but also on the way consumers understand and interpret the value of the policy.

Recommendations

Based on the results of the study, cosmetics industry players are advised to improve product value communication more clearly and educationally, especially related to environmental benefits and product safety, in order to strengthen the perception of value in the eyes of consumers. In addition, companies need to build trust through ingredient transparency, official certification, and avoid greenwashing practices that can reduce credibility. Marketing strategies should also be adjusted to consumer characteristics, especially in the adult age group and consumers with stable incomes who are potential markets. On the other hand, education to younger consumers also needs to be improved so that awareness of the use of eco-friendly cosmetics can develop more widely in the future.

Implications

The findings of this study show that value perception and trust have an important role in shaping consumer attitudes towards eco-friendly cosmetics. This means that consumer decisions are not only determined by the functional quality of the product, but also by how consumers assess the environmental benefits and the extent to which they believe the claims made. This implies that companies need to manage product value comprehensively, not only from the quality aspect, but also information transparency and brand credibility. In addition, these results also reinforce that trust is an important mechanism that bridges the perception of value to attitudes, so that without trust, the value felt by consumers will not be optimal in forming positive attitudes.

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BUYER INTEREST IN THE HAR RESTAURANT SINCE 1947 IN THE CITY OF PALEMBANG

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Abstract

Consumer behavior manifests as an interest or desire to purchase a product or service. In terms of purchasing interest, consumers are categorized as potential consumers—that is, consumers who have not yet made a purchase at the present time and can be referred to as prospective buyers. This study aims to determine the influence of product innovation, price perception, and promotion on purchase interest at HAR Restaurant in Palembang, considering that HAR Restaurant, which has been in operation since 1947, remains in business despite the emergence of many modern food options that are also popular among the public. The population in this study consists of all consumers who have dined at HAR Restaurant across from the Grand Mosque, at Simpang Sekip, and in front of PTC within the last 3 months. Based on the survey, more than 1,000 people have dined at HAR Restaurant, but only 850 respondents returned the questionnaire; therefore, the sample size is 850 respondents. The sampling technique used was random sampling. To determine the sample size, the researcher used the Slovin formula with a 10% margin of error, resulting in a sample of 90 respondents. The results of the multiple regression analysis showed that, in part, product innovation influences purchase intention with a coefficient value of 0.618, price perception influences purchase intention with a coefficient value of 0.319, and promotion influences purchase intention with a coefficient value of 0.327. The results of the coefficient of determination test indicate that the variables of product innovation, price perception, and promotion account for 60.1% of the variation, while the remaining 38.9% is influenced by other variables not included in this study.

Keywords: *Product Innovation, Price Perception, Promotion, Purchase Intention*

1. Introduction

Martabak HAR is one of Palembang's most famous and legendary dishes. It has become a must-try culinary icon alongside Pempek for tourists visiting Palembang. The delicious egg martabak is served with curry sauce, black vinegar, and sliced green chili peppers. Spicy and aromatic. Martabak HAR is an egg martabak served with curry sauce and a blend of spices mixed with potatoes and sliced meat. This martabak has been around since 1947. The man who first created it, Haji Abdul Rozak, was an Indian immigrant who decided to settle in Palembang. The name "HAR" itself is an acronym for Haji Abdul Rozak. As for its distinctive features, this martabak uses a lot of spices. "The sauce uses plenty of spices. Combined with potatoes and sliced meat, Martabak HAR isn't just served with curry sauce but also black vinegar mixed with sliced green chili peppers. The sensation is a sharp, stinging heat when the customer bites into that slice of green chili."

Although Martabak HAR has been around since 1947, it remains in high demand—not only among older generations but also among today's youth—thanks to innovations in how Martabak HAR products are sold, which have enhanced the convenience and service for customers when enjoying or purchasing Martabak HAR products. Currently, in the city of Palembang, Martabak HAR is sold everywhere—from well-established shops to small kiosks—both in the Ulu and Ilir districts of Palembang. Below is a list of Martabak HAR restaurants in the city of Palembang.

Tabel 1

HAR restaurants in Palembang

Number	Shop	Address
1	Martabak HAR Masjid Agung	Jl. Sudirman dekat Megaria
2	Martabak HAR Sekanak	Jl. Sekanak
3	Martabak HAR simpang Sekip	Jl. Sudirman
4	Martabak HAR Demang	Jl. Demang Lebar Daun
5	Martabak HAR mas Adi	Jl. Srijaya Negara
6	Martabak HAR Palembang Icon	Mall Palembang Icon
7	Martabak HAR 1947	Depan PTC
8	Martabak HAR Herbes	Jl.Jendral Sudirman
9	Martabak HAR Maraton	Jl. Jendral Sudirman
10	Martabak HAR KM 9	KM 9 Palembang

Source: Survey Results

Given the continued existence of the original Martabak HAR restaurant and the growing number of Martabak HAR restaurants in the city of Palembang, the author felt it necessary to conduct research on the influence of product innovation, price perception, and promotion on purchase intent at Martabak HAR restaurants.

2. Literature Review

2.1. Theoretical Framework

A. Product Innovation

Innovation is defined as the introduction of something new, and innovation itself is often associated with something that people perceive as a novelty in their environment. However, in marketing, it is often associated with a product or service that has new characteristics; in other words, innovation is a "process" or the "result" of various developments undertaken to create and improve a product so that it becomes more meaningful (Wijana et al., 2023). According to Wahid & Santoso (Agustin & Prio Santoso, 2023), innovation encompasses not only products but can also take the form of ideas or methods for effecting change.

According to Kotler and Keller (Sanana et al., 2021), product innovation is "any good, service, or idea that someone perceives as new, regardless of its history, or the spread of a new idea from its source of invention or creation to its ultimate users or adopters." This means that innovation is a product, service, or idea that is considered new by someone, regardless of its history, or the spread of a new idea from its source of invention or creation to its users. Based on the above definition, it is concluded that product innovation is the ability to create added value or utility, select and develop or improve a product, and maintain product quality so that the product differs from its original form. Dhewanto et al. (Sanana et al., 2021) explain that product innovation can be measured by product quality, product features, and product design. Innovation is a necessity and serves as one of the essential factors and key determinants for winning global competition and achieving the ultimate goals of a company or organization, as the current business environment is characterized by rapid and uncontrollable changes (Kurniawan et al., 2023).

B. Price Perception

According to Wiranto & Adialita (Fadillah & Ludiya, 2024) Price perception is a consumer's subjective evaluation of a price—whether it is perceived as low, high, or fair—by comparing the value of the product and service with that of competitors. The perceived price depends on the quality of service, which must be commensurate with the sacrifice made, as price perception reflects the customer's actual experience regarding a specific transaction and their overall evaluation (Liu & Lee in Fadillah & Ludiya, 2024). Price perception indicators, according to Kotler and Keller (Mufidah & Darmawan, 2025), are divided into four categories: 1) Affordability—the price is within consumers' reach based on the selected market segment; 2) Price-quality fit—the amount consumers pay is commensurate with the quality provided relative to its specifications; 3) Price competitiveness, where the offered price may be higher or lower than the average; and 4) Price-benefit alignment, where consumers will naturally feel satisfied with the benefits received after obtaining a product at a suitable price.

C. Promotion

According to Tanata & Christian (Agustin et al., 2023), promotion refers to all actions taken to market a product to the market with the aim of providing customers with information about its advantages, benefits, and availability, thereby encouraging them to purchase it. Promotion is one of the marketing activities used by companies to introduce and inform consumers about the benefits of a product (Ati et al., in Zararosa & Khasanah, 2023).

D. Purchase Intention

According to Afriyanti & Rahmidani (Agustin et al., 2023), purchase intention is an attitude that arises in a person's consciousness and drives them to act in accordance with their desires. Kotler (Mufidah & Darmawan, 2025) states that purchase intention is the behavior exhibited by consumers when they wish to make a selection in advance before using a product. According to Hasan (Wahyudianto, 2020), purchase intention is a consumer's tendency to buy a product or take actions related to a purchasing decision, measured by the likelihood of the consumer making a transaction.

According to Ferdinand (Sepyadi et al., 2022), purchasing interest can be identified through the following indicators: a. Transactional interest, which is a person's tendency to purchase a product. b. Referential interest, which is a person's tendency to recommend a product to others. c. Preferential interest, which describes the behavior of a person who has a primary preference for that product. This preference can only be replaced if something is associated with their preferred product. d. Exploratory interest, which describes the behavior

of a person who is constantly seeking information about the product of interest and looking for information to support the positive characteristics of that product.

2.2. Previous Research

1. Research by Putu Ade Wijana, Luh Kadek Budi Martini in 2023, and Robertus Mataufue titled "The Effect of Product Innovation, Price Perception, and Promotion on Purchase Intention at Maya Sanur Resort & Spa," found that the independent variables—product innovation, price perception, and promotion—have a positive and significant effect on purchase intention.
2. A study by Anita Sanana, Muslichah Erma W, and Enny Istanti in 2021 "The Influence of Product Innovation, Promotion, Electronic Word of Mouth (eWOM), and Brand Image on Purchase Interest in Pucelle Products During the Covid-19 Pandemic in Surabaya" found that the independent variables—product innovation, price perception, and promotion—have a positive and significant influence on purchase interest
3. A study by Vernando Wijaya, Fenny Krisna Marpaung, and Christin Imelda Girsang in 2026 titled "The Effect of Product Innovation, Promotion, Pricing on Purchase Interest in Kopi Kenangan" The results of this study suggest that a combination of attractive product innovation, effective promotional strategies, and appropriate pricing are key factors in increasing consumer purchase interest in Kopi Kenangan products.

2.3.Research Framework

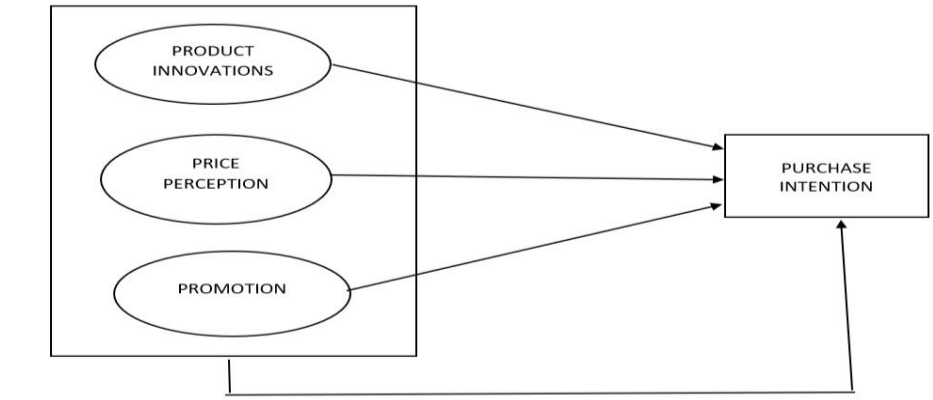


Figure 1: Research Framework

2.4. Hypotheses

The following hypotheses were formulated in this study:

H1 : It is hypothesized that product innovation influences purchase intention at HAR restaurants in Palembang

H2 : It is hypothesized that price perception influences purchase intention at HAR restaurants in Palembang City

H3 : It is hypothesized that there is an effect of promotions on purchase intention at HAR restaurants in Palembang City

H4 : It is hypothesized that there is an effect of product innovation, price perception, and

Promotions on purchase intention at HAR restaurants in Palembang City

3. Research Methodology

The subjects of this study are consumers who have dined at HAR Restaurant, located across from the Grand Mosque at Simpang Sekip and in front of PTC. The research method employed by the author is a quantitative research method, based on data obtained from distributed questionnaires. This study is a quantitative study seeking to identify causal associations. Sugiyono (Pondarta et al., 2025) states that associative research is research that examines the relationship between two or more variables. A causal relationship is one that involves cause and effect. According to Umar (Warni Z, 2021), there are two types of data used in research, namely:

1. Qualitative Data

Data in research typically takes the form of words, images, and—in research terminology—individual responses, descriptive conclusions, or both. Data is usually measured on a nominal, ordinal, or interval scale.

2. Quantitative Data

Quantitative data bases research findings on mathematical calculations

that subsequently provide an overview of a phenomenon or case presented in the study. The numerical data generated serves as a reference or parameter for a level that has been predetermined. The methods used may include tests (pre- or post-tests) that are then subjected to various data validity checks.

According to Ferdinand (Warni Z, 2021), a population is the collective of all elements—whether events, things, or people—that share similar characteristics and are the focus of a researcher's attention; as such, it is regarded as the research universe. The population in this study consists of all consumers who have dined at the HAR restaurant across from the Grand Mosque, at Simpang Sekip, and in front of PTC over the past three months. According to the survey, more than 1,000 people have dined at the HAR restaurant, but only 850 respondents returned the questionnaire; thus, the population comprises 850 respondents. The sampling technique used is random sampling. Random sampling is a method in which members or elements of the population are not given equal chances of being selected (Sofyan in Kurniawan et al., 2023). In determining the sample size, the researcher used the Slovin formula with a 10% margin of error (Sugiyono in Romadona, 2023).

Slovin formula:

$$n = N / (1 + (N \times e^2)$$

Description:

n = Sample Size

N = Population Size

e = Precision Level

Based on the Slovin formula, the sample size is:

$$n = N / (1 + (850 \times 0{,}1^2))$$

n = 850 / (1 + (850 x 0,01))

n = 850 / 9,5

n = 89,4

Therefore, the sample size used in this study was 89.4, rounded up to 90 respondents.

4. Research Results and Discussion

4.1. Research Results

a. Multiple Regression Analysis

According to Sugiyono (Sampura, 2025), multiple linear regression is a form of linear regression based on the functional or causal relationship between one independent variable and the dependent variable. The corresponding linear regression calculation model can be determined using the formula:

$$\mathbf{Y = a + b1X1 + b2X2 + b3X3}$$

Notes:

a. Y: Dependent variable (response variable or outcome variable)

b. X: Independent variable (predictor variable or causal factor)

c. Sa: Constant

d. b: Regression coefficient (slope); the amount of response caused by the predictor.

Table 2

Results of the Multiple Regression Analysis

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	1,097	2,087		,530	,000
	(X1) Product Inovation	,618	,039	,911	20,027	,000
	(X2) Price Preception	,319	,046	,271	4,523	,002
	(X3) Promotion	,327	,087	,182	2,775	,005

b. Dependent Variable: Y

The regression equation derived from the statistical calculations is as follows:

Y = a + b1X1 + b2X2 + b3X3

Purchase Intention = 1,097 + 0,618 +0,319 +0,327

1. The constant (a) value of 1.097 means that when product innovation, price perception, and promotion are assumed to be zero, the purchase intention is 1.09.

2. The regression coefficient for the product innovation variable is 0.618. This means that for every 1-unit increase in product innovation, purchase interest increases by 0.618, assuming all other variables remain constant.
3. The regression coefficient for the price perception variable is 0.319. This means that a 1-unit increase in price perception will increase purchase intent by 0.319, assuming all other variables remain constant.
4. The regression coefficient for the promotion variable is 0.327. This means that a 1-unit increase in promotion will increase purchase interest by 0.327, assuming all other variables remain constant.
5. Standard error of the probability. The standard error of the effect on Y, but it is not included in the equation.

b. t-Test

The t-test is used to test the significance of the relationship between variables X and Y, specifically whether variables X1, X2, and X3 actually influence variable Y separately or partially. The following explains the partial testing of each variable. The results of the t-test on the product innovation variable yielded a calculated t-value of 20.027, while the critical t-value was 1.667, with a significance level of 0.000 < 0.05, indicating that product innovation has a positive and significant impact on purchase intent. The results of the t-test for the price perception variable yielded a calculated t-value of 5.523, while the critical t-value is 1.667, with a significance level of 0.002 < 0.05, indicating that price perception has a positive and significant impact on purchase intent. The results of the t-test for the promotion variable yielded a calculated t-value of 2.775, while the critical t-value was 1.667, with a significance level of 0.005 < 0.05, indicating that promotion has a positive and significant impact on purchase intention.

c. F-Test

The F-test essentially determines whether all independent variables collectively influence the dependent variable. To verify this, an F-test is conducted; the results of the simultaneous regression analysis, or F-test, are shown in the table below:

Table 3

Results of the F-Test

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	675,753	2	241,562	146,803	,000[b]
	Residual	84,907	59	1,345		
	Total	760,660	57			

a. Dependent Variable: Y

b. Predictors: (Constant), X3,X2, X1

In the table above, the results of the hypothesis test show that the calculated F-value is 146.803 with a significance level of 0.000 < 0.05, which means that the variables of product innovation, price perception, and promotion collectively have a significant effect on the purchase intention variable.

d. Coefficient of Determination Test

According to Priyanto (Asmas D & Tarmizi A, 2019), the coefficient of determination is used to determine the percentage of the combined contribution of the independent variables to the dependent variable. The coefficient of determination indicates the extent to which the variation in the independent variables used in the model explains the variation in the dependent variable.

Tabel 4

Results of the Coefficient of Determination Test

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,775[a]	,601	,632	1,962

a. Predictors: (Constant), X

From Table 4 above, the R-squared value is 0.601. This indicates that the total percentage of the influence of variable X on variable Y is 60.1%, while the remaining 38.9% is influenced by other variables not included in this study.

4.2. Discussion

The results of the multiple regression analysis show that, in part, product innovation influences purchase intention with a coefficient of 0.618, price perception influences purchase intention with a coefficient of 0.319, and promotion influences purchase intention with a coefficient of 0.327. This is consistent with the 2023 study by Putu Ade Wijana and Luh Kadek Budi Martini, is consistent with the research by Anita Sanana, Muslichah Erma W, and Enny Istanti in 2021, and the research by Vernando Wijaya, Fenny Krisna Marpaung, and Christin Imelda Girsang in 2026, which found that product innovation, price perception, and promotion have a positive and significant effect on purchase intention. The results of the regression analysis, which show that product innovation influences purchase intention with a coefficient of 0.618, indicate that product innovation has a significantly greater influence than other variables, namely price perception and promotion.

4.3. Conclusions and Recommendations

The results of the multiple regression analysis show that product innovation, price perception, and promotion have a positive and significant partial effect on purchase intention. Simultaneously, product innovation, price perception, and promotion collectively have a positive and significant effect on purchase intention. Based on the coefficient of determination, product innovation, price perception, and promotion account for 60.1% of the variation, while the remaining 38.9% is influenced by other variables not included in this study.

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INFLUENCE SERVICE EXCELLENT QUALITY, PRICE VALUE, AND CUSTOMER EXPERIENCE TO CSUSTOMER LOYALTY WITH CUSTOMER ENGAGEMENTAS A MEDIATING VARIABLE

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Abstract

This study aims to determine the influence*Service Excellent Quality*, *Price Value*, And *Customer Experience* to *Customer Loyalty* with *Customer Engagement*As a Mediating Variable at PT Pesonna Optima Jasa. The population is all consumers of PT Pesonna Optima Jasa whose number is unknown and the sample used is 100 respondents with a sampling technique using*Purposive sampling*. The analysis technique used is SEM (*Structure Equation Modelling*). The results of the study were that there was a positive and significant influence*Service Excellent Quality* to *Customer Engagement*, there is a positive and insignificant influence*Price Value* to *Customer Engagement*, there is a positive and significant influence*Customer Experience* to *Customer Engagement*, there is a positive and significant influence*Service Excellent Quality* to *Customer Loyalty*, there is a positive and insignificant influence*Price Value* to *Customer Loyalty*, there is a positive and insignificant influence*Customer Experience* to *Customer Loyalty*and there is a positive and significant influence*Customer Engagement* to *Customer Loyalty*.

Keywords: ***Service Excellent Quality*, *Price Value*, *Customer Experience*, *Customer Loyalty* And *Customer Engagement***

INTRODUCTION

The increasingly competitive and dynamic global business environment has prompted companies to shift their marketing strategy orientation from transactional marketing to relationship marketing. Companies no longer focus solely on achieving short-term sales, but also on building long-term relationships with customers through sustainable value creation. In this context, customer loyalty has become a strategic asset for companies because loyal

customers not only contribute through repeat purchases but also serve as a source of word-of-mouth promotion (*word of mouth*), increase company profitability, and strengthen competitive position amidst increasingly intense market competition.

In the service industry, customer loyalty plays a very important role because of the characteristics of services which are*intangible, heterogeneous, inseparable, and perishability*This causes customers to value the overall interaction experience more than just the final service outcome. Loyal customers tend to have lower price sensitivity, maintain long-term relationships with the company, and demonstrate a commitment to continue using the services offered (Kotler & Keller, 2016). Therefore,*customer loyalty*seen as an indicator of a company's success in creating strong and sustainable relationships with customers.

Conceptually,*customer loyalty*defined as a customer's deep commitment to repurchase or reuse a product or service consistently in the future despite situational influences and marketing efforts from competing companies that could potentially cause customer switching (Kotler & Keller in Aditya Wardhana, 2024). Customer loyalty not only reflects repeat purchasing behavior but also involves attitudinal dimensions in the form of emotional attachment, trust, and customer preference for a particular company or brand. From a modern marketing perspective, customer loyalty is a source of competitive advantage that is difficult for competitors to imitate because it is formed through a long-term relationship between the company and its customers (Kotler & Armstrong, 2020).

One of the main factors that influences the formation of customer loyalty in service companies is*service excellent quality*Service quality is a company's ability to meet customer needs and expectations by delivering reliable, fast, and accurate services, while also providing a sense of security and comfort to customers. Parasuraman, Zeithaml, and Berry in Tjiptono (2016) explain that service quality is related to efforts to fulfill customer needs and the accuracy of service delivery to meet customer expectations. The concept*service excellent quality emphasizes* that companies must be able to provide services that exceed customer expectations through dimensions*reliability, responsiveness, assurance, empathy,* And *tangible*.

Improving service quality not only impacts customer satisfaction but also creates long-term emotional bonds and trust between customers and the company. Customers who receive superior service tend to have positive perceptions of the company, increasing the likelihood of repeat purchases and customer loyalty (Tjiptono, 2019). In today's competitive service business, service quality is a crucial element that differentiates companies from competitors, as customers are increasingly critical in assessing the consistency, professionalism, and speed of service provided by companies.

Apart from service quality, other factors that determine customer loyalty are:*price value*From a marketing perspective, price is not only seen as a means of economic exchange but also as a representation of the value customers receive from a product or service. Kotler and Armstrong (2018) state that price is the amount of money charged for a product or service, or the amount of value customers exchange to obtain the benefits of using that product or service. In the service industry, customers do not always seek the lowest price, but rather consider the balance between the costs incurred and the benefits received.

Draft *price value*Research shows that customer loyalty will increase if customers perceive that the price paid is commensurate with the quality of service and benefits received.

A positive perception of price value can increase customer trust in the company and encourage the formation of long-term relationships. Conversely, if customers feel that the price paid does not match the quality of service received, the potential for customer switching to competitors will increase. Therefore, service companies are required to be able to establish competitive, fair pricing strategies that align with customer expectations in order to maintain sustainable customer loyalty.

In the development of modern marketing,*customer experience is* also an important determinant in forming customer loyalty. Lemon and Verhoef (2016) explain that customer *experiences* the overall customer response that occurs during the interaction process with the company, both before, during, and after using the product or service. Meanwhile, Shaw and Hamilton (2016) define customer *experience as* customer perceptions of the rational, emotional, physical, and psychological interactions experienced when dealing with a company.

Customer experience is crucial because modern customers aren't just buying services; they're also seeking experiences that leave a positive and emotional impression. Customer experience can be reflected in ease of service access, clarity of information, convenience of the service process, employee professionalism, and the company's ability to provide solutions to customer needs.*Customer experience*Positive feedback will create emotional satisfaction that strengthens the relationship between customers and the company, thereby increasing customer loyalty in the long term.

Although *service excellent quality, price value*, And *customer experience has* an important influence on customer *loyalty*However, these relationships don't always occur directly. In a relationship marketing approach, companies need to build customer engagement as a bridge between customers and the company.*Customer engagement is* a psychological condition that indicates the level of customer involvement, interaction, participation, and commitment to a particular company or brand. Brodie et al. (2019) explain that customer *engagement formed* through ongoing interactions between customers and companies, thus creating a stronger emotional connection.

Customers who have a certain level of engagement High-performing individuals tend to be more active in providing feedback, following company activities, recommending services to others, and maintaining long-term relationships with the company.*customer engagement*It not only plays a role as a result of service quality and customer experience, but also serves as a mechanism for strengthening customer loyalty. In the context of service businesses, customer engagement is crucial because the relationship between the company and its customers is intensively developed through a continuous service process.

Several previous studies have shown a relationship between service *quality, price value, customer experience*, *customer engagement*, And *customer loyalty*. Ramadhan and Kusuma's (2021) research on online transportation services in Jakarta shows that customer *experience has* a positive and significant influence on customer *loyalty*, temporary *service quality also* has a direct impact on customer loyalty. However,*price perception*It doesn't have a significant impact if it's not supported by a good customer experience. The research results indicate that customer loyalty is influenced not only by functional factors but also by the customer's emotional experience during their interaction with the company.

Putri and Santoso's (2022) research on the telecommunications services industry in Bandung found that*service quality*and price value has a positive effect on customer *engagement*. Furthermore, *customer engagement proved* to be able to increases customer *loyalty and* mediates the relationship between service quality and price value on customer loyalty. The study emphasizes the importance of customer *engagement as* a mediating variable in building long-term relationships between companies and customers.

Furthermore, research by Lestari, Nugroho, and Fahmi (2023) on the e-commerce sector in Indonesia shows that service *quality, price value*, And *customer experience has* a positive and significant effect on customer *engagement*. Besides that, *customer engagement*has a significant impact on *customer loyalty*and acts as a partial mediator in the relationship between variables. These findings reinforce the view that customer loyalty is formed through a combination of service quality, perceived price value, and customer experience, which can increase customer engagement with the company.

Although various previous studies have examined the factors that influence customer *loyalty*, there are still research gaps that need further study. First, most previous research was conducted in the online transportation, telecommunications, and e-commerce sectors, while research on outsourcing and vehicle rental companies is still relatively limited. Second, research results regarding the influence of *price value*on customer loyalty shows inconsistency because in several studies, this variable does not have a direct effect on customer loyalty without certain mediating factors. Third, there is still limited research that integrates service*excellent quality, price value*, And *customer experience simultaneously* with customer engagement as a mediating variable in the context of public service companies in Indonesia. Therefore, this study has academic and practical urgency to develop a more comprehensive customer loyalty model in service companies.

The object of this research is PT Pesonna Optima Jasa, a general services company with its main business lines in outsourcing and vehicle rental. The company was founded on November 19, 2014, as a subsidiary of PT Pegadaian. As the business grew, on June 13, 2024, the company's shares were transferred to PT Pegadaian Galeri Dua Empat as part of the company's strategic move to strengthen its organizational structure and enhance its business capabilities. The company currently has 11 representative offices and 20 area offices spread across various regions in Indonesia.

As a service company, PT Pesonna Optima Jasa faces significant challenges in maintaining customer loyalty amidst the increasingly competitive service industry. Advances in digital technology and rising customer expectations have led to increased customer discretion in selecting service providers. Customers consider not only the quality of service but also the overall experience of interacting with a company, from communication processes, speed of service, employee professionalism, to the appropriateness of price to the benefits received.

The current situation indicates that customer loyalty at PT Pesonna Optima Jasa has not yet been optimally developed. This is evident in the continued use of the company's services situationally, the tendency of customers to compare services with competitors, and the low level of customer commitment to establishing long-term relationships with the company. This situation indicates that the company needs to strengthen its relationship marketing strategy by improving service quality, creating positive customer experiences, providing appropriate

pricing, and strengthening customer engagement to ensure sustainable customer loyalty growth.

Based on this description, this research is important to conduct in order to analyze the influence*service excellent quality, price value,* And *customer experience* to *customer loyalty* with *customer engagement as* a mediating variable at PT Pesonna Optima Jasa. This research is expected to provide theoretical contributions to the development of relationship marketing and customer behavior studies, while also providing practical contributions for companies in formulating strategies to increase customer loyalty effectively and sustainably.

LITERATURE REVIEW

Customer Loyalty

*Customer loyalty*Loyalty is a crucial concept in modern marketing because it relates to a company's ability to retain customers in the long term. Customer loyalty is demonstrated not only through repeat purchases but also through the customer's commitment to continue using a company's products or services despite the availability of numerous alternatives from competitors. In the service business context, customer loyalty is a strategic factor because loyal customers tend to provide sustainable benefits to the company through repeat purchases and positive recommendations to other customers.

According to Ismanto (2020), customer loyalty is a customer's willingness to remain loyal to a company because the company is perceived as providing better value than competitors. Hasan (2018) states that customer loyalty is key to a company's success in creating sustainable competitive advantage. Meanwhile, Tjiptono (2022) explains that customer loyalty is reflected in consistent repeat purchase behavior for a particular product or service.

Kotler and Keller (2016) define*customer loyalty*as a customer's commitment to repurchase or reuse a preferred product or service consistently in the future despite situational influences and competitive marketing efforts. This definition suggests that customer loyalty is formed through satisfaction, positive experiences, and a long-term relationship between the customer and the company.

According to Kotler and Keller (2016), customer loyalty can be measured through several indicators, namely loyalty in making repeat purchases, resistance to negative influences or offers from competitors, and customer willingness to recommend the company to others. Furthermore, customer loyalty is influenced by several factors such as customer satisfaction, repeat purchases,*word of mouth*, *evangelism*, And *ownership towards* the company.

Customer Engagement

Customer engagement is a concept that describes customer engagement and interaction with a particular company or brand. In modern marketing developments, customers no longer act solely as buyers but also as individuals who actively participate in company activities through communication, reviews, and recommendations to other customers.

ITS Science and Arts (2016) defines customer *engagement as* customer engagement through interactions between customers and brands that involve communication, participation, purchasing, and support for the brand. Harmeling et al. (2017) explain that customer *engagement*It is a customer's voluntary behavior in contributing to the company. Meanwhile, Thakur (2018) states that customer engagement is a psychological condition of customers that encourages interaction with the company beyond direct transactional purposes.

Mahandy and Sanawiri (2018) explain that customer *engagement*It's a company's effort to build emotional bonds between customers and the company. Consistent and relevant interactions will strengthen customer relationships, thereby increasing long-term customer loyalty.

According to Thakur (2018),*customer engagement*Customer engagement can be influenced by several factors, such as customer experience, service quality, effective communication, customer satisfaction, customer trust, emotional factors, social interaction, personalization, and ease of service access. Customer engagement indicators include customer activity level, customer involvement level, and customer influence level on the company.

Service Excellent Quality

*Service excellent quality*It is a company's ability to provide the best service according to customer needs and expectations. In service companies, service quality is a key factor in determining customer satisfaction and loyalty because customers directly experience the interaction with the company during the service.

Kotler and Keller (2016) explain that*service excellent*is a service that meets quality standards according to customer expectations and satisfaction. Tjiptono (2022) stated that*service excellent*Excellent service is a service that is oriented towards meeting customer needs and the company's ability to provide services that exceed customer expectations. Supeno (2018) also explains that excellent service is a form of service designed to minimize errors and is oriented towards customer needs.

According to Tjiptono (2022), service quality can be measured through five main dimensions of SERVQUAL, namely*tangibles, reliability, responsiveness, assurance,* And *empathy*. *Tangibles*related to physical facilities and employee appearance.*Reliability*related to the company's ability to provide services accurately and consistently.*Responsiveness*shows the company's readiness to help customers.*Assurance*related to the ability of employees to provide a sense of security and trust to customers, whereas*empathy*related to the company's attention and understanding of customer needs.

In addition, Tjiptono (2022) explains that service quality is influenced by design *quality, production quality, delivery quality,* And *relationship quality related* to the design process, delivery, and company-customer relationships.

Price Value

Price value is the customer's perception of the appropriateness of the benefits received and the costs incurred to acquire a product or service. In the context of service marketing,

customers not only consider the low price but also assess whether the price paid is commensurate with the quality of service and benefits received.

Sunyoto (2019) states that price is the amount of money a customer pays to obtain a particular product or service. Meanwhile, Kotler and Keller (2016) explain that price is an element of the marketing mix that generates revenue and signals the value and quality of a product or service in the eyes of customers.

According to Kotler and Armstrong (2016),*price value* can be measured through price affordability, the suitability of price to product or service quality, the suitability of price to benefits obtained, and price competitiveness compared to competing companies. Furthermore, Tjiptono (2019) explains that price *value influenced* by internal company factors such as marketing objectives, marketing strategies, and costs, as well as external factors such as market conditions, demand, and level of competition.

Customer Experience

*Customer experience*It is the overall experience a customer experiences while interacting with a company, whether before, during, or after using a product or service. Customer experience is a crucial factor in modern marketing because customers are looking not only for a product or service but also for a pleasant and memorable experience.

Shaw and Hamilton (2016) define customer *experience* as customer perceptions of rational, emotional, physical, and psychological interactions with a company that influence customer behavior. Jusoh et al. (2022) explain that customer *experience is* a unique experience that customers feel during their relationship with the company. Meanwhile, Ali et al. (2018) stated that customer *experience is* the customer experience when interacting with service providers, both new and old customers.

According to Schmitt in Wiyata et al. (2020),*customer experience*It consists of five main dimensions: sense, feel, think, act, and relate. Sense relates to the customer's sensory experience through the five senses. Feel relates to the customer's emotional experience. Think relates to the customer's cognitive and rational experience. Act relates to experiences that influence customer behavior and lifestyle, while relate relates to the customer's social experience with a particular environment or community.

METHOD

This research was conducted at PT Pesonna Optima Jasa, located at Jalan Menumbing No. 467 A, Kepandean Baru, South Sumatra. The research aims to analyze the influence of service *excellent quality, price value*, And *customer experience* to *customer loyalty* with *customer engagement as* a mediating variable.

This study used a quantitative approach with an associative approach to examine the relationships between the research variables. This approach was chosen because the study focuses on measuring variables through numerical data analyzed statistically to test the formulated hypotheses. Data collection was conducted using a questionnaire with a five-point Likert scale, ranging from 1 = strongly disagree to 5 = strongly agree.

The data used in this study consisted of primary and secondary data. Primary data was obtained through questionnaires distributed to respondents, while secondary data was obtained from company documents, literature, and other supporting sources relevant to the study. The study population was all consumers of PT Pesonna Optima Jasa, whose exact number is unknown. Therefore, the sampling technique used was a random sampling technique.*non-probability sampling*with the method *purposive sampling*Respondents were selected based on the criteria of consumers who currently or have used the company's services. The research sample size was determined using the Cochran formula, achieving a minimum of 96 respondents, then rounded up to 100 respondents.

This study uses five variables, namely*service excellent quality, price value*, And *customer experience* as an independent variable,*customer engagement as* a mediating variable, as well as*customer loyalty*as a dependent variable. Measurement of the dependent variable*service excellent quality*refers to the SERVQUAL dimensions which consist of *tangibles, reliability, responsiveness, assurance*, And *empathy*. Variable price *measured* through price affordability, price-to-quality ratio, price-to-benefit ratio, and price competitiveness.*Customer experience measured* using dimensions*sense, feel, think, act,* And *relate*. *Customer engagement measured* through the level of customer activity, customer engagement, and customer impact, whereas customer *loyalty measured* through repeat purchases, resistance to negative influences, and willingness to recommend the company to others.

Data analysis was performed using*Structural Equation Modeling*(SEM) with the help of LISREL 8.8 software. Before hypothesis testing was conducted, the research instrument was tested through validity and reliability tests. Construct validity was evaluated using the value*standardized loading factor*≥ 0.50 and*Average Variance Extracted*(AVE) ≥ 0.50. The construct reliability was tested using*Construct Reliability*(CR) ≥ 0.70 and*Variance Extracted* (VE) ≥ 0,50.

The suitability of the research model is evaluated using several indicators.*goodness-of-fit*, that is *Goodness of Fit Index* (GFI), *Root Mean Square Error of Approximation* (RMSEA), *Tucker Lewis Index* (TLI), *Comparative Fit Index*(CFI), and*Normed Chi-Square*(CMIN/DF). The model is said to be fit if it meets the value*cut-off*recommended in SEM analysis. Hypothesis testing is done by looking at the value/critical *ratio*(CR) probability *value*(p-value). The hypothesis is accepted if the CR value is > 1.96 and the p-value is ≤ 0.05, which indicates a significant influence between the research variables.

RESULTS AND DISCUSSION

Research result

Based on the results of data processing using analysis*Structural Equation Modeling*(SEM) with the help of LISREL 8.8 software as follows:

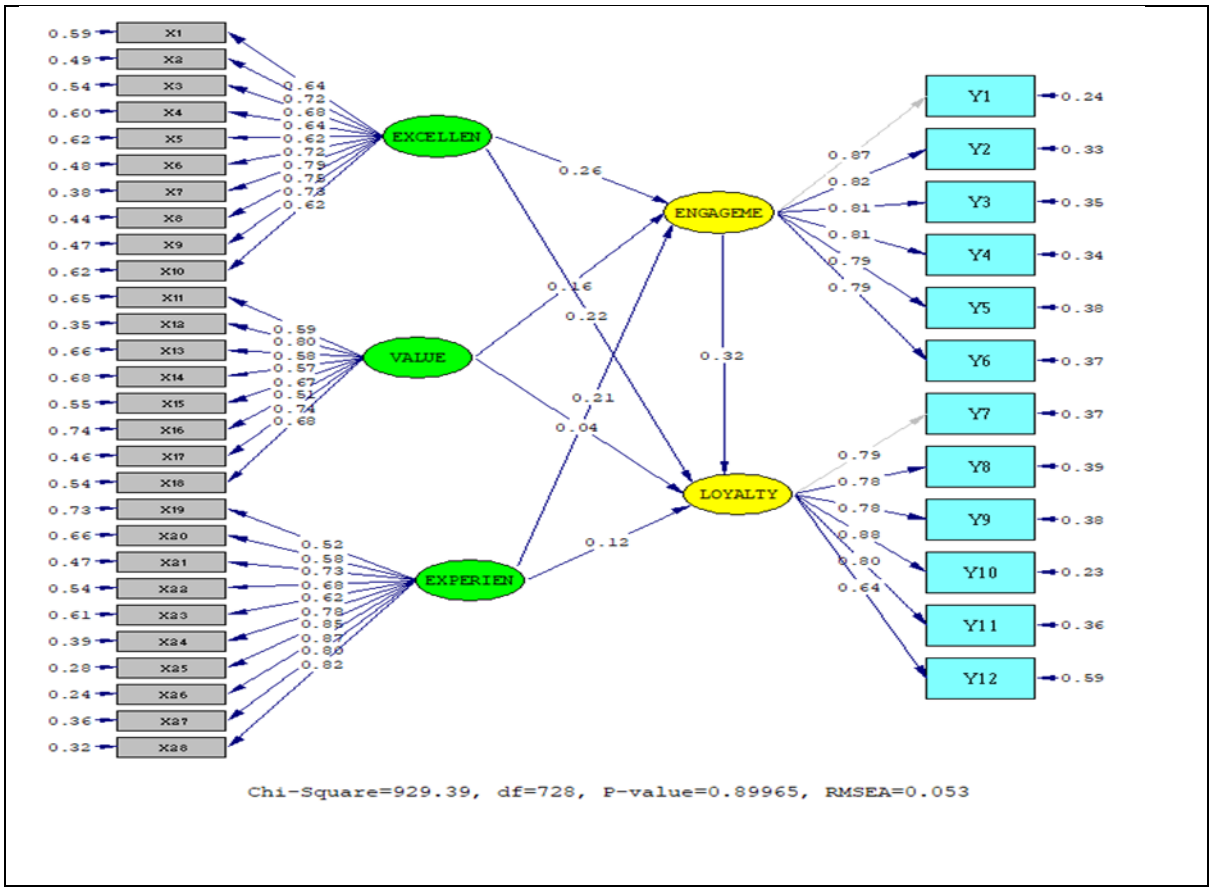


Figure 1.*Confimatory Factor Analysis*

Based on the image above, it shows that all loading factor variables have values greater than 0.50. This indicates that the CFA test (*Confirmatory Factor Analysis*) in the initial stage in the image above it has been fulfilled for the next stage of testing.

Table 1.*Goodness Of Fit Index*

Goodness Of Fit Index	Cut Of Value	Analysis Results	Model Evaluation
GFI	> 0,90	0.68	Fit
RMSE$A	< 0,08	0.05	Close Fit
E$CVI	The Smaller the Better	11.25	Good Fit
TLI/NNFI	> 0,90	0.92	Good Fit
NFI	> 0,90	0.81	Marginal Fit

AGFI	> 0,90	0.64	Fit
IFI	> 0,90	0.93	Good Fit
CFI	> 0,90	0.93	Good Fit
CMIN/DF	< 2,00	1.28	Good Fit
Critical N	>200	706.47	Good Fit

Based on the table above, it can be concluded that the model is good because the criteria*goodness of fit index*Overall, it falls into the good fit category, so no model modifications are necessary. Model testing yielded good confirmation of the factor dimensions and causal relationships between factors, thus the model is acceptable.

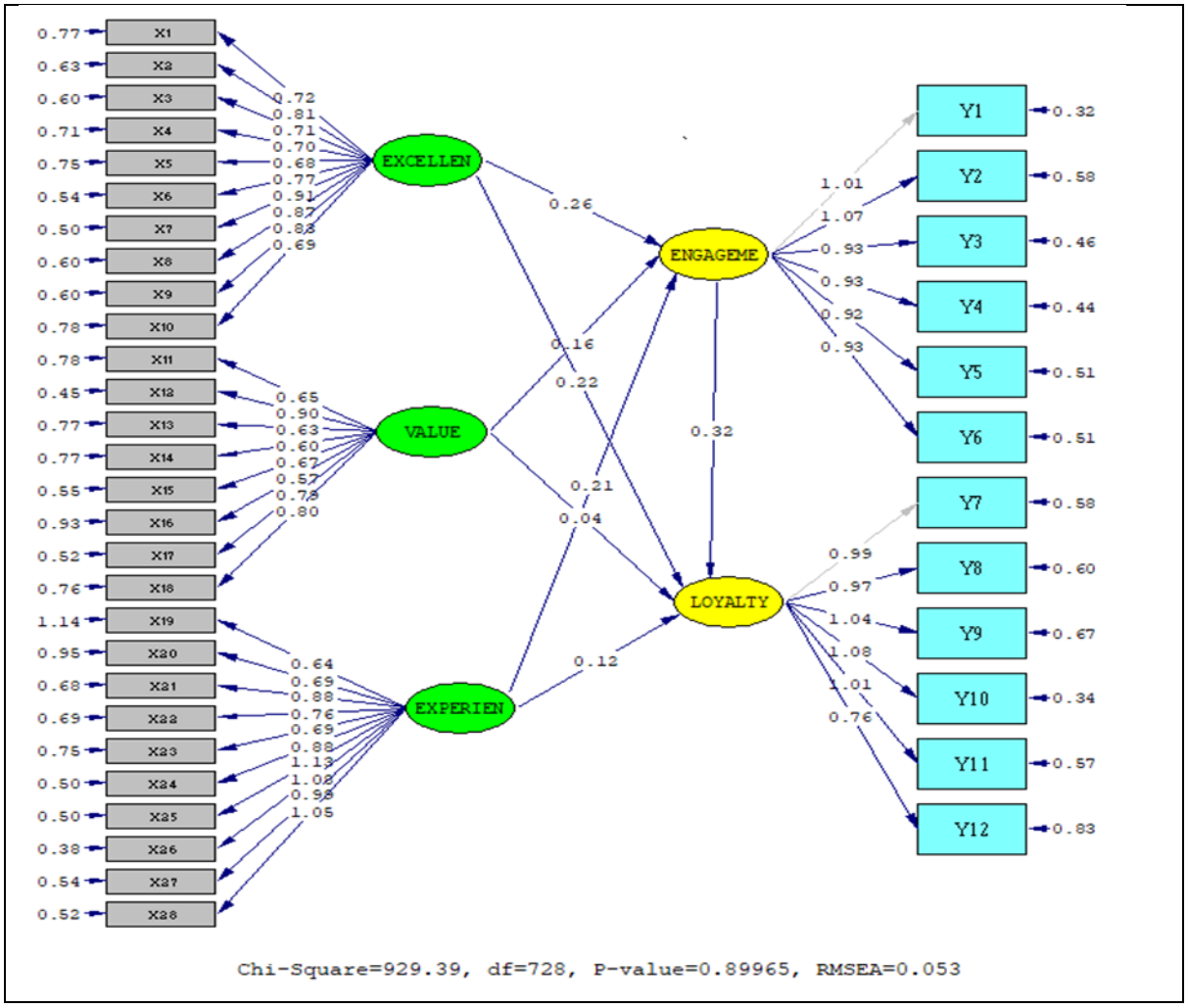


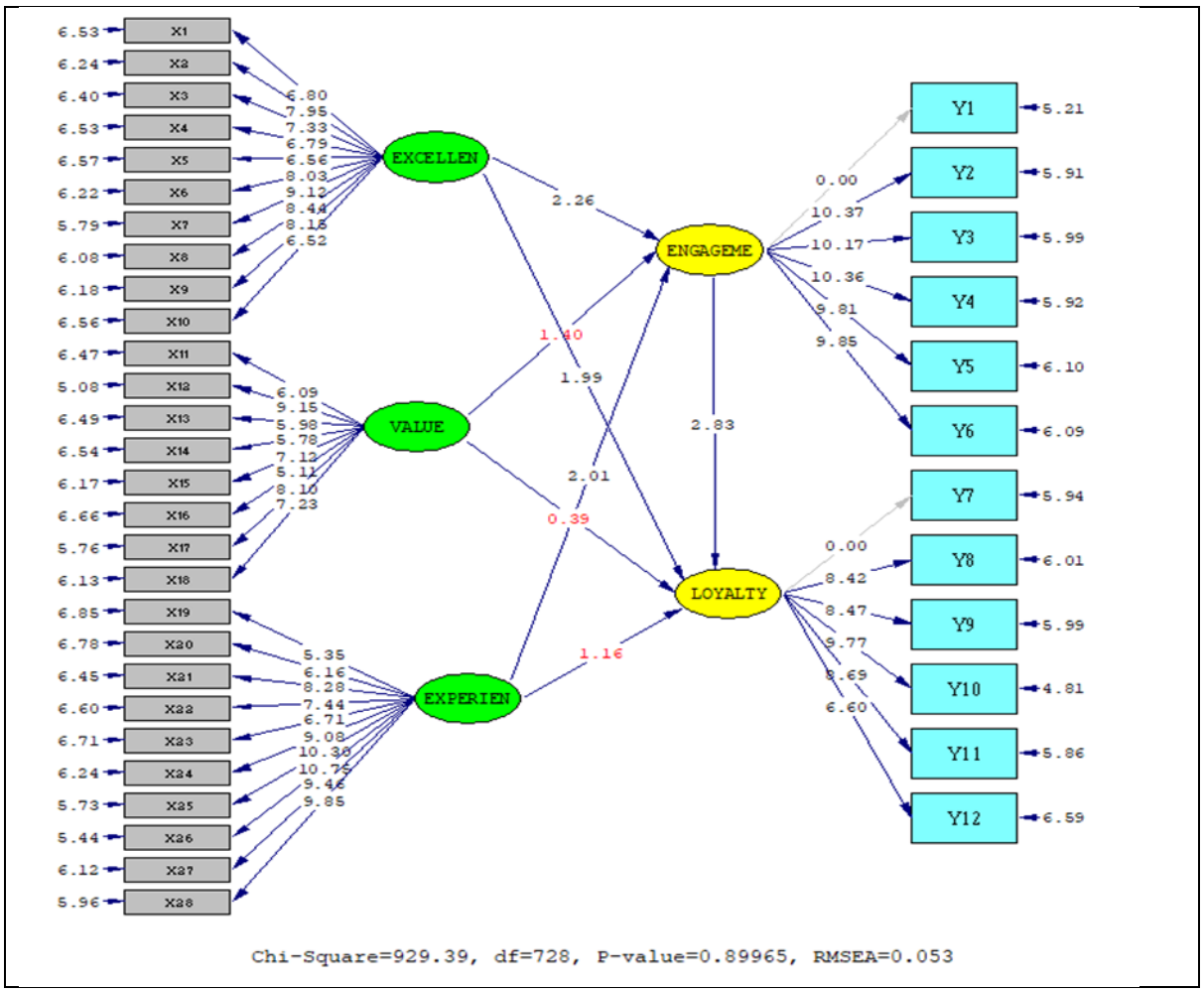
Figure 2 *Path Analysis*

Information

$\eta_1 = 0.26\ x_1 + 0{,}16\ x_2 + 0.21\ x_3$

$\eta_2 = 0.22\ x_1 + 0{,}04\ x_2 + 0.12\ x_3 + 0.32\ \eta_1$

.



Picture 3. T –*Value*

Table 2. Hypothesis Testing

No	Variables	Nilai T-Values	Cr Rate	Information
1	*Service Excellent Quality - Customer Engagement*	2.26	> 1,96	Significant

2	*Price Value - Customer Engagement*	1.40	< 1,96	Not Significant
3	*Customer Experience - Customer Engagement*	2.01	> 1,96	Significant
4	*Service Excellent Quality - Customer Loyalty*	1.99	> 1,96	Significant
5	*Price Value - Customer Loyalty*	0.39	< 1,96	Not Significant
6	*Customer Experience - Customer Loyalty*	1.16	< 1,96	Not Significant
7	*Customer Engagement - Customer Loyalty*	2.83	> 1,96	Significant

DISCUSSION

Influence *Service Excellent Quality* to *Customer Engagement*

The results of the study show that*Service Excellent Quality*has a positive and significant effect on*Customer Engagement*at PT Pesonna Optima Jasa with a coefficient of 0.26. This finding indicates that good service quality can increase customer engagement in the form of interaction, participation, and a more active relationship with the company. The better the service provided, the higher the level of customer engagement.

This finding is in line with Thakur's theory (2018) which states that service quality is one of the main factors influencing*customer engagement*Responsive, professional service that meets customer expectations will encourage consumers to actively engage with the company. The results of this study also support research by Nugroho and Suprapti (2022), Mainaki and Husda (2025), and Kurniawan and Ariyani (2021), which found that service quality significantly influences customer satisfaction.*customer engagement*.

However, the results of this study differ from the research of Indra Rifqi and Wicaksana (2026) which shows that*service excellent*did not significantly influence customer engagement. This difference is thought to be due to differences in measurement indicators, respondent characteristics, and the research industry context.

Based on respondents' responses, some consumers still believe that employees do not provide friendly, polite, and professional service. This situation has resulted in low customer participation in company programs and feedback. Therefore, PT Pesonna Optima Jasa needs to improve service quality through training.*service excellent*, strengthening interpersonal communication, and regular service evaluation so that customer engagement can increase.

Influence *Price Value* to *Customer Engagement*

The results of the study show that*Price Value*has a positive but not significant effect on*Customer Engagement*with a coefficient of 0.16. This indicates that consumer perceptions of price-benefit compatibility have not been able to directly drive customer engagement.

This finding aligns with Thakur's (2018) theory, which states that customer engagement is more influenced by customer experience, interaction quality, and emotional value than price.*price value*plays more of a supporting role than a primary factor in building customer engagement.

The results of this study are in line with the research of Abidin, Yudistria, and Ramli (2025) which found that*price value*does not have a direct impact on*customer engagement*However, this result differs from the research of Mainaki and Husda (2025) which showed a significant influence between*price value* And *customer engagement*. These differences are likely influenced by differences in research indicators, respondent characteristics, and the type of industry studied.

Based on the respondents' findings, some consumers believe product prices are not yet competitive enough and the benefits received do not fully justify the price paid. Therefore, companies need to improve perceived value through price adjustments, service enhancements, and product value-add enhancements to enhance consumer perceptions of price value.

Influence *Customer Experience* to *Customer Engagement*

The results of the study show that*Customer Experience*has a positive and significant effect on*Customer Engagement*with a coefficient of 0.21. This indicates that a good customer experience can increase customer engagement with the company.

This finding supports Thakur's (2018) theory which states that*customer experience*is an important factor in forming*customer engagement*Positive experiences will encourage consumers to engage more actively and build relationships with the company. The results of this study align with those of Kurniawan and Ariyani (2021) and Mainaki and Husda (2025).

However, this result differs from the research of Abidin, Yudistria, and Ramli (2025) which found that*customer experience*does not have a direct impact on*customer engagement*. These differences may be caused by differences in measurement indicators and respondent characteristics.

Respondent responses indicate that some consumers still believe that company information is not conveyed clearly and that the relationship between the company and its customers has not been optimally developed. Therefore, companies need to improve the quality of communication, ease of information access, and the quality of service interactions to ensure customer satisfaction.*customer engagement*can increase.

Influence *Service Excellent Quality* to *Customer Loyalty*

The results of the study show that*Service Excellent Quality*has a positive and significant effect on*Customer Loyalty*with a coefficient of 0.22. This finding indicates that good service

quality can increase customer loyalty through repeated service use and long-term relationships with the company.

This finding aligns with Kotler and Keller's (2016) theory, which states that superior service quality can increase customer loyalty. This research also supports the research of Nugroho and Suprapti (2022), which found that*service excellent*has a significant impact on*customer loyalty*.

However, several other studies have shown different results, with service quality having a stronger influence on loyalty through mediating variables such as customer satisfaction. These differences in results are likely influenced by differences in research indicators and industry context.

Based on the respondents' results, some customers still consider employee service to be insufficiently friendly and professional. Therefore, the company needs to improve service quality through employee training, service performance evaluations, and the implementation of consistent service standards to increase customer loyalty.

Influence *Price Value* to *Customer Loyalty*

The results of the study show that*Price Value*has a positive but not significant effect on*Customer Loyalty*with a coefficient of 0.04. This indicates that the perception of price value has not been able to directly increase customer loyalty.

This finding supports Thakur's theory (2018) which states that customer loyalty is more influenced by experience, relationship quality, and*customer engagement*compared to price factors. The results of this study are also in line with research by Abidin, Yudistria, and Ramli (2025).

On the other hand, research by Fadhil and Fadli (2025) found that*price value*has a significant impact on*customer loyalty*. The difference in results is thought to be influenced by differences in industrial sectors and customer sensitivity to price.

Respondents still believe that service prices are not yet competitive enough, and the benefits received do not fully justify the costs. Therefore, companies need to increase the added value of their services and strengthen their differentiation strategies to enhance customer perceptions of value.

Influence *Customer Experience* to *Customer Loyalty*

The results of the study show that*Customer Experience*has a positive but not significant effect on*Customer Loyalty* with a coefficient of 0.12. This indicates that customer experience is not yet able to directly shape customer loyalty.

These findings align with Thakur's (2018) theory, which states that customer loyalty is influenced not only by experience but also by customer engagement and emotional connection with the company. These research findings also support Dewantara and Laulita's (2024)

research, which found that*customer experience*more effectively influence loyalty through*customer engagement*.

Some respondents still felt that company information was unclear and customer relations were suboptimal. Therefore, companies need to improve the quality of the customer experience through more effective communication, responsive service, and better long-term relationships with customers.

Influence *Customer Engagement* to *Customer Loyalty*

The results of the study show that*Customer Engagement*has a positive and significant effect on*Customer Loyalty*with a coefficient of 0.32. This finding indicates that customer engagement plays an important role in shaping customer loyalty.

This finding supports Thakur's (2018) theory which states that*customer engagement* is a major factor driving customer loyalty. Highly engaged customers tend to have strong emotional connections, repeat purchases, and recommend the company to others. The results of this study also align with Manggarani's (2018) research, which found that*customer engagement*has a significant impact on*customer loyalty*.

However, there are still customers who are less active in participating in the company's programs and are unwilling to provide feedback. This situation results in a low tendency for customers to recommend the company to others. Therefore, PT Pesonna Optima Jasa needs to improve its*customer engagement*through interactive programs, more engaging communications, and the provision of easily accessible feedback channels so that customer loyalty can increase sustainably.

CONCLUSION

This study aims to analyze the influence*Service Excellent Quality, Price Value,* And *Customer Experience* to *Customer Loyalty* with *Customer Engagement* as a mediating variable at PT Pesonna Optima Jasa. Based on the results of the analysis*Structural Equation Modeling*(SEM), several main findings were obtained.

First, *Service Excellent Quality*proven to have a positive and significant impact on*Customer Engagement* as well as *Customer Loyalty*These findings indicate that good service quality can increase customer engagement and strengthen customer loyalty to the company. Second,*Customer Experience*also has a positive and significant impact on*Customer Engagement*, but does not have a significant effect on*Customer Loyalty*This indicates that customer experience plays a greater role in building customer engagement than direct loyalty.

Third, *Price Value*shows a positive but not significant influence on*Customer Engagement*and*Customer Loyalty*This finding indicates that price perception is not yet a major factor in shaping customer engagement and loyalty in the context of this study. Fourth,*Customer Engagement*proven to have a positive and significant impact on*Customer*

Loyalty, thus showing that customer engagement has an important role in creating long-term relationships between customers and companies.

Overall, this study confirms that service and customer engagement are key determinants of customer loyalty. Therefore, PT Pesonna Optima Jasa needs to prioritize improving service quality, customer experience, and customer engagement strategies to strengthen customer loyalty sustainably.

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RECONSTRUCTION OF STUDENT COMPETENCE IN THE ERA OF MULTIPLE DISRUPTIONS: A SYSTEMATIC LITERATURE REVIEW BASED ON *THE GRADUATE CAPITAL MODEL APPROACH*

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ABSTRACT

The era of digital disruption and the dynamics of global economic restructuring demand a radical redefinition of the anatomy of student competencies in higher education. This study aims to map the transformation of graduate profiles by adopting the *Graduate Capital Model framework* , while positioning " *Meaning of Work* " as the main psychological mediator that shifts the paradigm of traditional academic engagement. Through the Systematic Literature Review (SLR) method that strictly adheres to the PRISMA protocol guidelines, this study extracts globally reputable empirical literature from Scopus, Web of Science, and ERIC databases within the publication period of 2018 to mid-2026. The results of the thematic analysis synthesize four structural pillars of modern competency: (1) the transition of digital literacy towards algorithmic mindset agility and critical data evaluation; (2) strengthening psychological capital driven by clarity of work meaning to build resilience; (3) the urgency of accumulating social capital through building relational networks and cross-disciplinary collaboration skills; and (4) the crucial role of institutional orchestration in providing an industrial simulation ecosystem and curriculum alignment with practitioners. This study concludes that to neutralize the skills gap , universities must break down rigid scientific barriers, completely restructure the opportunity infrastructure, and transform the role of lecturers into strategic mentors who oversee the formation of students' professional identities holistically.

Keywords: Student Competence, *Meaning of Work* , *Graduate Capital Model* , Systematic Literature Review, Work Readiness, Digital Era.

1. BACKGROUND

Contemporary higher education is currently at the epicenter of a civilizational transition marked by dual disruptions: the exponential acceleration of digital transformation and the post-pandemic restructuring of the global economic landscape. These highly dynamic conditions cumulatively demand a radical and fundamental redefinition of student competency profile outcomes. The discourse on student competency in the 21st century can no longer be limited to the achievement of theoretical cognitive academic indicators or mastery of classical

literature alone. Instead, the modern higher education paradigm requires a holistic integration encompassing psychological readiness, technological agility, sensitivity to corporate social responsibility, and tactical skills aligned with fluctuations in the global labor market.

The World Economic Forum's (2020) comprehensive report on the future of work, reinforced by strategic projections from Bakhshi, Downing, Osborne, and Schneider (2019), strongly underscores the urgency of developing adaptive skills. The report categorizes digital literacy, emotional intelligence, and unstructured problem-solving skills as crucial foundations for the future workforce. However, empirical evidence synthesized from recent literature reviews, including research by Garcia-Aracil, Monteiro, and Almeida (2021) and a critical review by Nghia, McClelland, and Chen (2020), reveals a systemic anomaly in the form of a persistent skills gap.

This phenomenon indicates that the competency outcomes produced by universities often lag behind industry-demanded specifications, creating serious challenges to the overall employability of graduates. To address the complexity of this gap, this systematic literature review moves away from conventional approaches and adopts a far more comprehensive analytical lens, namely the Graduate Capital Model formulated by Tomlinson (2017). This conceptual framework is considered highly capable of analyzing the student learning and development ecosystem because it views students not merely as passive recipients of knowledge but as active agents building a series of multidimensional capital. This model divides competencies into five main forms of capital: human capital, which encompasses cognitive and technical skills; social capital, which relates to relational networks; cultural capital, which encompasses an understanding of industry values; identity capital, which focuses on the formation of professional narratives; and most importantly, psychological capital, which encompasses resilience, proactivity, and mental adaptability. This approach allows academics and policymakers in higher education to evaluate the anatomy of student competencies more comprehensively, going beyond traditional metrics such as the Grade Point Average (GPA) which has proven to be inadequate as a single predictor of career success in the era of digital disruption (Holmes, 2013; Jackson, 2014).

In analyzing the pillars of student psychological capital, the most fundamental aspect, currently sparking intense debate in contemporary pedagogical literature, is how to define the driving force or mediator of learning motivation. Previous studies tended to rely on academic engagement as an indicator of success. However, modern literature reviews have progressively begun to sideline this engagement construct. Engagement is considered inherently flawed due to its often superficial, volatile nature, and its failure to explain the resilience of student commitment when faced with the uncertainties of the post-graduation workforce. As a step toward theoretical renewal, recent research developed by Rosso, Dekas, and Wrzesniewski (2010), Steger, Dik, and Duffy (2012), and specifically applied to the higher education ecosystem by Williams, Rawal, and Herr (2021), positions Meaning of Work as a crucial, central mediator. Meaning of work acts as an essential bridge connecting the process of acquiring theoretical knowledge in the classroom with the vision and expectations of realizing a meaningful professional career. This psychological construct provides a moral compass, intrinsic motivation, and clear direction for students to sort, select, and deepen skills that are specifically relevant to their career trajectory (Römgens, Scoupe, & Beausaert, 2020).

Furthermore, the integration of sustainability values and contemporary business ethics into students' work-related meanings is also beginning to receive widespread attention. In an era where industry is aggressively required to adhere to the principles of good governance and social responsibility, student competency is inextricably linked to their understanding of the macroeconomic context and corporate ethics (Mader, Scott, & Razak, 2022). Therefore, students with a high level of work-related meanings will not only be motivated to master mechanical technical skills but also proactively construct a professional identity narrative that is sensitive to issues of environmental justice, inclusive human resource governance, and long-term value creation. Based on the urgency and dynamics of this paradigm shift, this systematic literature review was conducted with the primary objective of extensively mapping globally reputable journal articles to identify new dimensions of student competency. This study seeks to evaluate the structural and psychological factors that are key drivers of graduate success, analyze the crucial role of higher education institutions, and formulate recommendations for designing a curriculum architecture that is accurately calibrated to future labor market demands.

2. METHODOLOGY

This research was rigorously designed and executed using a systematic literature review methodology that comprehensively adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This gold standard for systematic review reporting, recommended by Moher, Liberati, Tetzlaff, and Altman (2009), combined with the systematic review framework in the social sciences and management (Petticrew & Roberts, 2006; Tranfield, Denyer, & Smart, 2003), was rigorously implemented to ensure the highest level of transparency. The use of the PRISMA protocol aims to minimize literature selection bias, mitigate subjectivity in researcher interpretation, and ensure that the entire academic synthesis process is highly reliable, allowing for future replication, testing, and development by other researchers. This methodological process begins with an initial identification phase focused exclusively on globally reputable academic databases with rigorous indexing systems and impact metrics, namely Scopus, Web of Science (WoS), and the Education Resources Information Center (ERIC).

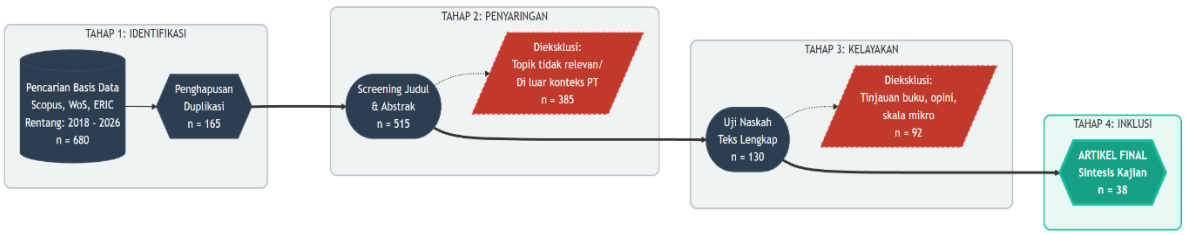


Figure 1. Journal screening process

In an effort to formulate accurate search parameters, the publications were precisely and deliberately limited to a timeframe from early 2018 to mid-2026. This decision to define this timeframe was not without merit; the past six years represent the most turbulent and dynamic phase in the history of modern higher education. This period not only captures in real

time the pedagogical disruption caused by the global pandemic, but also captures the wave of educational digitalization transitions, as well as the surge in automation and the penetration of generative artificial intelligence in the job market, which are directly changing the competency specifications required of graduates (Tsiotou, 2023). The literature search strategy was designed using a complex search string algorithm that combines various specific keywords and their lexical variants through Boolean operator logic. The lexical combinations executed in the database search engine include terminology clusters such as student competence, graduate employability, digital dexterity/skills, meaning of work, and higher education to work transition.

The initial search process identified hundreds of potential literatures, which were then input into reference management software for automated screening of duplicate documents. The remaining unique manuscripts were then subjected to a series of inclusion and exclusion criteria, rigorously applied during the title and abstract screening stages. The primary inclusion criteria stipulated that articles eligible for further analysis must be peer-reviewed empirical research journal manuscripts, written in English to ensure global comparability, and present both primary and secondary data—whether through quantitative, qualitative, or mixed methods approaches—on the competency attributes of higher education students. The exclusion criteria were designed to eliminate all forms of literature, including book reviews, popular opinion articles, editorials, conference proceedings that have not undergone blind peer review, internal institutional reports, and micro-scale studies conducted below the higher education level (such as primary and secondary education) as they are not aligned with the context of professional labor market readiness.

For articles that passed the abstract screening, the process continued with full-text downloads for in-depth methodological feasibility testing. The quality of each manuscript was carefully evaluated to ensure that only studies with high research design rigor would contribute to the final conclusions of this paper. Data extraction was conducted on dozens of final selected articles. The extracted data went beyond summarizing statistical figures, focusing on core findings, the theoretical foundations used by the original authors, and the geographical and cultural contexts of the research. To generate a coherent narrative from the literature, this study employed thematic analysis techniques adapted from Braun and Clarke's (2006) approach. The researchers conceptually coded key findings from each manuscript, looked for recurring patterns, identified divergences in arguments among global scholars, and ultimately grouped these codes into central theme clusters that encapsulate the overall architecture of the dynamics of digital-era student competencies. The qualitative synthesis of these theme clusters is then presented descriptively and analytically in the results section.

3. RESULTS

A comprehensive and in-depth synthesis of reputable academic literature published over the past six years has revealed four key structural pillars that are redefining the anatomy of student competencies in modern-day higher education. The first pillar of these findings consistently highlights the supremacy and urgency of cognitive agility and advanced digital literacy as the primary foundations for professional survival in a digitalized work environment. A large-scale empirical study published by Zhao, Pinto Llorente, and Sánchez Gómez (2021), strongly supported by the findings of Blázquez, Mas-Machuca, and Marimon (2020),

conclusively proves that the definition of digital competency for today's students has transcended the outdated paradigm of merely mechanical ability to operate commercial software or basic office applications.

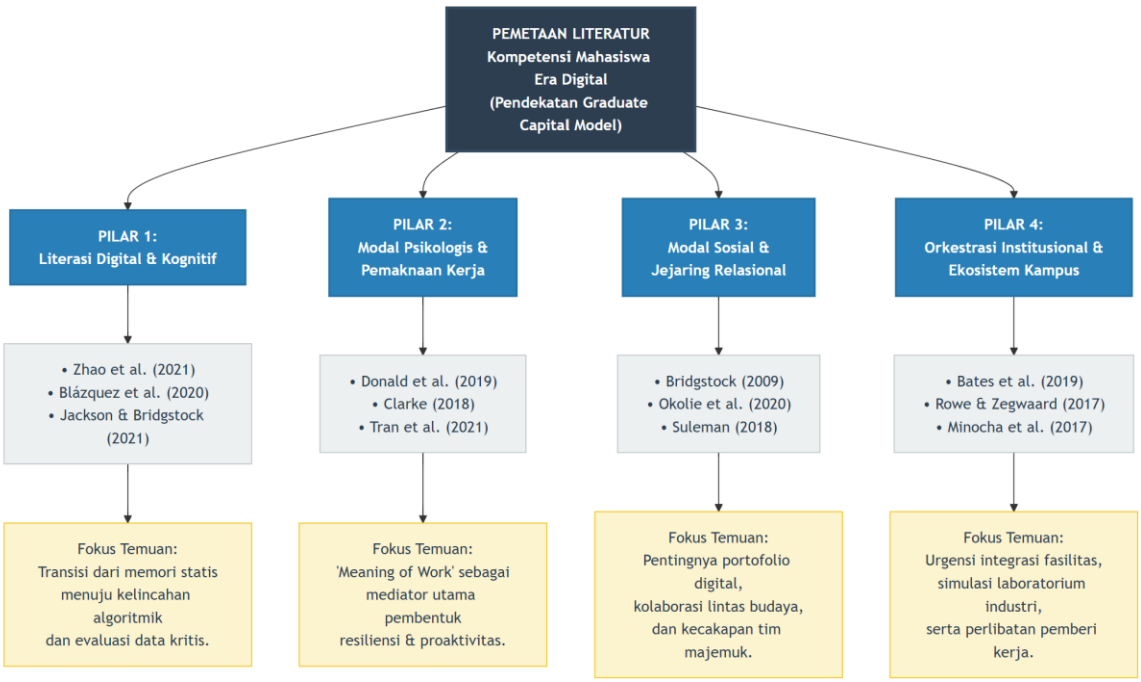


Figure 2. Visual Model of Journal Mapping

Recent literature confirms that industry competency demands have shifted radically toward mastery of big data synthesis and visualization skills, critical and ethical evaluation and curation of digital information to counter disinformation, and adaptability in interacting and collaborating in virtual architectural spaces (Tsiotou, 2023). This aligns with the critical argument developed by Jackson and Bridgstock (2021), who strongly emphasize the need to transition curriculum models from repetitive knowledge transfer (rote learning) to developing agile algorithmic thinking. In this context, contemporary students are no longer evaluated based on how much static information they can memorize, but rather on how resilient their intellectual resilience is in solving complex problems and responding rapidly to disruptive information.

The second pillar of this literature synthesis specifically examines the dimensions of psychological capital readiness and graduate identity formation, where the identified theoretical findings confirm a crucial shift in focus: the transition from the psychological variables of superficial engagement to the instilling of a full-fledged Meaning of Work. The sociology of education and career psychology literature by Donald, Ashleigh, and Baruch (2019) and the resilience study by Sarkar, Cleary, and Horwood (2020) reveal that true adaptability to the workplace cannot be achieved solely through indicators of students' physical activity in the classroom or administrative compliance in completing assignments. Clarke (2018) and Pham, Tomlinson, and Thompson (2019) confirm that intrapersonal and interpersonal competencies—such as mature emotional intelligence, inclusive collaboration, and cross-cultural communication capacity (Succi & Canovi, 2020)—can only be optimally internalized if students have a complete anchor of meaning of work within themselves.

Furthermore, a study by Tran, Ngo, Nguyen, and Dang (2021) on the labor market in developing countries empirically underscores that students driven by clarity regarding their projected meaning of future work are proven to manifest significantly higher levels of proactivity and determination in overcoming academic obstacles. Within this psychological spectrum, the existence and role of lecturers are required to metamorphose; no longer merely as conveyors of curriculum material, but as promoters of life values who guide students in navigating the essence of each assignment, thereby shifting their pragmatic mindset from merely pursuing transcript grades to an awareness of creating added value for the social and industrial ecosystem.

Moving on to the third pillar, extracts from selected literature reveal a transformation in the social capital aspect, emphasizing the importance of building relational networks and integrating social skills among students. A comprehensive study by Bridgstock (2009), updated by post-pandemic studies such as those by Okolie, Nwajiuba, Binuomote, Ehiobuche, Igu, and Ajoke (2020), demonstrates that the accumulation of human capital (technical knowledge) often becomes ineffective if not distributed through robust social capital channels. Students in this era are required to develop professional portfolios and positive digital footprints from the moment they enter college. The ability to present themselves professionally, build interdisciplinary networks, and negotiate and resolve conflicts within diverse work teams are competency elements that are as important as program-specific expertise (Suleman, 2018). This phenomenon emphasizes that college graduates must be able to position themselves not only as solitary intelligent individuals, but as strategic team players who are able to integrate into various dynamic and globally oriented organizational structures.

The fourth and final pillar of this synthesis clearly reveals the crucial role of institutional orchestration in providing a supportive ecosystem and opportunities for students to express themselves. The conclusions of research conducted by Bates, Rixon, Carbone, and Aragon (2019), along with empirical confirmation from Pitan and Muller (2020), convincingly demonstrate that successful student competency development cannot exist in isolation within an individual academic vacuum. It relies heavily on the commitment and capability of faculty and university management to design, fund, and oversee integrative infrastructure support. The availability of robust academic information systems platforms, modern practical laboratory facilities, entrepreneurial business incubators, and Work-Integrated Learning programs provide students with an empirical simulation platform that bridges the gap between theory and industry practice (Rowe & Zegwaard, 2017; Teng, Ma, Pahlevansharif, & Turner, 2019). Furthermore, contemporary literature also incorporates a new dimension of institutional adaptation, where the campus's capability to directly involve practitioners and employers in the curriculum development stage (employer engagement) is recognized as the most advanced strategy to minimize academic bias (Minocha, Hristov, & Reynolds, 2017). Accumulatively, these institutional pillars convey a very clear message that the construction of world-class student competencies will only be firmly established if fully facilitated by physical infrastructure, information technology systems, and strategic policy maneuvers at the institutional level of higher education.

Key Pillars of Transformation	Key Literature	Focus Analysis & Synthesis of Findings

Digital & Cognitive Literacy	• Zhao et al. (2021) • Blázquez et al. (2020) • Jackson & Bridgstock (2021)	Underlines the shift in competency from memorizing theory and basic computational skills to the agility of algorithmic thinking and the ability to critically and ethically evaluate information.
Psychological Capital & Meaning of Work	• Donald et al. (2019) • Clarke (2018) • Tran et al. (2021)	Dropping surface *engagement indicators* and placing " *Meaning of Work "* as an intrinsic anchor that encourages student adaptive proactivity.
Social Capital & Relational Networks	• Bridgestock (2009) • Okolie et al. (2020) • Suleman (2018)	Examining the importance of technical knowledge distribution through the ability to build a professional digital footprint, inclusive collaboration, and negotiation capacity within dynamic teams.
Institutional Orchestration	• Bates et al. (2019) • Rowe & Zegwaard (2017) • Minocha et al. (2017)	Highlighting that student competency is highly dependent on the campus ecosystem (integration of academic systems, real laboratories, and alignment of curriculum with industry practitioners).

Table 1. Research Synthesis

4. CONCLUSION

This systematic literature review, based on the PRISMA methodology and extracting dozens of globally reputable academic papers from the Scopus and WoS databases, concludes with an undeniable central thesis: the concept of student competency at the tertiary level has fundamentally metamorphosed. The old paradigm that glorified the passive acquisition of cognitive theoretical knowledge has collapsed, replaced by a multidimensional aggregation of competencies that absolutely demands adaptive digital literacy, advanced psychological capital resilience, social capital flexibility, and practical execution skills. The results of the comprehensive synthesis confirm that to respond to the dual technological and economic disruptions that are disrupting the labor market, the conventional pedagogical framework in higher education must be immediately and radically restructured. Through the conceptual lens of the Graduate Capital Model, it can be concluded that competency optimization relies heavily on a motivational paradigm that is based on career identity development. The abandonment of traditional, often fragile academic engagement metrics and the establishment of Meaning of Work as a core mediator have been empirically proven to be a catalytic force that encourages student independence, persistence, and tenacity in proactively acquiring competencies. This clarity of vision and meaning for their professional future guides students to selectively equip

themselves with the combination of technical (hard) and soft skills that best align with their career trajectory.

These academic findings ultimately lead to a series of strategic implications that urgently require immediate implementation by all stakeholders within the higher education ecosystem. Policymakers, rectorates, deans, and academics and researchers are strongly recommended to end operational practices confined within fragmented faculty silos. Higher education institutions are required to redesign (reengineer) their infrastructure to optimally supply exploration opportunities, ranging from implementing a responsive digital academic system, intensifying laboratory simulations based on real industry projects, to expanding national and global internship program partnership networks that guarantee the quality of Semester Credit Unit conversion. In parallel, educators and lecturers are required to renew their teaching approaches, transforming from literature dictators to strategic facilitators and mentors. Lecturers are no longer merely overseeing the transfer of textbooks, but are also required to oversee the process of internalizing the meaning of each individual's work in the classroom. Through the continuous synergy between human capital renewal, instilling a deep sense of work meaning, strengthening social capital, and a commitment to providing a complete institutional ecosystem, universities will have the strategic capacity to effectively neutralize the skills gap, while producing graduates who are not only intellectually brilliant, but also possess strong character, ethical integrity, and superior competitiveness in the post-disruptive global stage.

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DYNAMICS AND TRANSFORMATION OF THE MODERN ERA JOB FIELD: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

The dynamics of the labor market in the modern era are experiencing massive structural transformation due to the penetration of artificial intelligence technology, shifts in employment relationship models, and demands for global ecological sustainability. This study aims to synthesize literature related to the evolution of employment and map the shift in workforce competency profiles using the analysis instruments of the Ability, Motivation, and Opportunity Theory (AMO) and *the Resource-Based View* (RBV). Through the Systematic Literature Review (SLR) method that strictly adopts the PRISMA protocol guidelines, data searches are conducted on reputable academic databases namely Scopus, Web of Science, and Google Scholar for the publication year range 2019–2026. The results of the qualitative synthesis of the selected literature reveal three main pillars of employment transformation: (1) the acceleration of job polarization due to automation that disrupts middle-class administrative-routine tasks and triggers a surge in demand for complex cognitive skills; (2) the rise of the part-time economy (*gig economy*) that presents a dualism between flexible autonomy and vulnerability of social protection under the control of algorithmic management; and (3) the growth of the green jobs sector , which is urging organizations to implement *Green Human Resource Management* (GHRM) to build environmentally friendly competencies holistically. This study concludes that the resilience and competitive advantage of human resources are no longer solely based on basic technical skills, but rather on the integration of emotional intelligence, adaptive agility, and lifelong learning capacity. The strategic implications of this study require collaboration between educational institutions, governments, and human resource management architects in designing an ecosystem for skills improvement (*upskilling* and *reskilling*) to bridge the competency gap amidst the waves of future disruption.

Keywords: Job Transformation, Job Polarization, *Gig Economy* , *Green Jobs* , Systematic Literature Review, Human Resource Management.

1. BACKGROUND

The development of human civilization, now on the threshold of the Fourth Industrial Revolution and the transformation into a global smart society, has brought about extraordinary massive disruption to the employment landscape worldwide. Studying labor market dynamics is crucial and urgently requires in-depth analysis, given the fundamental paradigm shift, moving from conventional, mechanical forms of work to new roles that require a high level of

psychological adaptability, cognitive agility, and advanced digital literacy. This global phenomenon is reinforced by a 2023 World Economic Forum report that projects a double disruption phenomenon in which tens of millions of administrative, clerical, and repetitive positions will be gradually eliminated by the expansion of automation systems. At the same time, this transformation will also trigger the creation of millions of new jobs oriented towards artificial intelligence technology, large-scale data analysis, and the sustainable green economy sector.

This exponential escalation of change has triggered significant uncertainty within the workforce, giving rise to structural challenges in the form of a profound skills gap, where the competencies produced by educational institutions are often out of sync with the dynamic needs of today's fast-paced industry. Analyzing both historically and theoretically, the disruption of employment resulting from the penetration of computing technology and generative artificial intelligence demands a comprehensive understanding of how labor market structures respond to innovation. The classic theoretical study by Acemoglu and Restrepo (2019) on labor market mechanization and automation provides an important foundation, outlining the constant struggle between the effects of labor displacement and the effects of job recovery.

Displacement effects occur when machines and algorithms take over tasks previously performed by humans, which, if not offset, will trigger widespread structural unemployment; while recovery effects occur when technological innovation creates new tasks that are more complex, have high added value, and require unique human capabilities that cannot be defined by computer binary code. Therefore, the real challenge in modern workforce management is not simply to stop the flow of technology, but how to prepare the collective capabilities so that the workforce can shift from routine, automated tasks to the new workspaces created by these recovery effects.

When analyzed historically and theoretically, the disruption of the workforce due to the penetration of computing technology and generative artificial intelligence demands a comprehensive understanding of how labor market structures respond to innovation. The classic theoretical study of mechanization and automation developed by Acemoglu and Restrepo (2019) provides a crucial foundation, outlining the constant struggle between the effects of labor displacement and the effects of job recovery. Furthermore, from the Resource-Based View (RBV) perspective formulated by Barney (1991) and later developed in the context of human resources by Wright, Dunford, and Snell (2001), organizational competitive advantage in the era of disruption no longer rests solely on physical or technological capital—which are now easily replicated—but rather on human capital, which is rare, valuable, and difficult to imitate. This transformation makes employee learning agility a supreme strategic asset. Therefore, the real challenge in modern workforce management is not simply to stem the tide of technology, but rather to prepare the collective capabilities so that the workforce can shift into the new workspace created by the recovery effect.

In the context of human resource management and organizational behavior, the dynamics of this shift in the job market are highly relevant when analyzed using the theoretical lens of the Ability, Motivation, and Opportunity Theory (AMO Theory) proposed by Appelbaum et al. (2000). This theory has been integrated by contemporary scholars such as Jiang et al. (2012) to measure the impact of high-performance work systems. The ability component is disrupted as technical skills rapidly become obsolete, requiring training

restructuring. Motivation shifts as the psychological contract between workers and organizations changes amidst career uncertainty (Rousseau, 1995). Meanwhile, opportunity undergoes structural reconstruction due to workplace decentralization. The conceptual urgency of this research stems from the fact that failure to respond to this transformation will have systemic impacts. This systematic literature review was designed to synthesize a variety of empirical findings from various previous studies. Through in-depth synthesis, this study seeks to map the factors driving the shift, analyze the impact of automation, and formulate a comprehensive future skills map.

In the context of human resource management and organizational behavior, the dynamics of this shift in employment are highly relevant when analyzed using the theoretical lens of the Ability, Motivation, and Opportunity Theory, widely known as the AMO Theory, proposed by Appelbaum and colleagues in 2000. This theory states that optimal organizational and individual performance is an interactive function of three key, closely interrelated components. The first component, namely ability, is directly disrupted by digital transformation because past technical skills are rapidly becoming obsolete, thus requiring the restructuring of training curricula, skill enhancement programs, and the reconditioning of workers' cognitive capacities to remain relevant in the job market. The second component, namely motivation, is also shifting along with increasing career uncertainty and changes in the psychological contract between workers and organizations, where incentive systems, future certainty, and workers' mental well-being become determining variables in retaining the best talent. The third component, namely opportunity, is undergoing structural reconstruction due to workplace decentralization, the adoption of remote work systems, and the democratization of information that are changing how employees participate, collaborate, and make strategic contributions within increasingly flexible organizational boundaries.

The conceptual urgency of this research is rooted in the fact that failure to respond to the transformation of the job market will have systemic impacts, both on a macroeconomic scale in the form of declining national productivity and a swelling number of educated unemployment, as well as on a micro-organizational scale in the form of a loss of competitive advantage due to the scarcity of competent talent. Departing from the complexity of these problems, this systematic literature review was compiled with the main objective of synthesizing various empirical and conceptual findings from various previous studies spread across various parts of the world regarding the evolution of the job market.

Through in-depth synthesis, this study seeks to map the key drivers driving shifts in industrial needs, analyze the concrete impact of automation on the social structure of workers, and formulate a comprehensive future skills map. The results of this systematic literature review are expected to not only be a theoretical contribution enriching the body of human resource management knowledge but also serve as a valid and objective strategic guide for policymakers, industry practitioners, and academics in designing proactive and sustainable adaptation strategies.

2. METHODOLOGY

This study was conducted entirely as a rigorously designed systematic literature review by adopting the Preferred Reporting Items for Systematic Reviews and Meta-Analyses

(PRISMA) protocol guidelines standardized by Moher et al. (2009). The use of this scientific protocol, combined with the systematic review approach in evidence-based management suggested by Tranfield, Denyer, and Smart (2003), is considered crucial to ensure that all stages of literature collection, screening, evaluation, and synthesis are free from subjective bias, have high transparency, and meet the requirements of replicability.

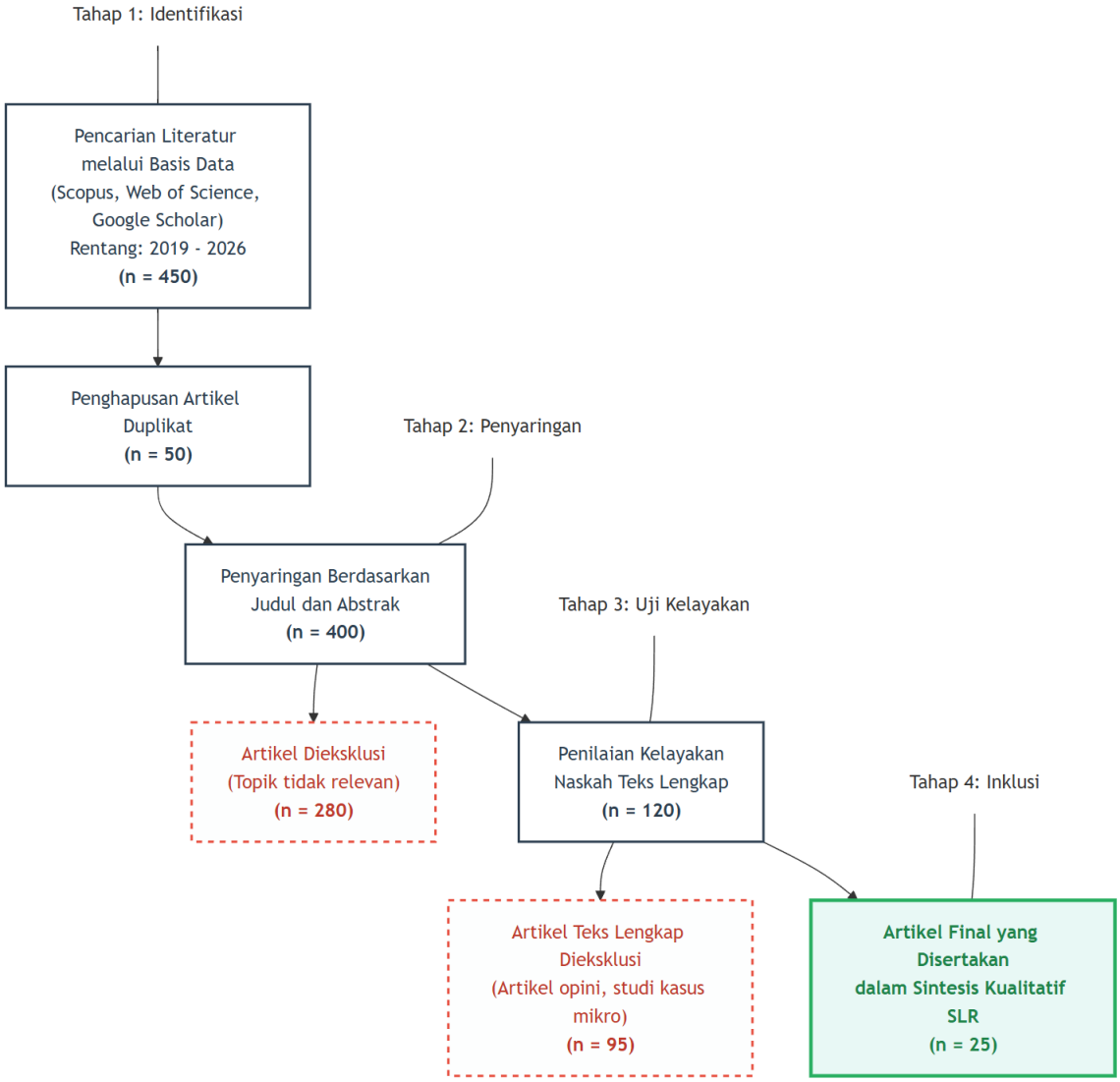


Figure 1. PRISMA Filtering Stage

The academic manuscript search process was conducted extensively, targeting three reputable global databases: Scopus and Google Scholar. The search strategy was designed using a search string formulation that combines specific keywords and Boolean operators. The keyword combination included labor market transformation, employment automation, gig economy dynamics, and the skills gap. A strict temporal limit was applied to the publication year range of 2019 to 2026 to capture post-pandemic dynamics and the impact of the wave of generative artificial intelligence. Inclusion criteria required articles to be qualitative/quantitative empirical research, in-depth theoretical studies, or macro-institutional reports published in peer-reviewed journals. Exclusion criteria excluded popular opinion

articles, unindexed proceedings, and micro-case studies specific to a single, small-scale business entity. Qualified manuscripts were then thoroughly reviewed for data extraction and thematic qualitative synthesis to map the consistencies and divergences of views among global labor researchers.

3. RESULTS

A thorough synthesis of dozens of selected academic literatures has revealed three major structural change patterns dominating the contemporary employment landscape. The first dominant finding is the increasingly pronounced acceleration of job polarization. This theoretical concept of polarization is rooted in the ALM Hypothesis introduced by Autor, Levy, and Murnane (2003), later expanded by Autor and Dorn (2013) and Goos, Manning, and Salomon (2014). They demonstrated that the labor market is experiencing a cleavage: a sharp surge in demand for high-skill jobs (non-routine cognitive analysis, creativity, and complex problem solving) and growth in low-skill jobs (personal services), while middle-skill jobs (routine administrative and clerical) are experiencing an exponential decline. Frey and Osborne (2017), in their computational probability study, also emphasized that jobs with a high degree of process standardization are maximally vulnerable to being replaced by computer algorithms, triggering the hollowing out of the middle-class structure in the global labor market. The second key finding highlights the expansive rise of the gig economy as an alternative form of employment that is redefining conventional employment relationships. Based on a comprehensive analysis by Wood et al. (2019) and a critical review by De Stefano (2015), the shift from permanent employees to freelancers offers significant autonomy and flexibility. However, literature from Kalleberg and Dunn (2016) objectively reveals the dark side of this transformation in the form of the rise of "precarious work." This model presents serious economic vulnerabilities for workers due to the loss of social safety nets, the lack of guaranteed monthly income, and minimal legal protection. Furthermore, Kellogg, Valentine, and Christin (2020) underscore the emergence of new threats of exploitation through algorithmic management systems , where worker evaluation and assignments are completely controlled by artificial intelligence without any room for human negotiation.

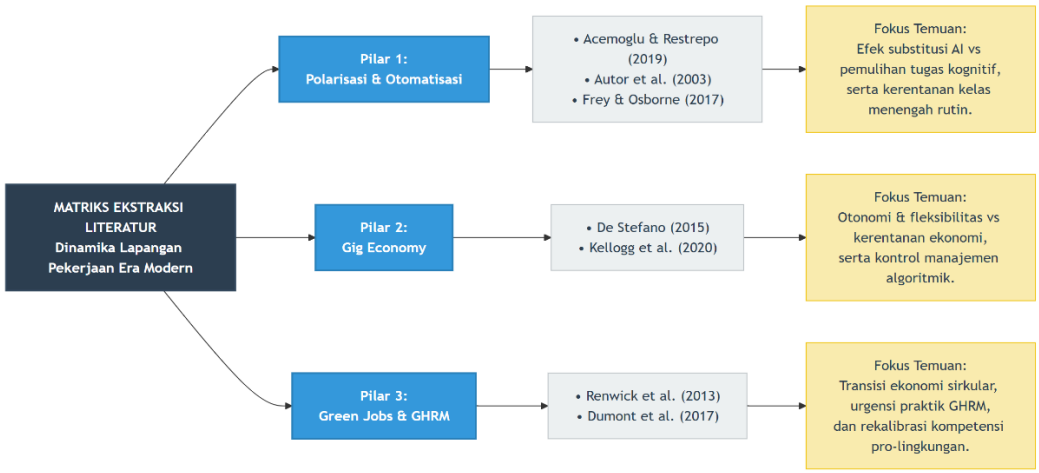


Figure 1. Literacy Dimension Focus Model

The third key finding highlights the emergence and growth of the green jobs sector as an industry response to the global climate crisis and institutional pressures. According to a report by the International Labour Organization (2018), the transition to a circular economy is forcing companies to reconstruct their operations. This macro-level change has triggered the massive integration of Green Human Resource Management (GHRM) practices at the micro-organizational level. Analysis by Renwick, Redman, and Maguire (2013), further deepened empirically by Dumont, Shen, and Deng (2017) and Tang et al. (2018), shows that GHRM is creating a new competency niche. Employers now demand candidates who possess not only technical expertise but also voluntary environmentally friendly behavior (Organizational Citizenship Behavior for the Environment). Jabbour (2013) identified the readiness of human resources to adopt these sustainability values as a key foundation for companies to gain social legitimacy and sustainable competitive advantage in the future.

When all these findings are integrated, the literature unanimously confirms a radical recalibration of competency profiles. Mastery of basic technical skills is no longer sufficient if not combined with advanced soft skills. Heckman and Kautz (2012) have long validated the crucial role of non-cognitive skills, and in this contemporary era, variables such as emotional intelligence, empathetic communication, agile leadership, and lifelong learning capacity are anchoring individuals' resilience amidst the wave of job market disruption.

Key Pillars of Transformation	Key Literature	Focus Analysis & Findings
Polarization & Automation	• Acemoglu & Restrepo (2019) • Autor et al. (2003) • Frey & Osborne (2017)	Examines the labor displacement effects of AI automation and projects a drastic reduction in routine-administrative jobs (the hollowing out of the middle class).
Gig Economy	• De Stefano (2015) • Kellogg et al. (2020)	Analyzing the dualism of freelance work: time autonomy versus social security vulnerability, and the dominance of algorithm-based management control over humans.
Green Jobs & GHRM	• Renwick et al. (2013) • Dumont et al. (2017)	Highlighting the organization's response to the climate crisis through the creation of green jobs and the implementation of GHRM to encourage voluntary environmentally friendly behavior in the workplace.

Table 1. Key literature

4. CONCLUSION

Based on a comprehensive and objective synthesis of the systematic literature that has been conducted, a solid academic conclusion can be drawn that the transformation of the modern job market is not a process of absolute elimination of human labor by the presence of machines, but rather a process of very fundamental structural restructuring. Artificial

intelligence-based automation, the expansion of the part-time economy, and the global demand for the creation of green jobs have radically changed the anatomy of the labor market, shifting the map of required competencies, and redefining conventional employment relationship patterns that have persisted for centuries. This phenomenon provides a strong theoretical affirmation that the possession of a formal educational diploma alone is no longer able to act as an absolute guarantee of future career stability, but must always be supported by an individual's capability for lifelong learning and flexibility in adapting to continuous environmental changes.

The biggest and most crucial challenge identified from this literature review is the widening skills gap between the competencies produced by conventional educational institutions and the real needs of the industrial world driven by high technology and ecological awareness. This condition has very serious macro implications for policymakers and managers of higher education institutions to immediately undertake a radical curriculum overhaul, integrate data literacy and technology into all study programs, and build an adaptive partnership ecosystem with the industrial world to create dynamic harmony. In addition, the government is required to formulate new, more progressive labor law regulations and design an innovative social safety net to provide equitable protection for the millions of freelance workers in the part-time economy ecosystem so they do not get caught in a vortex of prolonged economic vulnerability.

At the micro-organizational level, the findings of this systematic literature review have profound strategic implications for the future direction of human resource management evolution. Human resource management practices should no longer be confined to rigid, traditional personnel administration functions, but rather fully transform into strategic talent architects that proactively facilitate continuous employee retraining and upskilling programs. Drawing on the AMO Theory framework, organizations must design work environments that not only enhance employees' new technical capabilities but also build adaptive motivation systems that promote mental well-being and open up opportunities for employees' active involvement in business innovation. By integrating technology adoption readiness, green human resource management implementation, and a commitment to human capacity development, organizations will have the strategic resilience to navigate the changing tides of the modern workplace, achieving holistic sustainability.

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STUDENTS' PERCEPTION OF USING PICTURE DICTIONARY IN LEARNING VOCABULARY OF FIFTH GRADE AT SD NEGERI 10 PALEMBANG.

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ABSTRACT

This study aimed to investigate students' perceptions of using picture dictionaries in learning English vocabulary at SD Negeri 10 Palembang. The study employed a qualitative research design involving 38 students from Grade V and Grade VI as the participants. The data were collected through observation, interviews, and questionnaires. The data were analyzed using the interactive model proposed by Miles, Huberman, and Saldaña, consisting of data reduction, data display, and conclusion drawing.

The findings showed that students had positive perceptions toward the use of picture dictionaries in vocabulary learning. The observation results indicated that 73.7% of students demonstrated positive responses, while 15.8% showed neutral responses and 10.5% showed negative responses. The interview results revealed that picture dictionaries helped students understand and remember vocabulary more easily, increased their motivation, and encouraged active participation during classroom activities. Furthermore, the questionnaire results showed that the majority of students selected "Strongly Agree" (39.21%) and "Agree" (34.91%) responses regarding the effectiveness of picture dictionaries. The cognitive, affective, and behavioral aspects of students' perceptions were categorized as very positive.

In conclusion, picture dictionaries were perceived positively by students and contributed to better vocabulary understanding, increased learning motivation, and greater classroom engagement. Therefore, picture dictionaries can be considered an effective learning medium for teaching English vocabulary to elementary school students.

Keywords: Students' Perception, Picture Dictionary, Vocabulary Learning, Elementary School Students, English Vocabulary.

INTRODUCTION

English plays a significant role in the modern world because it is widely used as a means of international communication. In Indonesia, English is taught as a foreign language and has become an important subject in schools. Learning English at an early age is essential because children have greater opportunities to develop language skills when exposed to a foreign language during their formative years. Among the various components of English learning, vocabulary is considered one of the most important because it serves as the foundation of language proficiency.

Vocabulary refers to the collection of words that learners understand and use in communication. According to Nation (2023), vocabulary knowledge is a crucial element in second-language acquisition because learners cannot communicate effectively without adequate vocabulary. Students who possess a rich vocabulary are more capable of

understanding reading materials, expressing ideas, participating in conversations, and producing written texts.

However, vocabulary learning is not always easy for elementary school students. Many young learners struggle to remember unfamiliar words, understand meanings, and use vocabulary appropriately in different contexts. These difficulties often arise because English vocabulary differs significantly from students' first language. Furthermore, traditional vocabulary teaching methods frequently emphasize memorization and translation, which may reduce students' interest and motivation.

Teachers therefore need effective instructional strategies and learning media that can support vocabulary acquisition. One learning medium that has been widely recognized is the picture dictionary. A picture dictionary is a vocabulary learning resource that combines words with visual illustrations. The visual images provide contextual support that helps learners understand vocabulary meanings more easily.

Visual learning media have been shown to enhance students' learning experiences. Mayer (2024) argues that learners process information more effectively when verbal and visual information are presented simultaneously. This principle, known as Multimedia Learning Theory, suggests that learners can construct stronger mental representations when they receive information through multiple channels.

Similarly, Dual Coding Theory proposed by Paivio explains that information presented both verbally and visually is easier to remember because it is stored in two different cognitive systems. When students learn vocabulary through picture dictionaries, they not only read the words but also observe images that represent their meanings. As a result, vocabulary learning becomes more meaningful and memorable.

Previous studies have consistently demonstrated the benefits of visual learning media. Hidayati et al. (2024) reported that visual materials significantly improved students' vocabulary comprehension and retention. Likewise, Rahman and Hidayat (2023) found that students expressed positive perceptions toward visual learning media because they increased classroom participation and motivation.

Despite these findings, limited studies have specifically explored students' perceptions toward the use of picture dictionaries in elementary school settings. Most previous studies focused on vocabulary achievement rather than students' perceptions. Understanding students' perceptions is important because positive perceptions influence motivation, engagement, and learning outcomes.

Based on these considerations, this study investigates students' perceptions toward the use of picture dictionaries in learning English vocabulary at SD Negeri 10 Palembang.

LITERATURE REVIEW

2.1 Vocabulary Learning

Vocabulary is one of the essential components of language learning. Without vocabulary, learners cannot express ideas or understand messages effectively. According to Schmitt (2023), vocabulary knowledge consists of understanding word meanings, pronunciation, spelling, and usage. Vocabulary learning involves both receptive and productive knowledge. Receptive vocabulary refers to words that learners can recognize and understand, whereas productive vocabulary refers to words that learners can actively use in speaking and writing. Elementary school students generally require extensive exposure and repetition to develop both types of vocabulary knowledge.

2.2 Picture Dictionary

A picture dictionary is a learning resource that presents vocabulary items together with visual illustrations. Unlike traditional dictionaries, picture dictionaries rely on images to represent meanings. This approach is particularly useful for young learners because children tend to learn better through visual stimuli.

Picture dictionaries provide several educational benefits:

1. They help students understand vocabulary meanings.
2. They facilitate memory retention.
3. They reduce dependence on translation.
4. They increase learning motivation.
5. They encourage active participation.

According to Mayer (2024), visual representations help learners organize information and create meaningful connections between concepts.

2.3 Students' Perception

Perception refers to the process through which individuals interpret and understand information obtained from their environment. In educational settings, students' perceptions influence their attitudes, behaviors, and learning outcomes.

Brown (2022) categorizes perception into three dimensions:

1. Cognitive Perception

   Cognitive perception relates to students' understanding, knowledge, and beliefs about learning experiences.

2. Affective Perception

Affective perception refers to students' emotions, feelings, motivation, and attitudes toward learning.

3. Behavioral Perception

Behavioral perception involves students' actions, participation, and engagement during learning activities.

METHOD

This study employed a qualitative research design. Qualitative research aims to understand participants' experiences, opinions, and perceptions in depth. The study focused on exploring students' perceptions of using picture dictionaries during vocabulary learning activities.

The participants consisted of 38 students from Grade V and Grade VI of SD Negeri 10 Palembang. The students were selected using purposive sampling because they had prior experience learning vocabulary through picture dictionaries.

Three instruments were used to collect data:

1. **Observation**

   Observation was conducted to identify students' engagement, participation, and responses during vocabulary learning activities using picture dictionaries. The observation focused on vocabulary understanding, learning motivation, and classroom participation.

2. **Interview**

   Semi-structured interviews were conducted with teachers and selected students. The interviews aimed to obtain detailed information regarding students' experiences, motivation, understanding, and engagement while using picture dictionaries.

3. **Questionnaire**

   A questionnaire consisting of cognitive, affective, and behavioral indicators was distributed to students. The questionnaire employed a Likert Scale ranging from Strongly Agree to Strongly Disagree.

Data were analyzed using the interactive analysis model proposed by Miles, Huberman, and Saldaña (2023), consisting of data reduction, data display, and conclusion drawing. Data triangulation was used to compare findings obtained from observation, interviews, and questionnaires.

DISCUSSION

1. Observation Results

The observation findings revealed that most students demonstrated positive perceptions toward the use of picture dictionaries. Out of 38 students, 28 students (73.7%) showed positive responses, 6 students (15.8%) demonstrated neutral responses, and only 4 students (10.5%) displayed negative responses.

The findings indicate that students were actively engaged during learning activities. They paid attention to the teacher's explanation, participated in classroom discussions, and showed enthusiasm while learning vocabulary through picture dictionaries. The visual representations helped students understand vocabulary meanings more effectively.

2. Interview Results

Interview findings revealed positive perceptions from both teachers and students. Teachers reported that students understood vocabulary more quickly when picture dictionaries were used. Students were also able to remember vocabulary more effectively because pictures helped them associate words with meanings.

Students stated that picture dictionaries made vocabulary learning easier and more enjoyable. They felt more confident in using English vocabulary and were more willing to participate in classroom activities. Furthermore, students expressed that learning became less boring and more interesting because of the visual support provided by picture dictionaries. Overall, both teachers and students agreed that picture dictionaries were effective learning media for vocabulary instruction.

3.3 Questionnaire Results

1. Cognitive Aspect

The cognitive aspect measured students' understanding and retention of vocabulary.

Statement	**Percentage**	**Category**
Understanding vocabulary easily	89%	Very Positive
Remembering vocabulary better	87%	Very Positive
Recognizing English vocabulary	84%	Very Positive

The results indicate that students perceived picture dictionaries as useful tools for understanding and remembering vocabulary.

2. Affective Aspect

The affective aspect focused on students' feelings and motivation.

Statement	**Percentage**	**Category**
Interest in learning vocabulary	95%	Very Positive

Enjoyment during learning	92%	Very Positive
Motivation in learning English	89%	Very Positive

The findings demonstrate that picture dictionaries increased students' interest, enjoyment, and motivation.

3. Behavioral Aspect

The behavioral aspect measured students' participation and confidence.

Statement	**Percentage**	**Category**
Active participation	95%	Very Positive
Paying attention during learning	92%	Very Positive
Confidence in using vocabulary	89%	Very Positive

These findings indicate that picture dictionaries encouraged students to participate actively and confidently in learning activities.

DISCUSSION

The findings of this study indicate that students had positive perceptions toward the use of picture dictionaries in learning English vocabulary. The consistency of findings across observation, interviews, and questionnaires strengthens the validity of the results.

From the cognitive perspective, students reported that picture dictionaries helped them understand and remember vocabulary more effectively. These findings support Nation's Vocabulary Learning Theory, which emphasizes meaningful connections between words and their meanings. Visual representations allow learners to process vocabulary more efficiently and retain information longer.

The affective findings revealed that students were highly motivated and interested in learning vocabulary through picture dictionaries. These findings are consistent with Mayer's Multimedia Learning Theory, which suggests that visual and verbal information enhance learner engagement and understanding. Students felt happier and more enthusiastic because learning activities became more interactive and enjoyable.

The behavioral findings also demonstrated positive impacts. Students participated more actively, paid closer attention, and showed greater confidence in using English vocabulary. These findings align with constructivist learning principles, which emphasize active learner involvement in knowledge construction.

The interview findings further confirmed the positive effects of picture dictionaries. Students stated that pictures helped them understand vocabulary more clearly and encouraged them to participate in classroom activities. Teachers also observed improvements in students' motivation, participation, and vocabulary comprehension.

Overall, picture dictionaries function as effective visual learning media that support vocabulary acquisition and create meaningful learning experiences for young learners.

CONCLUSION

This study investigated students' perceptions of using picture dictionaries in learning English vocabulary at SD Negeri 10 Palembang. The findings demonstrated that students had positive perceptions toward the use of picture dictionaries.

Observation results showed that most students displayed positive responses during learning activities. Interview findings indicated that students understood vocabulary more easily, remembered words better, and became more motivated. Questionnaire results revealed very positive perceptions in cognitive, affective, and behavioral aspects.

Therefore, picture dictionaries can be considered effective learning media for vocabulary instruction at the elementary school level. Teachers are encouraged to integrate picture dictionaries into English lessons to support vocabulary development, increase motivation, and encourage active classroom participation.

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AN ANALYSIS OF VOCABULARY LEARNING DIFFICULTIES FACED BY FOURTH-GRADE STUDENTS AT SD NEGERI 010 PALEMBANG

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Abstract

Vocabulary is one of the most essential components in language learning because it supports learners in developing listening, speaking, reading, and writing skills. However, many elementary school students still experience difficulties in mastering English vocabulary, which may hinder their language development and academic achievement. This study aimed to analyze the vocabulary learning difficulties faced by fourth-grade students at SD Negeri 010 Palembang. The research employed a descriptive qualitative design. The participants consisted of 30 fourth-grade students selected through total sampling. Data were collected through a questionnaire consisting of 50 statements related to vocabulary learning difficulties. The data were analyzed using descriptive statistical techniques and qualitative interpretation. The findings showed that 55.47% of the students experienced difficulties in learning English vocabulary. These difficulties were classified into four main categories: cognitive difficulties, linguistic difficulties, psychological difficulties, and environmental difficulties. Cognitive difficulties included forgetting vocabulary and slow comprehension of word meanings. Linguistic difficulties involved pronunciation, spelling, understanding multiple meanings of words, and contextual usage. Psychological difficulties included low motivation, boredom, exam pressure, and lack of self-confidence. Environmental difficulties were related to limited language exposure, less attractive learning resources, and monotonous teaching methods. The study concludes that vocabulary learning difficulties are influenced by various interconnected factors and require comprehensive efforts frzom teachers, students, and educational institutions to improve vocabulary mastery.

Keywords: vocabulary learning, learning difficulties, English vocabulary, elementary students, qualitative research, language learning

INTRODUCTION

Language is an essential tool for communication and social interaction. Through language, people can express their thoughts, emotions, ideas, and experiences. In the context of education, language serves as a medium for acquiring knowledge and developing intellectual abilities. English, as an international language, has become one of the most important subjects taught in schools because it enables students to communicate globally and access a broader range of information.

One of the fundamental elements of language learning is vocabulary. Vocabulary refers to the collection of words that individuals know and use in communication. Without adequate vocabulary knowledge, learners may find it difficult to understand spoken and written texts or

express their ideas effectively. Vocabulary serves as the building block of language because grammar and communication cannot function properly without words.

According to Nation (2022), vocabulary knowledge plays a crucial role in language proficiency. Students who possess a rich vocabulary tend to perform better in reading comprehension, writing tasks, listening activities, and oral communication. Similarly, Schmitt (2023) argues that vocabulary acquisition is one of the strongest predictors of successful language learning. Therefore, vocabulary development should receive significant attention in language education.

For elementary school students, vocabulary learning is particularly important because it provides a foundation for future language development. At the elementary level, students begin to acquire basic vocabulary related to everyday life, school activities, family, animals, colors, occupations, and other common topics. This vocabulary serves as a basis for more advanced language learning in higher educational levels.

Despite its importance, vocabulary learning is often challenging for young learners. Students may struggle to understand the meanings of words, remember newly learned vocabulary, pronounce words correctly, spell words accurately, and use vocabulary appropriately in context. These difficulties may prevent students from achieving optimal language learning outcomes.

Researchers and language educators have identified various factors that contribute to vocabulary learning difficulties. Cognitive factors involve memory, information processing, and word retention. Linguistic factors relate to the characteristics of language itself, including pronunciation, spelling, semantics, and contextual usage. Psychological factors involve learners' motivation, confidence, attitudes, and emotions. Environmental factors include teaching methods, learning resources, classroom atmosphere, and opportunities for language exposure.

Previous studies have reported similar findings. Rahmawati and Suryani (2022) found that students often experience difficulties remembering English vocabulary because they rely heavily on memorization techniques. Hidayat and Lestari (2022) reported that visual learning media can improve vocabulary retention and comprehension among young learners. Fitriani (2023) found that students generally have positive perceptions toward picture dictionaries because visual elements help them understand vocabulary more effectively. Meanwhile, Wulandari (2024) demonstrated that students who learn vocabulary through picture dictionaries

perform better in pronunciation, spelling, and vocabulary recognition than those who use conventional methods.

Based on preliminary observations conducted at SD Negeri 010 Palembang, many fourth-grade students appeared to face challenges in learning English vocabulary. Students frequently forgot newly learned words, hesitated to use English during classroom activities, and struggled to understand vocabulary presented in learning materials. These challenges affected their participation and performance in English lessons.

Considering the importance of vocabulary mastery and the existence of various learning difficulties, it is necessary to investigate the specific challenges experienced by students. Understanding these difficulties can help teachers design more effective instructional strategies and provide appropriate support for learners. Therefore, this study aims to analyze the vocabulary learning difficulties faced by fourth-grade students at SD Negeri 010 Palembang. The research question addressed in this study is: What are the vocabulary learning difficulties experienced by fourth-grade students at SD Negeri 010 Palembang?

METHOD

Research Design

This study employed a descriptive qualitative research design. Qualitative research is suitable for exploring educational phenomena and understanding participants' experiences in depth. The descriptive approach was chosen because the study aimed to describe the difficulties encountered by students in learning English vocabulary without manipulating variables or testing causal relationships.

According to Creswell and Poth (2022), qualitative research enables researchers to explore social phenomena through detailed descriptions and interpretations. In this study, the researcher focused on describing students' vocabulary learning difficulties based on their responses to the questionnaire.

Participants

The participants of this study were fourth-grade students of SD Negeri 010 Palembang during the 2025/2026 academic year. The total population consisted of 30 students. Since the population was relatively small, the researcher used total sampling, meaning that all students participated in the study.

The participants represented learners who were actively studying English vocabulary as part of their educational curriculum. Their experiences and perceptions provided valuable information regarding vocabulary learning difficulties at the elementary school level.

Research Instrument

The primary instrument used in this study was a questionnaire consisting of 50 statements. The questionnaire was designed to identify difficulties experienced by students in learning English vocabulary.

The statements were categorized into four aspects:

1. Cognitive difficulties.
2. Linguistic difficulties.
3. Psychological difficulties.
4. Environmental difficulties.

Students were asked to respond by choosing “Yes” or “No” according to their actual experiences.

Data Collection Procedure

The researcher first obtained permission from the school administration to conduct the study. After receiving approval, the questionnaires were distributed to all fourth-grade students. Students were provided with explanations regarding how to complete the questionnaire.

After all questionnaires had been completed, the researcher collected and reviewed the responses to ensure completeness and accuracy.

Data Analysis

The collected data were analyzed using descriptive statistical techniques. Frequencies and percentages were calculated to determine the prevalence of vocabulary learning difficulties among students. The quantitative results were then interpreted qualitatively to provide a comprehensive description of the phenomenon under investigation.

FINDINGS AND DISCUSSION

Overall Findings

The study involved 30 students who responded to 50 questionnaire items, resulting in a total of 1,500 responses. The analysis revealed that 832 responses (55.47%) were “Yes,” while 668 responses (44.53%) were “No.”

These findings indicate that more than half of the students experienced difficulties related to vocabulary learning. Although the percentage is not extremely high, it demonstrates that vocabulary learning difficulties are a significant issue among fourth-grade students at SD Negeri 010 Palembang.

Cognitive Difficulties

The findings revealed that cognitive difficulties were common among students. One of the most frequently reported difficulties was forgetting newly learned vocabulary. Many students stated that they could remember vocabulary during lessons but forgot it shortly afterward.

This finding suggests that students rely heavily on rote memorization rather than meaningful learning strategies. When vocabulary is memorized without contextual understanding or regular practice, retention becomes weak and temporary.

Students also experienced difficulties in processing word meanings. They often needed additional time to understand unfamiliar vocabulary while reading texts or listening to explanations. As a result, they sometimes failed to understand the overall meaning of sentences and passages.

These findings support theories of cognitive learning, which emphasize the importance of repetition, meaningful practice, and contextual learning in vocabulary acquisition.

Linguistic Difficulties

Linguistic difficulties constituted another major challenge for students. Many participants reported difficulties in pronouncing English words correctly. Since English pronunciation differs significantly from Indonesian pronunciation, students often found it difficult to produce unfamiliar sounds.

Spelling also emerged as a common problem. Students frequently made mistakes when writing English words because English spelling patterns do not always correspond directly to pronunciation.

Another challenge involved understanding polysemy, or words with multiple meanings. Students often became confused when encountering words that carried different meanings in different contexts.

Additionally, students struggled to use vocabulary appropriately in sentences. Although they understood individual word meanings, they frequently translated directly from Indonesian to English, resulting in grammatically incorrect expressions.

Psychological Difficulties

Psychological factors significantly affected students' vocabulary learning experiences. Many students reported feeling bored during vocabulary lessons. Traditional teaching methods based on memorization and repetition were often perceived as monotonous.

The findings also indicated that many students learned vocabulary primarily to pass examinations. This form of extrinsic motivation encouraged short-term memorization rather than meaningful learning.

Another important psychological factor was lack of self-confidence. Students frequently hesitated to use English vocabulary because they feared making mistakes. This fear reduced opportunities for practice and limited vocabulary development.

These findings highlight the importance of creating a supportive learning environment where students feel comfortable experimenting with language and learning from errors.

Environmental Difficulties

Environmental factors also contributed to vocabulary learning difficulties. Most students reported limited exposure to English outside the classroom. They rarely encountered English through books, media, or social interactions.

Students also perceived available learning materials as less engaging and insufficiently connected to their interests and daily experiences. Consequently, they found it difficult to remain motivated during learning activities.

Furthermore, teaching methods were often described as teacher-centered and repetitive. The lack of interactive activities reduced student participation and engagement.

The findings suggest that increasing language exposure and diversifying instructional approaches may help improve vocabulary learning outcomes.

Discussion

The results demonstrate that vocabulary learning difficulties are complex and multifaceted. Cognitive, linguistic, psychological, and environmental factors interact to influence students' vocabulary acquisition.

For example, monotonous teaching methods may reduce motivation, which in turn decreases students' willingness to practice vocabulary. Limited exposure to English may further hinder retention and application of newly learned words.

These findings support previous studies emphasizing the importance of meaningful learning experiences, interactive teaching methods, and supportive classroom environments. Teachers should integrate games, songs, storytelling, visual aids, and communicative activities into vocabulary instruction to increase student engagement and retention.

CONCLUSION

Based on the findings, it can be concluded that vocabulary learning difficulties remain a significant issue among fourth-grade students at SD Negeri 010 Palembang. More than half of the students reported experiencing difficulties related to vocabulary acquisition.

The difficulties identified in this study can be categorized into four major aspects: cognitive difficulties, linguistic difficulties, psychological difficulties, and environmental difficulties. These factors are interconnected and collectively influence students' ability to learn and use English vocabulary effectively.

To address these challenges, teachers should implement more engaging and student-centered instructional strategies. Students should be encouraged to increase their exposure to English through reading, media, and communication activities. Schools should also provide supportive facilities and learning resources to enhance language learning opportunities

Future researchers are encouraged to conduct interviews and classroom observations to obtain deeper insights into the causes of vocabulary learning difficulties and explore effective intervention strategies.

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CORRELATION OF THE ABILITY TO LISTEN TO FABLES WITH THE ABILITY TO WRITE FABLE FOR GRADE VIII STUDENTS OF SMP NEGERI 2 KAYUAGUNG

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Abstract

This study aims to investigate whether there is a relationship between the ability to listen to fables and the ability to write fables among grade VIII students at SMP Negeri 2 Kayuagung. The method applied in this study is a quantitative approach with a correlational type. The sample used was students from class VIII.2. Data collection was carried out through objective tests and performance assessments. To analyze the data, the product-moment formula and SPSS software version 25 were used. The results of the analysis showed a positive relationship between the ability to listen to fables and the ability to write fable stories. The average score for the ability to listen to a fable was recorded at 2296, while the average score for the ability to write a fable was 1985. From the analysis carried out, the rxy value was obtained of 163920, with a calculation of 0.454 and a table of 0.374. This suggests that the two variables have a significant positive relationship at a confidence level of 5%. Therefore, the research hypothesis (Ha) is acceptable, which indicates an important relationship between the ability to listen to fables and write fable stories among grade VIII students of SMP Negeri 2 Kayuagung.

Keywords: *listening, writing, fable*

INTRODUCTION

Education plays a crucial role in developing high-quality and competitive human resources. According to Mulyasa (2009), education is a conscious effort to develop students' potential so that they possess spiritual strength, self-control, personality, intelligence, noble character, and essential skills. In Indonesian language learning, these goals are achieved through the mastery of four fundamental language skills: listening, speaking, reading, and writing.

Among these skills, listening serves as the foundation for the development of other language abilities. Subyantoro and Hartono (as cited in Hijriyah, 2016) distinguish between hearing, listening, and attentive listening. Hearing refers to the process of receiving sounds consciously, listening involves paying attention to sounds, while attentive listening is the process of listening accompanied by a deep understanding of the message being conveyed. Effective listening enables students to comprehend information and ideas that can later be expressed through spoken or written language.

Writing, on the other hand, is a productive language skill that requires learners to organize and express ideas coherently and systematically in written form. Tarigan (2008) states that writing is an activity of expressing thoughts, ideas, and feelings through written language

to achieve specific communicative purposes. Therefore, writing requires not only linguistic competence but also the ability to generate and organize ideas effectively.

One type of learning material that can facilitate the development of both listening and writing skills is the fable text. A fable is a narrative text in which animals are portrayed with human characteristics and behaviors, often conveying moral values and life lessons (Kosasih, 2014). Through listening to fables, students can identify important story elements such as characters, setting, plot, and moral messages. This understanding can subsequently support them in composing their own fable stories.

However, many students still encounter difficulties in writing fables. Common challenges include generating ideas, developing appropriate characters, organizing events into a coherent plot, and conveying moral messages effectively. These difficulties indicate that students may require stronger comprehension of narrative structures, which can be developed through listening activities. In this regard, listening skills may contribute significantly to students' ability to write fable texts because the information obtained from listening can provide a framework for constructing stories.

Previous research has demonstrated a positive relationship between listening and writing skills. Rahayu (2023), for example, found a significant correlation between listening ability and anecdotal text writing ability among tenth-grade students of SMA Negeri 10 Palembang. The study reported a correlation coefficient (r) of 0.525, which was higher than the critical value of 0.291 at the 5% significance level. While Rahayu's study focused on anecdotal texts, the present study examines the relationship between students' ability to listen to fables and their ability to write fable texts. Therefore, this study extends previous research by investigating a different text genre and educational context.

Based on the background above, the research problem of this study is: "Is there a significant correlation between the ability to listen to fables and the ability to write fable texts among Grade VIII students of SMP Negeri 2 Kayuagung?"

METHOD

Research Design

This study employed a quantitative approach using a correlational research design. The correlational method was chosen because it is appropriate for examining the relationship between two variables without manipulating them. In this study, the ability to listen to fables served as the independent variable (X), while the ability to write fable texts served as the dependent variable (Y).

Respondents

The population of this study consisted of all Grade VIII students of SMP Negeri 2 Kayuagung during the 2024/2025 academic year, comprising a total of 120 students. The sample was selected using a simple random sampling technique, which provides each member of the population with an equal opportunity to be chosen as a research participant.

The sampling process was conducted through a lottery drawing. As a result, Class VIII.2, consisting of 28 students, was selected as the sample for this study. The selected students participated in all research activities and served as the source of data for examining the correlation between students' ability to listen to fables and their ability to write fable texts.

Instruments

The instruments used in this study consisted of two types of tests. The first instrument was an objective test in the form of 25 multiple-choice questions designed to measure students' ability to listen to fables. The test covered several indicators, including comprehension of the story content, identification of characters, understanding of the setting, recognition of the plot, and interpretation of the moral message.

The second instrument was a performance test that required students to write a fable story. The students' writing was assessed based on several criteria, namely the relevance of the content to the assigned theme, the completeness of the narrative structure, the effective use of language, spelling accuracy, and the appropriate use of punctuation.

Prior to data collection, both instruments were subjected to validity and reliability testing. The validity test was conducted to determine whether each test item accurately measured the intended indicators, while the reliability test was performed to examine the consistency of the instruments. The results of the analysis indicated that all test items were valid and that both instruments demonstrated a high level of reliability. Therefore, the instruments were considered appropriate for use in collecting the research data.

Procedures

Data collection was conducted in two stages. First, the students completed a fable listening test designed to measure their ability to comprehend fable texts. In this stage, students listened to a fable read by the researcher and then answered 25 multiple-choice questions related to the content of the story, including its characters, setting, plot, and moral message. The second stage involved a writing test. Students were instructed to write a fable story based on a predetermined theme. Their written work was assessed using a scoring rubric that evaluated content relevance, narrative structure, language use, spelling accuracy, and punctuation. The scores obtained from both tests were used as the research data for further analysis.

Data Analysis

The data obtained from the listening and writing tests were analyzed using descriptive and inferential statistics. Descriptive statistics were used to summarize the students' scores, including the mean, maximum score, minimum score, and standard deviation for both variables.

Before testing the research hypothesis, prerequisite analyses were conducted. The normality of the data distribution was examined using the Kolmogorov–Smirnov test, while the linearity test was performed to determine whether a linear relationship existed between the ability to listen to fables and the ability to write fable texts.

After the assumptions of normality and linearity were met, Pearson's Product-Moment Correlation was employed to examine the relationship between the two variables. This statistical test was used to determine both the strength and the significance of the correlation between students' ability to listen to fables (X) and their ability to write fable texts (Y). The hypothesis was tested at a significance level of 0.05. All statistical analyses were conducted using SPSS version 23.

FINDINGS AND DISCUSSION

The normality of the data was examined using the Kolmogorov–Smirnov test. The decision criterion was based on the significance value (Sig.). If the significance value was greater than 0.05, the data were considered normally distributed. Conversely, if the significance value was less than 0.05, the data were considered not normally distributed.

The results of the normality test (Table 1) indicated that the listening-to-fables scores were normally distributed. The Kolmogorov–Smirnov test yielded a significance value of 0.146, which was higher than the significance level of 0.05. Therefore, it can be concluded that the data for students' ability to listen to fables met the assumption of normality and were suitable for further statistical analysis.

Table 2. Test of Normality in Listening

One-Sample Kolmogorov-Smirnov Test

N		28
Normal Parameters[a,b]	Mean	82.00
	Std. Deviation	11.022
	Absolute	.143
	Positive	.127
	Negative	-.143
Test Statistic		.143
Asymp. Sig. (2-tailed)		.146[c]

The normality of the fable writing scores (Table 2) was assessed using the Kolmogorov–Smirnov test. The decision was based on the significance value (Sig.). A significance value greater than 0.05 indicates that the data are normally distributed, whereas a value lower than 0.05 indicates that the data are not normally distributed.

The results of the normality test showed that the fable writing scores had a significance value of 0.193, which exceeded the threshold of 0.05. Therefore, it can be concluded that the data were normally distributed. This finding indicates that the assumption of normality was met, allowing the data to be used for further parametric statistical analyses.

Table 2. Test of Normality in Writing Fables

Table 3
Test of Normality in Writing Fable Stories

One-Sample Kolmogorov-Smirnov Test

N		28
Normal Parameters[a,b]	Mean	70.89
	Std. Deviation	8.504
	Absolute	.137
	Positive	.113
	Negative	-.137
Test Statistic		.137
Asymp. Sig. (2-tailed)		.193[c]

A homogeneity test was conducted to determine whether the variances of the data were equal. The results showed that the significance value for the listening-to-fables test was 0.220, while the significance value for the fable writing test was 0.216.

Using a significance level of 0.05, the data are considered homogeneous when the significance value exceeds 0.05. Since both significance values were greater than 0.05, the data were deemed homogeneous. These findings indicate that the variances of the two datasets were relatively similar and met the assumptions required for further statistical analysis.

Table 3. Test of Homogeneity

Statistical Tests

	Value	df	Asymp. Sig
Pearson Chi-Square	48.738[a]	42	.220
Likelihood	48.886[b]	42	.216
Linear-by-Linear Association	5.575	1	.018
N of Valid Cases	28		

Based on the results of the correlation analysis in Table 4, the critical value of r (r-table) for a sample size of 28 at the 5% significance level was 0.374, whereas the calculated correlation coefficient (r-value) obtained using SPSS version 23 was 0.454. Since the obtained r-value (0.454) was greater than the r-table value (0.374), the null hypothesis was rejected and the alternative hypothesis was accepted. This finding indicates that there is a significant positive relationship between students' ability to listen to fables and their ability to write fable texts among Grade VIII students of SMP Negeri 2 Kayuagung.

Furthermore, the correlation coefficient of 0.454 falls within the range of 0.400–0.599, which is classified as a moderate correlation. Therefore, it can be concluded that the two variables are positively related with a moderate degree of correlation. In other words, students who demonstrate better listening comprehension of fables tend to exhibit better performance in writing fable texts.

Table 4. The Results of the Correlation

Correlation Test of Listening to Fables by Writing Fable Stories

		Menyimak Fabel	Menulis Cerita Fabel
Menyimak Fabel	Pearson Correlation	1	.454*
	Sig. (2-tailed)		.015
	N	28	28
Menulis Cerita Fabel	Pearson Correlation	.454*	1
	Sig. (2-tailed)	.015	
	N	28	28

The findings of this study revealed a significant positive relationship between students' ability to listen to fables and their ability to write fable texts among Grade VIII students of SMP Negeri 2 Kayuagung. The correlation analysis showed that the obtained r-value (0.454) was higher than the critical value of r-table (0.374) at the 5% significance level. Therefore, the alternative hypothesis was accepted, indicating that students who demonstrated better listening comprehension of fables tended to achieve higher scores in writing fable texts.

The correlation coefficient of 0.454 falls within the moderate category, suggesting that listening ability contributes to writing ability, although it is not the only factor affecting students' writing performance. This finding indicates that students who can understand the content of a fable through listening are more likely to identify important story elements, such as characters, setting, plot, and moral values, which can subsequently be applied when composing their own fable texts.

The results support the theoretical perspective that listening serves as a foundation for the development of other language skills. According to Tarigan (2008), listening is a language

skill that enables learners to receive, understand, and interpret messages conveyed orally. Through listening activities, students acquire information, vocabulary, and knowledge of text organization that can later be transferred to writing tasks. Similarly, Brown (2004) stated that receptive skills, including listening, provide essential language input that supports the development of productive skills such as writing and speaking. Therefore, students with stronger listening comprehension are likely to possess a better understanding of narrative structures and language features needed in writing.

The findings also support the view that writing is a complex process that requires sufficient language input and understanding. As stated by Tarigan (2008), "writing is a productive and expressive language skill used to communicate ideas and feelings through written language." In the context of fable writing, students need to understand the characteristics of narrative texts before they can effectively construct their own stories. Listening to fables provides learners with examples of story structures, character development, and moral lessons that can guide their writing process.

Furthermore, the results are consistent with the findings of Rahayu (2023), who reported a significant relationship between listening ability and the ability to write anecdotal texts among senior high school students. Although the present study focused on fable texts, both studies demonstrate that listening comprehension contributes to writing performance. This similarity suggests that students who are capable of understanding information through listening are generally better equipped to organize and express ideas in written form.

Despite the significant correlation identified in this study, the strength of the relationship was moderate rather than strong. This finding suggests that listening ability is only one of several factors influencing students' writing performance. According to Susanto (2017), vocabulary mastery plays an important role in supporting language skills, including writing. In addition, factors such as grammar knowledge, reading habits, creativity, motivation, and prior writing experience may also affect students' ability to produce quality written texts. Consequently, improving listening skills alone may not be sufficient to maximize students' writing achievement.

Overall, the findings emphasize the importance of integrating listening activities into Indonesian language instruction, particularly when teaching narrative texts such as fables. By providing students with meaningful listening experiences, teachers can help learners develop a deeper understanding of story elements and text structures, which can subsequently improve their writing ability. As Brown (2004) argued, language learning becomes more effective when receptive and productive skills are developed in an integrated manner. Therefore, listening and writing activities should be taught collaboratively to support students' overall language development.

CONCLUSION

Based on the findings of the study, it can be concluded that there is a significant positive relationship between students' ability to listen to fables and their ability to write fable texts among Grade VIII students of SMP Negeri 2 Kayuagung. The correlation analysis revealed that the obtained r-value (0.454) was higher than the r-table value (0.374) at the 5% significance level, indicating that the alternative hypothesis was accepted. The correlation coefficient falls within the moderate category, suggesting that students with better listening comprehension of fables tend to demonstrate better performance in writing fable texts. These findings highlight the important role of listening skills in supporting writing development and suggest that integrating listening activities into Indonesian language instruction can contribute to improving students' writing abilities, particularly in composing narrative texts such as fables.

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THE EFFECT OF DUOLINGO-ASSISTED LEARNING ON ENGLISH VOCABULARY MASTERY OF EFL STUDENTS

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Abstract

Vocabulary mastery plays a crucial role in English language learning, as it supports learners' ability to understand and communicate effectively. This study investigated the effect of Duolingo-assisted learning on the English vocabulary mastery of EFL students. The study employed a pre-experimental one-group pretest-posttest design involving 20 students from the English Education Study Program at Universitas Islam Ogan Komering Ilir (UNISKI) Kayuagung. A vocabulary test consisting of 50 items was administered before and after a 30-day Duolingo-assisted learning intervention. The collected data were analyzed using descriptive statistics and a paired-samples t-test. The findings revealed a significant improvement in students' vocabulary achievement. The mean score increased from 75.05 in the pre-test to 96.60 in the post-test, with a mean gain of 21.55 points. The paired-samples t-test indicated a statistically significant difference between the pre-test and post-test scores ($t = 3.964$, $p = .001$), confirming that Duolingo-assisted learning had a positive effect on students' English vocabulary mastery. The findings suggest that Duolingo facilitates vocabulary acquisition through interactive activities, repeated exposure, and continuous practice. The study highlights the potential of mobile-assisted language learning applications as effective supplementary tools for vocabulary development among EFL learners. It is recommended that English educators consider integrating Duolingo into language learning activities to support vocabulary improvement and promote autonomous learning.

Keywords: *Duolingo-assisted learning, vocabulary mastery, EFL students, mobile-assisted language learning, English vocabulary*

INTRODUCTION

Vocabulary is a core element of language acquisition and serves as the foundation for developing the four major language skills: listening, speaking, reading, and writing. In English as a Foreign Language (EFL) settings, particularly in Indonesia, having a strong vocabulary base is vital as it helps learners comprehend information and express their ideas clearly and

effectively in communication. Vocabulary refers to the lexicon available to an individual or a community, which serves as the language foundation for efficient expression and communication (Harli et al., 2024). Alqahtani (2015) also emphasizes that vocabulary is the foundation of communication, arguing that while limited grammar may still allow some communication, without vocabulary nothing can be conveyed. Likewise, Susanto and Fazlinda (2016) state that vocabulary mastery is one of the most important language components supporting students' overall language proficiency. Therefore, acquiring a rich vocabulary is a key factor in achieving successful English language learning.

The rapid development of educational technology has transformed language learning by providing students with more flexible, engaging, and autonomous learning opportunities. Digital learning applications have become increasingly popular because they offer innovative ways to enhance language acquisition (Arif, 2025). Among these applications, Duolingo has gained considerable attention due to its gamified learning environment. Duolingo provides various interactive activities, such as multiple-choice exercises, translation tasks, listening practices, storytelling, and pronunciation activities that encourage learners to practice language skills in an enjoyable manner (Al-Othman, 2025). Jaskova (2014) described Duolingo as a platform that enables users to learn languages in a fun and accessible way, while Munday (2016) found that students perceived Duolingo as more attractive and easier to use than traditional learning assignments.

Several studies have demonstrated the effectiveness of Duolingo in improving learners' vocabulary achievement. Setyawan et al. (2026), for example, reported significant vocabulary improvement among pharmacy students after 30 days of Duolingo practice, with mean scores increasing from 57.25 in the pretest to 81.70 in the posttest. Likewise, Hia (2024) found that university students using Duolingo achieved better vocabulary mastery than those taught through conventional methods. Furthermore, Duolingo has been shown to increase learners' motivation, engagement, and enthusiasm toward language learning (Nisrina, 2024; Irawan et al., 2020). Its gamification features, such as progress tracking, streak rewards, and achievement badges, contribute to sustained learner participation and motivation.

In addition to improving vocabulary acquisition, Duolingo promotes learner autonomy and confidence in language learning. Salsabila et al. (2025) reported that the application encourages students to take greater responsibility for their own learning process, fostering self-directed learning habits. Similarly, a systematic review by Liebnis et al. (2025) revealed that Duolingo supports various aspects of English language development, including vocabulary growth, grammatical competence, speaking proficiency, and metacognitive awareness. Furthermore, Bazan (2021) found that Duolingo positively influences English language skills, particularly reading and writing, and recommended its use as a complementary tool alongside traditional face-to-face instruction. In short, Duolingo is an effective and versatile language-learning platform that can enhance both learners' linguistic competence and their engagement in the learning process.

Despite these advantages, several researchers have identified limitations in the use of Duolingo. Cahyani and Hapsari (2025) argued that Duolingo functions more effectively as a supplementary learning tool rather than a primary instructional medium. They found that the application provides limited exposure to academic vocabulary and may not adequately support the transfer of vocabulary knowledge to authentic communication contexts. Similarly, some scholars have noted that while Duolingo can facilitate vocabulary acquisition, its effectiveness may depend on how it is integrated with classroom instruction and other learning activities.

Although numerous studies have reported the benefits of Duolingo in enhancing vocabulary learning, learner motivation, and engagement, several gaps remain in the existing literature. Previous studies have primarily focused on students' perceptions of Duolingo, its motivational impact, or comparisons between Duolingo and conventional teaching methods.

While some research has demonstrated positive effects on vocabulary acquisition, limited studies have specifically examined the extent of vocabulary improvement by comparing students' vocabulary achievement before and after the implementation of Duolingo through a pre-test and post-test design in the Indonesian EFL context. Moreover, the findings of previous studies have suggested that Duolingo functions most effectively as a supplementary learning tool, indicating the need for further empirical evidence regarding its effectiveness in improving students' vocabulary mastery.

The novelty of this study lies in its focus on measuring the impact of Duolingo on students' vocabulary achievement through a direct comparison of pre-test and post-test scores among EFL students. Unlike previous studies that mainly investigated learners' perceptions, motivation, or general language development, this study provides empirical evidence of vocabulary gains resulting from the implementation of Duolingo. Therefore, this research contributes to the growing body of literature on technology-assisted language learning by offering a clearer understanding of Duolingo's effectiveness in improving vocabulary mastery among EFL learners.

Therefore, this study aims to investigate whether there is a significant difference between students' pre-test and post-test vocabulary scores after the implementation of Duolingo among EFL students at UNISKI Kayuagung. This study seeks to provide empirical evidence regarding the effectiveness of Duolingo in improving students' vocabulary mastery in the context of higher education. By focusing on university students at UNISKI Kayuagung, the findings are expected to contribute to the growing body of research on technology-assisted language learning and offer practical insights into the integration of mobile-assisted language learning applications in EFL classrooms.

METHOD

Research Design

This study employed a pre-experimental research design using a one-group pre-test and post-test design to investigate the effect of Duolingo-assisted learning on the English vocabulary mastery of EFL students at UNISKI Kayuagung. This design was selected because it enables researchers to measure students' vocabulary achievement before and after the implementation of the treatment. According to Creswell and Creswell (2017), a pre-experimental design is appropriate for examining the effect of an intervention when a control group is not available. Similarly, Ary et al. (2018) state that comparing pre-test and post-test scores can provide evidence of learning gains resulting from a particular treatment.

Respondents

The respondents of this study were 20 students from the English Education Study Program at Universitas Islam Ogan Komering Ilir (UNISKI) Kayuagung. The respondents were selected through purposive sampling based on several criteria, namely being EFL learners, possessing basic English proficiency, actively using smartphones, and being willing to use Duolingo as a learning tool during the study. The selection of participants familiar with mobile technology was considered important because mobile-assisted language learning facilitates vocabulary development through continuous exposure and practice (Gafni et al., 2017).

Instruments

The instrument used in this study was a vocabulary test administered as both a pre-test and a post-test. The test consisted of 50 items covering word meaning, synonyms and antonyms, sentence completion, and contextual vocabulary use. The pre-test was given before the treatment to identify students' initial vocabulary mastery, while the post-test was administered after the treatment to measure their vocabulary improvement. According to Webb

and Nation (2017), vocabulary assessment should measure both word knowledge and vocabulary use in context.

The validity of the test was established through content validity. The test items were developed based on the learning objectives and vocabulary indicators and were reviewed by English language experts. Based on the experts' evaluation, the instrument was considered valid for measuring students' vocabulary mastery.

The reliability of the test was calculated using the Kuder–Richardson Formula 21 (KR-21). The result showed that the reliability coefficient was higher than 0.70, indicating that the instrument was reliable and consistent for assessing students' vocabulary mastery (Brown, 2004).

Procedures

The study was conducted in three stages. First, the participants completed a vocabulary pre-test consisting of 50 items to identify their initial level of vocabulary mastery. Second, the treatment was implemented through the use of Duolingo for 30 days. During this period, students were required to achieve a minimum target of 20 Experience Points (XP) per day. The learning activities provided by Duolingo included vocabulary matching, sentence translation, listening exercises, pronunciation practice, and contextual vocabulary tasks. These activities provided repeated exposure to target vocabulary and encouraged active learning. According to Loewen et al. (2019), app-based language learning can enhance vocabulary acquisition through repetition, immediate feedback, and interactive practice. After completing the 30-day treatment, the participants took a post-test with a level of difficulty equivalent to that of the pre-test. The post-test was administered to measure the extent of students' vocabulary improvement after using Duolingo-assisted learning.

Data Analysis

The data obtained from the pre-test and post-test were analyzed using descriptive and inferential statistics. Descriptive statistics, including mean scores, minimum and maximum scores, and standard deviations, were used to describe students' vocabulary achievement before and after the treatment. To determine whether there was a statistically significant difference between the pre-test and post-test scores, a paired-samples t-test was conducted using Statistical Package for the Social Sciences (SPSS) version 26. The level of significance was set at 0.05. If the significance value (p) was less than 0.05, the alternative hypothesis would be accepted, indicating that Duolingo-assisted learning had a significant effect on the English vocabulary mastery of EFL students at UNISKI Kayuagung.

FINDINGS AND DISCUSSION

This study aimed to investigate the effect of Duolingo-assisted learning on the English vocabulary mastery of EFL students at Universitas Islam OKI (UNISKI) Kayuagung. To measure the effectiveness of the treatment, students completed a vocabulary pre-test before the implementation of Duolingo and a post-test after participating in Duolingo-assisted learning for 30 days. The results of both tests were analyzed using descriptive statistics. The descriptive statistics were conducted to examine students' vocabulary achievement before and after the implementation of Duolingo-assisted learning.

Table 1. Descriptive Statistics of Pre-test and Post-test Scores

Test	N	Mean	Standard Deviation
Pre-test	20	75.05	26.01
Post-test	20	96.60	6.56

As shown in Table 1, the mean score of the pre-test was 75.05 (SD = 26.01), indicating that students' vocabulary mastery before the treatment varied considerably. After participating in Duolingo-assisted learning, the mean score increased to 96.60 (SD = 6.56). The mean gain

score was 21.55 points. In addition, the standard deviation decreased substantially from 26.01 to 6.56, indicating that students' performance became more consistent after the treatment. These findings suggest that Duolingo-assisted learning contributed positively to the improvement of students' English vocabulary mastery.

A paired-samples t-test was conducted to determine whether there was a statistically significant difference between students' pre-test and post-test scores.

Table 2. Paired-Samples t-Test Results

Variable	Mean Difference	t	df	Sig. (2-tailed)
Post-test – Pre-test	21.55	3.964	19	0.001

The results of the paired-samples t-test revealed a statistically significant difference between the pre-test and post-test scores, $t(19) = 3.964$, $p = .001$. Since the significance value (.001) was lower than the predetermined alpha level of .05, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted.

These findings indicate that Duolingo-assisted learning had a significant positive effect on the English vocabulary mastery of EFL students at UNISKI Kayuagung. The significant increase in students' post-test scores demonstrates that the use of Duolingo helped students improve their vocabulary knowledge through repeated exposure, interactive exercises, and continuous practice.

The findings of this study revealed that Duolingo-assisted learning significantly improved the English vocabulary mastery of EFL students at UNISKI Kayuagung. The students' mean score increased from 75.05 in the pre-test to 96.60 in the post-test, and the paired-samples t-test indicated a statistically significant difference between the two tests ($p = .001$). These findings suggest that Duolingo-assisted learning contributed positively to students' vocabulary development and helped them achieve better vocabulary mastery after 30 days of learning activities.

The improvement in students' vocabulary achievement highlights the important role of vocabulary in language learning. Vocabulary is a fundamental component of language acquisition because it enables learners to understand messages, express ideas, and participate in communication effectively (Danilina & Shabunina, 2020; Hashemian & Farhang, 2020). The significant increase in students' post-test scores supports Alqahtani's (2015) argument that vocabulary is the foundation of communication. Without adequate vocabulary knowledge, learners may struggle to comprehend and convey meaning. Therefore, the improvement observed in this study indicates that Duolingo-assisted learning helped students strengthen one of the most essential components of English proficiency. The findings also support Susanto and Fazlinda's (2016) view that vocabulary mastery is a crucial element underlying students' overall language competence.

One possible explanation for the improvement is the learning environment provided by Duolingo. The application offers various interactive activities, including multiple-choice exercises, translation tasks, listening practices, pronunciation exercises, and contextual vocabulary activities. These features expose learners to vocabulary repeatedly and encourage active engagement with language. Through continuous practice, students have opportunities to recognize, understand, and use vocabulary in different contexts, which may facilitate vocabulary retention and acquisition. This finding suggests that technology-enhanced learning environments can effectively support vocabulary development when learners engage with them regularly.

The findings of the present study are consistent with previous research on the effectiveness of Duolingo in vocabulary learning. Setyawan et al. (2026) reported significant vocabulary gains among pharmacy students after 30 days of Duolingo practice, with mean scores increasing from 57.25 in the pre-test to 81.70 in the post-test. Similarly, Hia (2024) found that university students who used Duolingo achieved better vocabulary mastery than

those who learned through conventional methods. The consistency between these studies and the present findings strengthens the evidence that Duolingo can serve as an effective tool for improving vocabulary acquisition among EFL learners.

The results also support studies emphasizing the motivational benefits of Duolingo. Previous research has shown that learners perceive Duolingo as engaging and enjoyable because of its gamification features, such as progress tracking, streak rewards, achievement badges, and interactive tasks (Nisrina, 2024; Irawan et al., 2020). Although this study did not specifically measure students' motivation, the substantial improvement in vocabulary scores may indicate that these gamified elements encouraged students to practice consistently throughout the treatment period. Regular engagement with vocabulary learning activities is likely to have contributed to the observed gains in vocabulary mastery.

Furthermore, the findings align with studies highlighting the role of Duolingo in promoting learner autonomy. Salsabila et al. (2025) reported that Duolingo encourages learners to take responsibility for their own learning, while Kelas (2025) emphasized its user-friendly design and accessibility. During the treatment period, students were able to access learning materials independently through their smartphones and practice vocabulary beyond classroom hours. This flexibility may have increased learning opportunities and allowed students to engage with English vocabulary more frequently, thereby supporting vocabulary improvement.

The present study also contributes to the existing literature by addressing a gap identified in previous research. While many studies have examined students' perceptions, attitudes, and motivation toward Duolingo, relatively few have focused on measuring actual vocabulary gains among university students in Indonesian EFL contexts. Moreover, research conducted at private universities in regional areas remains limited. Therefore, the findings of this study provide additional empirical evidence regarding the effectiveness of Duolingo-assisted learning in higher education, particularly among EFL students at UNISKI Kayuagung.

Despite the positive findings, the results should be interpreted with caution. Duolingo should not be viewed as a replacement for classroom instruction. This supports the argument of Cahyani and Hapsari (2025), who stated that Duolingo functions most effectively as a supplementary learning tool rather than a primary instructional medium. While the application can enhance vocabulary acquisition through repeated practice and interactive learning, comprehensive vocabulary development still requires guidance from teachers, meaningful classroom interaction, and exposure to authentic language use. Therefore, integrating Duolingo with formal English instruction may provide more optimal learning outcomes.

Overall, the findings indicate that Duolingo-assisted learning is an effective supplementary tool for improving English vocabulary mastery among EFL students. The significant increase in students' vocabulary scores, together with evidence from previous studies, suggests that Duolingo can support vocabulary acquisition by providing engaging, accessible, and autonomous learning opportunities. These findings reinforce the growing importance of technology-assisted language learning in higher education and highlight the potential of Duolingo as a valuable resource for vocabulary development in EFL contexts.

Despite the positive findings, several limitations should be acknowledged. First, this study involved a relatively small sample of only 20 students from the English Education Study Program at UNISKI Kayuagung, which may limit the generalizability of the findings to other EFL contexts. Second, the study employed a pre-experimental one-group pretest-posttest design without a control group. As a result, it is difficult to determine whether the improvement in students' vocabulary mastery was solely attributable to Duolingo-assisted learning or influenced by other factors, such as students' independent study, classroom instruction, or prior vocabulary knowledge. Third, the treatment lasted only 30 days, which may not be sufficient to examine the long-term effects of Duolingo on vocabulary retention. Finally, this study focused exclusively on vocabulary mastery and did not investigate the impact of Duolingo on

other language skills, such as reading, speaking, listening, or writing. Therefore, future research is recommended to involve larger and more diverse samples, employ experimental or quasi-experimental designs with control groups, extend the treatment period, and explore the effectiveness of Duolingo in developing other aspects of English language proficiency.

CONCLUSION

This study found that Duolingo-assisted learning effectively improved the English vocabulary mastery of EFL students at UNISKI Kayuagung. The findings indicate that Duolingo can support vocabulary acquisition by providing interactive, engaging, and flexible learning opportunities that encourage regular practice beyond the classroom. These results highlight the potential of mobile-assisted language learning applications as valuable supplementary tools in English language education. Therefore, English lecturers and educators may consider integrating Duolingo into teaching and learning activities to enhance students' vocabulary development and promote autonomous learning. However, the findings should be interpreted with caution due to the relatively small sample size and the absence of a control group. Future research is recommended to involve larger and more diverse samples, employ experimental or quasi-experimental designs, and examine the long-term effects of Duolingo on vocabulary retention as well as other language skills, such as reading, writing, listening, and speaking.

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CONSUMER PROTECTION AGAINST BUSINESS ACTORS' ADVERTISING AND PROMOTIONAL ACTIVITIES ON SOCIAL MEDIA

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Abstract

The development of social media has provided business actors with greater convenience in promoting and marketing products to the public. However, the use of social media has also created various legal issues, particularly regarding misleading advertisements and promotions that may harm consumers. This study aims to examine the legal regulations concerning consumer protection against advertisements and promotions on social media, to analyze the responsibilities of business actors in digital promotions, and to identify legal protection efforts available for consumers against violations in digital promotional activities. This research employs a normative legal research method using statutory and conceptual approaches. The results indicate that consumer protection in Indonesia is regulated under Law Number 8 of 1999 concerning Consumer Protection, the Electronic Information and Transactions Law, and Government Regulation Number 71 of 2019 concerning the Implementation of Electronic Systems and Transactions. Business actors are legally obligated to provide accurate, clear, and honest information regarding products promoted through social media. In cases where consumers suffer losses due to misleading promotions, business actors may be subject to civil, administrative, and criminal liabilities in accordance with applicable laws and regulations.Legal protection for consumers may be carried out through preventive measures, such as public education and supervision of digital advertisements, as well as repressive measures through complaints to the Consumer Dispute Settlement Agency (BPSK) or through court proceedings. Therefore, cooperation among the government, business actors, and society is necessary to create a safe, fair, and responsible digital trading environment.

Keywords: *consumer protection; social media; digital advertising; business actors; digital promotion*

INTRODUCTION

The rapid advancement of information and communication technology has brought fundamental changes to various aspects of human life, including business and commercial activities. The emergence of the Internet and social media has created a new ecosystem for electronic commerce (e-commerce), which continues to grow exponentially. According to Saraswati and Purwanti (2022), digital transformation has fundamentally altered the way business actors interact with consumers, with social media becoming one of the most dominant and effective marketing channels in the modern era.

According to the We Are Social Report (2024), Indonesia is among the countries with the largest number of social media users worldwide, with more than 191 million active users, representing approximately 68.9% of the total population. Platforms such as Instagram, TikTok, Facebook, YouTube, and WhatsApp have become integral parts of everyday life for Indonesian society. This condition has been extensively utilized by business actors to market

their products and services through increasingly sophisticated digital advertising and promotional strategies (Pratama & Setiawan, 2023).

Social media has emerged as one of the most effective and efficient marketing tools for businesses. Various forms of advertising and promotional activities have proliferated across these platforms, including targeted advertisements, sponsored content, influencer or Key Opinion Leader (KOL) endorsements, flash sales, giveaways, and promotional techniques that leverage social media algorithms to reach potential consumers (Hidayat & Kusuma, 2021). The phenomenon of influencer marketing in Indonesia has developed into a multi-trillion-rupiah industry, with thousands of content creators actively promoting products to millions of followers.

Despite these advantages, serious issues have emerged that threaten consumer rights. Rahayu (2023) notes that many irresponsible business actors exploit regulatory loopholes and consumers' limited digital literacy to engage in misleading, deceptive, and even fraudulent advertising practices. False advertising, misleading product claims, fake reviews, and non-transparent endorsement practices have become increasingly concerning issues.

Data from the Indonesian Consumers Foundation (YLKI, 2024) indicate that complaints related to digital transactions, including misleading advertisements on social media, continue to increase annually. In 2023, complaints related to e-commerce accounted for 34.7% of all complaints received by YLKI, with misleading advertisements and promotions ranking among the most frequently reported issues. This situation demonstrates that Indonesian consumers remain highly vulnerable to unethical marketing practices in the digital environment.

Indonesia's consumer protection legal framework, as stipulated in Law Number 8 of 1999 concerning Consumer Protection, establishes various consumer rights and business obligations. However, as argued by Nugroho and Halim (2022), legislation enacted prior to the emergence of social media contains significant legal gaps and is unable to adequately address the challenges posed by digital advertising. Although several supplementary regulations have been introduced, their implementation and coordination remain less than optimal.

The rise of influencer marketing has also generated distinct legal concerns. Wulandari (2023) argues that product endorsements on social media are often conducted without clear disclosure of the commercial relationship between influencers and business actors. Consequently, consumers are unable to distinguish between genuine recommendations and paid advertisements. This practice directly infringes upon consumers' right to receive accurate and truthful information.

Based on the foregoing background, this study seeks to examine consumer protection against business advertising and promotional activities on social media from a legal perspective. It is expected that this research will provide a comprehensive understanding of the existing issues, the applicable legal framework, and potential measures to strengthen consumer protection in the digital era.

The research questions focus on: (1) the legal framework governing consumer protection against misleading advertisements and promotions on social media; (2) the role of government institutions in supervising digital advertising; and (3) the enforcement mechanisms and sanctions applicable to business actors who violate advertising regulations.

METHOD

This study employs a normative legal research method, which examines statutory regulations, legal theories, and legal literature relating to consumer protection in the digital sphere. The approaches used are the statutory approach and the conceptual approach. The legal materials utilized consist of primary legal materials in the form of legislation and secondary legal materials comprising books, scholarly journals, and legal articles.

FINDINGS AND DISCUSSION

1. Legal Protection for Consumers Against Misleading Advertisements

Indonesia's consumer protection framework provides various legal instruments designed to protect consumers from misleading advertising practices. Kristiyanti (2021) classifies such protection into two categories: preventive protection, aimed at preventing violations before they occur, and repressive protection, aimed at addressing violations that have already occurred.

From a preventive perspective, Articles 8 to 17 of the Consumer Protection Law prohibit various unlawful business practices. Article 9 specifically prohibits business actors from offering, promoting, or advertising goods and/or services in a misleading manner. Article 17 further prohibits advertisers from producing advertisements that deceive consumers regarding the quality, quantity, composition, function, or price of goods and services. Nugroho and Halim (2022) emphasize that these provisions also apply to digital advertising, despite the fact that social media is not explicitly mentioned in the statute.

Regarding endorsement practices, Wulandari (2023) argues that Indonesian regulations do not yet specifically require transparency in social media endorsements. By comparison, the United States Federal Trade Commission (FTC) has established guidelines requiring clear and conspicuous disclosure of material relationships between endorsers and business entities. Indonesia should adopt a similar approach by introducing technical regulations governing endorsement transparency standards.

With respect to personal data protection in digital advertising, Zulfikri and Anwar (2024) note that Indonesia has enacted Law Number 27 of 2022 concerning Personal Data Protection (PDP Law), which became fully effective in September 2024. The PDP Law provides safeguards against the misuse of personal data for targeted advertising purposes and requires data controllers to obtain explicit consent from data subjects before using their data for marketing activities.

Repressive protection is provided through dispute resolution mechanisms regulated under the Consumer Protection Law. Rahayu (2023) identifies several available mechanisms, including direct negotiation, settlement through the Consumer Dispute Settlement Agency (BPSK), mediation, arbitration, and litigation before the courts. However, many consumers fail to utilize these mechanisms due to a lack of awareness regarding their legal rights.

Pratama and Setiawan (2023) emphasize the importance of strengthening class action mechanisms as an effective instrument for consumer protection in cases involving large-scale digital advertising violations. Given that misleading advertisements often affect millions of consumers while causing relatively small individual losses, class actions offer a more efficient remedy than individual lawsuits.

2. The Role of Government and Related Institutions in Digital Advertising Supervision

The supervision of advertisements and promotional activities on social media involves various governmental and non-governmental institutions with distinct functions and authorities. Hidayat and Kusuma (2021) describe this framework as a multi-layered system consisting of governmental regulation, industry self-regulation, and civil society oversight.

The Ministry of Trade of the Republic of Indonesia plays a central role in supervising digital advertising through its Directorate of Consumer Protection and Trade Compliance. Since 2021, the Ministry has intensified oversight of digital commerce through the establishment of a special task force responsible for monitoring and responding to violations on e-commerce and social media platforms (Nugroho & Halim, 2022).

The National Agency of Drug and Food Control (BPOM) possesses specific authority to supervise advertisements related to food products, pharmaceuticals, cosmetics, and medical

devices on social media. According to Rahayu (2023), BPOM has developed a digital advertising monitoring system utilizing artificial intelligence to automatically detect problematic advertisements across various platforms.

The Ministry of Communication and Information Technology (Kominfo) plays a significant role in supervising online content pursuant to the Electronic Information and Transactions Law and the Government Regulation on Electronic Systems and Transactions. Kominfo is authorized to block or remove content that violates applicable regulations, including fraudulent advertisements. Nevertheless, stronger coordination among Kominfo, BPOM, and the Ministry of Trade remains necessary to ensure more effective enforcement.

The Indonesian Consumers Foundation (YLKI) contributes significantly to consumer rights advocacy and public education. Beyond receiving consumer complaints, YLKI actively conducts research and policy advocacy aimed at improving consumer protection regulations in response to technological developments.

The Indonesian Advertising Council (DPI) and the Indonesian Advertising Companies Association (P3I) contribute to advertising ethics enforcement through the Indonesian Advertising Code of Ethics. Although these self-regulatory instruments provide comprehensive ethical standards, their effectiveness remains limited due to the absence of legally binding enforcement mechanisms.

Wulandari (2023) proposes the establishment of a Digital Advertising Supervisory Authority (OPID), an independent institution dedicated specifically to monitoring compliance with digital advertising regulations. Such an institution would possess cross-sectoral authority to coordinate the currently fragmented supervisory framework.

3. Law Enforcement and Sanctions Against Business Actors

Business actors engaging in advertising and promotional activities through social media are legally obligated to provide accurate, clear, and truthful information regarding the products and services they offer. Misleading, exaggerated, or inaccurate representations may cause consumer harm and constitute violations of consumer protection principles.

Legal enforcement against violations may be pursued through civil, criminal, and administrative mechanisms. Under civil law, consumers who suffer losses due to misleading advertisements may seek compensation based on tort liability or breach of contract. Article 19 of the Consumer Protection Law obliges business actors to provide compensation in the form of refunds, replacement goods, medical treatment, or other appropriate remedies.

Under criminal law, Article 62 of the Consumer Protection Law imposes penalties of up to five years' imprisonment or fines of up to IDR 2 billion for advertising violations. Furthermore, Article 45A of the Electronic Information and Transactions Law provides criminal sanctions for the dissemination of false information causing consumer losses in electronic transactions, punishable by up to six years' imprisonment and/or fines of up to IDR 1 billion.Administrative sanctions are the most frequently applied enforcement instruments and may include written warnings, temporary suspension of promotional activities, revocation of business licenses, administrative fines, product recalls, corrective advertising obligations, and the blocking of content or accounts by social media platforms upon request from regulatory authorities.

Several challenges hinder the effective enforcement of digital advertising regulations in Indonesia, including cross-border jurisdictional issues, the anonymity of online business actors, the rapid dissemination of advertisements, and limited institutional capacity to address the complexity of the digital advertising ecosystem.

To address these challenges, Saraswati and Purwanti (2022) recommend a co-regulation approach that combines governmental regulation, industry self-regulation, and civil society oversight. Within this framework, social media platforms should actively enforce policies

prohibiting misleading advertisements, provide accessible reporting mechanisms, and cooperate with governmental authorities in enforcement efforts.

CONCLUSION

Indonesia's consumer protection framework, primarily based on the Consumer Protection Law of 1999 and its supplementary regulations, provides a substantial legal foundation for protecting consumers. Nevertheless, significant regulatory gaps remain, particularly regarding digital advertising standards, endorsement transparency requirements, and personal data protection.

The supervision of digital advertising involves multiple institutions operating in a fragmented manner. More effective coordination among the Ministry of Trade, Kominfo, BPOM, and other relevant institutions is essential to establish a comprehensive and responsive supervisory system.

The enforcement of digital advertising regulations faces numerous challenges, particularly concerning cross-border jurisdiction, the anonymity of digital actors, and limited enforcement capacity. A co-regulatory approach involving social media platforms, governmental authorities, and civil society is therefore necessary to address these challenges effectively.

RECOMMENDATIONS

The Government of Indonesia should promptly issue specific technical regulations governing advertising standards on social media, particularly regarding transparency obligations in endorsement and influencer marketing practices, drawing upon international best regulatory practices. In addition, social media platforms operating in Indonesia should be required to actively enforce policies prohibiting misleading advertisements, provide accessible complaint and reporting mechanisms, and cooperate with Indonesian authorities in enforcing applicable consumer protection laws.

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LAW AND FREEDOM OF EXPRESSION ON SOCIAL MEDIA: AN INDONESIAN LEGAL PERSPECTIVE

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Abstract

The development of information technology has brought significant changes to society, especially in the use of social media as a means of expressing opinions. Freedom of expression is part of human rights guaranteed by the 1945 Constitution of the Republic of Indonesia. However, in practice, such freedom often creates legal issues due to the misuse of social media, including hate speech, hoaxes, defamation, and provocation. This study aims to analyze the relationship between law and freedom of expression on social media and to identify the legal limitations on such freedom in Indonesia. The research method used is normative juridical with statutory and conceptual approaches. The results indicate that freedom of expression on social media must still comply with applicable laws, particularly the Electronic Information and Transactions Law (ITE Law) and human rights regulations. Therefore, a balance is needed between protecting freedom of expression and enforcing the law to maintain public order and security.

Keywords: *Law, Freedom of Expression, Social Media, ITE Law, Human Rights.*

INTRODUCTION

Social media has become an essential part of modern society. The emergence of various digital platforms has provided extensive opportunities for individuals to express their opinions,

criticisms, aspirations, and information quickly and openly. Freedom of expression is a constitutional right guaranteed under Article 28E paragraph (3) of the 1945 Constitution of the Republic of Indonesia, which stipulates that every person has the right to freedom of association, assembly, and expression.

However, the development of social media also gives rise to various legal issues. Many social media users express opinions without paying attention to legal norms and ethics, resulting in hate speech, the spread of false news, defamation, and provocation that can disturb public order. This condition creates the need for legal regulations that are able to provide protection for freedom of expression while also setting limits so that such freedom does not harm other parties..

In practice, the Electronic Information and Transactions Law (EIT Law) is frequently used as the legal basis for addressing violations committed through social media. However, the implementation of the EIT Law has also generated considerable debate, as it is often perceived as potentially restricting the public's freedom of expression. Therefore, it is important to examine the relationship between law and freedom of expression on social media from the perspective of Indonesian law.

The development of information and communication technology in the era of globalization has brought significant changes to society. One manifestation of this development is the emergence of social media as a modern communication tool used by people to share information, exchange opinions, and express themselves freely. Social media is no longer merely a means of personal communication; it has evolved into a digital public sphere that allows individuals to communicate their views, criticisms, and aspirations to a wider audience.

Advancements in digital technology have had a positive impact on the development of democracy, as people can actively participate in expressing their opinions without limitations of time and place. Freedom of expression is a fundamental human right and an important element in a democratic state. Within a democratic system, citizens have the right to convey their thoughts and opinions, both orally and in writing, as a form of participation in national and public life.

In Indonesia, freedom of expression is constitutionally guaranteed under Article 28E paragraph (3) of the 1945 Constitution, which states that every person has the right to freedom of association, assembly, and expression. Furthermore, Article 28F of the Constitution guarantees that every individual has the right to communicate and obtain information for the development of themselves and their social environment. These provisions demonstrate that the state provides protection for freedom of expression as a constitutional right of its citizens.

In practice, the use of social media in Indonesia has grown rapidly. People utilize various digital platforms such as Facebook, Instagram, X (Twitter), TikTok, and YouTube as means of communication and information dissemination. Social media has become an effective tool for shaping public opinion and expressing criticism regarding government policies and various social issues within society.

Nevertheless, freedom of expression on social media is often misused by certain internet users. Many individuals use social media to spread hate speech, fake news (hoaxes), slander, provocation, and insults directed at particular individuals or groups. Such actions create legal problems and may disrupt public order as well as social unity.

The phenomenon of spreading hoaxes and hate speech on social media has increased alongside the ease of internet access and the relatively low level of digital literacy among the public. Information that has not been verified can spread rapidly and influence public opinion. In some cases, the dissemination of false information has even led to social conflicts and

divisions within society. Therefore, freedom of expression on social media cannot be exercised absolutely without regard to legal norms and social ethics.

To address various forms of social media misuse, the Indonesian government has enacted regulations governing activities in the digital space, including Law Number 19 of 2016 concerning Amendments to Law Number 11 of 2008 on Electronic Information and Transactions (ITE Law). This law regulates various prohibited acts involving electronic media, including defamation, dissemination of false information, hate speech, and threats conveyed through social media.

The Electronic Information and Transactions Law (EIT Law) was fundamentally enacted to provide legal protection for the public in the use of information technology. However, its implementation has frequently generated public debate. Many stakeholders argue that certain provisions of the EIT Law have the potential to restrict freedom of expression and may be used to criminalize criticism of the government as well as opinions expressed by members of the public on social media..

The debate surrounding freedom of expression and law enforcement on social media demonstrates the complex relationship between law and democracy. On the one hand, the state is obligated to guarantee freedom of expression as a fundamental human right. On the other hand, the state also has a responsibility to maintain public order and protect the rights of others from the misuse of that freedom. Therefore, a balance between the protection of freedom of expression and the enforcement of law is essential to create a safe, healthy, and democratic digital environment..

In addition, the development of social media presents new challenges for law enforcement. The open, rapid, and borderless nature of social media makes the spread of information difficult to control. Law The existence of the ITE Law is fundamentally intended to provide legal protection for society in the use of information technology. However, its implementation has frequently generated controversy enforcement authorities are required to adapt to technological advancements so that they can effectively address legal violations in the digital sphere without infringing upon human rights.

From a legal perspective, freedom of expression is not an absolute freedom. It is subject to limitations that must be respected by every individual. Article 28J of the 1945 Constitution emphasizes that in exercising their rights and freedoms, every person must respect the human rights of others and comply with restrictions established by law for reasons of morality, security, and public order.. Therefore, social media should be used wisely and responsibly to avoid causing harm to others.

Based on the foregoing discussion, it can be understood that freedom of expression on social media is an important component of modern democratic life. However, its exercise must remain consistent with applicable legal provisions. Issues concerning the limits of freedom of expression, the implementation of the ITE Law, and the protection of human rights are important subjects for further study within the framework of Indonesian law. Therefore, research on law and freedom of expression on social media is highly relevant in order to understand how the state regulates and protects freedom of expression in the digital era.

Research Questions

1. How is freedom of expression on social media regulated under Indonesian law?
2. What are the legal limitations on freedom of expression on social media?

Research Objectives

1. To identify the legal regulations governing freedom of expression on social media in Indonesia.
2. To analyze the legal limitations on freedom of expression on social media.

Research Method

This study employs a normative juridical research method using both a statutory approach and a conceptual approach. The legal materials consist of primary legal materials in the form of laws and regulations, and secondary legal materials in the form of books, journals, and other legal literature.

DISCUSSION

A. Legal Regulation of Freedom of Expression on Social Media

Freedom of expression is a fundamental human right guaranteed by the Indonesian Constitution. Article 28E paragraph (3) of the 1945 Constitution states that every person has the right to express opinions. In addition, Article 28F of the Constitution grants every individual the right to communicate and obtain information.

Regulations concerning freedom of expression are also contained in Law Number 39 of 1999 concerning Human Rights. Article 23 paragraph (2) states that every person is free to hold, express, and disseminate opinions according to their conscience, both orally and in writing.

In the context of social media, freedom of expression is further regulated under Law Number 19 of 2016 concerning Amendments to Law Number 11 of 2008 on Electronic Information and Transactions (ITE Law). The ITE Law regulates the use of information technology and provides sanctions for unlawful acts committed in the digital sphere..

Several provisions of the ITE Law related to freedom of expression include Article 27 paragraph (3) concerning defamation, Article 28 paragraph (2) concerning the dissemination of hate speech, and Article 45 concerning criminal penalties for such violations.

These regulations demonstrate that the state grants citizens the freedom to express their opinions; however, such freedom is not absolute and remains subject to legal limitations aimed at maintaining public order and protecting the rights of others.

B. Legal Limitations on Freedom of Expression on Social Media

Freedom of expression is not an unlimited right. Article 28J of the 1945 Constitution emphasizes that every person must respect the human rights of others within social, national, and state life.

Legal limitations on freedom of expression are necessary to ensure that the use of social media does not cause harm to individuals or society. Common forms of violations occurring on social media include:

1. Defamation

Defamation refers to actions that damage a person's honor or reputation through electronic media. In practice, many social media users express criticism or comments containing insults, which may result in legal action under the ITE Law.

2. Dissemination of Hoaxes

The spread of false information or hoaxes can create public unrest and social division. Therefore, the dissemination of false information through social media may be subject to criminal sanctions under applicable laws and regulations.

3. Hate Speech

Hate speech refers to expressions containing hatred based on ethnicity, religion, race, or intergroup differences (SARA). Such actions may threaten national unity and are therefore prohibited by law.

4. Provocation and Threats

The use of social media to provoke others or issue threats also constitutes a legal violation because it may disrupt public security and order.

Nevertheless, law enforcement concerning freedom of expression must be conducted proportionally and should not conflict with democratic principles and human rights. The state must be able to distinguish between constructive criticism and actions that genuinely violate the law.

C. Efforts to Maintain a Balance Between Law and Freedom of Expression

Several measures can be taken to maintain a balance between law and freedom of expression on social media, including:

1. Improving public digital literacy.
2. Providing education on social media ethics.
3. Enforcing the law fairly and transparently.
4. Avoiding the criminalization of public criticism.
5. Strengthening the protection of human rights in the digital space.

By maintaining such a balance, social media can function as a healthy democratic platform without neglecting legal certainty and the protection of public rights.

CONCLUSION

A. Conclusion

Freedom of expression on social media is a human right guaranteed by the Constitution and various laws and regulations in Indonesia. However, this freedom is not absolute, as it must respect the rights of others, legal norms, and public order.

The regulation of freedom of expression on social media can be found in the 1945 Constitution, the Human Rights Law, and the ITE Law. In practice, various forms of social media misuse, such as defamation, hate speech, and the dissemination of hoaxes, may be subject to legal sanctions.

Therefore, a balance between the protection of freedom of expression and law enforcement is necessary to create a healthy, safe, and democratic digital environment.

B. Recommendations

1. The government should provide legal education and digital literacy programs to the public.
2. Social media users should be more responsible and prudent in expressing their opinions.
3. Law enforcement concerning social media violations should be carried out fairly and proportionally.
4. Certain provisions of the ITE Law should be revised to prevent multiple interpretations and potential criminalization.

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LEGAL PROTECTION FOR WORKERS IN INDONESIA IN THE DIGITAL ERA

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Abstract

This article is entitled Legal Protection for Workers in Indonesia in the Digital Era. The problem discussed in this article is How is Legal Protection for Workers in Indonesia in the Digital Era? The research method used in this study is the normative legal research method. The purpose of this study is to determine how is legal protection for workers in the digital era while the benefits obtained from this study are expected to enable readers to know and understand legal protection for workers in the digital era. From this study it can be concluded that current technological developments have had an impact on legal protection for workers in the current digital era, however, protection for workers in the digital era has not been specifically regulated in law, either regarding Termination of Employment due to technological developments or regarding Occupational Health and Safety for workers in the current digital era.

Keywords : *legal protection; workers; digital era*

INTRODUCTION

The rapid development of technology in the Industrial Revolution era has brought significant changes to the world of employment. Automation, digitalization, and the utilization of Artificial Intelligence (AI) and information technology have transformed work methods, job types, and the structure of industrial relations across various economic sectors. These changes not only create efficiency and productivity for companies but also pose major challenges to labor legal protection, particularly in developing countries such as Indonesia (Samuel Jossef Hamonangan & Rakha Rahardjo, 2025).

In Indonesia, these challenges are becoming increasingly complex because the labor protection system still faces various limitations in terms of legal substance, implementation, and supervision. Although Law Number 13 of 2003 concerning Manpower and Law Number 11 of 2020 concerning Job Creation regulate various aspects of employment relations, these regulations have not fully addressed the new challenges arising from economic digitalization, including the emergence of app-based freelance workers (gig workers), remote working arrangements, and project-based short-term contract systems.

Furthermore, the shift from traditional employment to technology-based work systems has implications for workers' normative rights, such as the right to job security, fair wages, social security protection, and the right to organize. Without adaptive regulatory adjustments, Indonesian workers risk exploitation and losing access to the legal protections guaranteed under the national labor law system.

Labor law in Indonesia is essential to ensure that citizens have access to employment opportunities as well as guarantees of their rights and obligations. In addition, workers require legal protection to ensure productivity and comfort in the workplace. The fourth paragraph of the Preamble to the 1945 Constitution of the Republic of Indonesia states that the Government of Indonesia shall protect the entire Indonesian nation. Furthermore, the Constitution stipulates that every citizen has the right to obtain employment and a decent standard of living.

Normatively, the 1945 Constitution guarantees every citizen's right to work. This guarantee is further reinforced in Chapter XA concerning Human Rights (Articles 28A–28J) following the Second Amendment to the Constitution. Article 28D mandates that every person has the right to work and to receive fair and proper remuneration and treatment in employment relationships. Furthermore, Article 28I paragraph (4) emphasizes that the protection,

promotion, enforcement, and fulfillment of human rights are the responsibility of the state, particularly the government.

Article 5 of Law Number 13 of 2003 concerning Manpower provides protection by guaranteeing that every worker has equal rights and opportunities to obtain employment and a decent livelihood without discrimination based on gender, ethnicity, race, religion, or political affiliation, in accordance with the worker's interests and abilities, including equal treatment for persons with disabilities (Muhammad Zubi, 2021).

Law Number 39 of 1999 concerning Human Rights, Article 38 paragraph (2), states that "every person has the right to freely choose employment according to their preference and is entitled to fair working conditions." Meanwhile, Article 71 regulates the government's responsibility to respect, protect, enforce, and promote human rights as stipulated in both national legislation and international law.

Based on the legal foundations above, it is evident that one of the constitutional obligations of the state and government is to provide employment opportunities and protect its citizens. As stated by Lalu Husni (2015), work constitutes part of the fundamental human rights of citizens in maintaining their existence and livelihood.

Labor law regulates all matters relating to workers before, during, and after employment. The objectives of labor law include empowering and utilizing the workforce optimally and humanely, ensuring equal employment opportunities, providing labor in accordance with national and regional development needs, protecting workers in achieving welfare, and improving the welfare of workers and their families.

However, despite the rapid advancement of information technology and the fact that the majority of workers now perform their jobs using sophisticated technological tools, there are still no specific provisions in Indonesian national legislation governing legal protection for workers in the digital era.

The research method employed in this article is normative legal research, which is conducted through the study of various legal literature and references related to the legal issues discussed (Peter Mahmud Marzuki, 2016).

The purpose of this study is to examine legal protection for workers in the digital era. It is expected that readers will gain knowledge and understanding regarding labor legal protection in the digital age.

Based on the foregoing discussion and considering developments in the current digital era, the issue addressed in this article is: How is Legal Protection for Workers in Indonesia Implemented in the Digital Era?

LITERATURE REVIEW

1. Legal Protection

   According to Satjipto Rahardjo, legal protection refers to the safeguarding of human rights that have been violated by others, ensuring that individuals can enjoy the rights granted to them by law. The principle of legal protection in Indonesia is based on the recognition and protection of human dignity and human rights, which are rooted in the values of Pancasila and the concept of a state governed by the rule of law (Sidi Alkahfi Setiawan, 2023).

2. Labor

   According to the Indonesian Dictionary (KBBI), labor refers to a person who works or performs a task and is capable of carrying out work, either within or outside an employment relationship. Meanwhile, Law Number 13 of 2003 concerning Manpower defines labor as every person who is capable of performing work, either within or outside an employment relationship, to produce goods and services for the fulfillment of societal needs (Engku Fiboda et al., 2024).

DISCUSSION

Legal Protection for Workers in the Digital Era

Technological advancements, particularly in automation, artificial intelligence (AI), and digitalization, have transformed the global employment landscape. This phenomenon has created significant challenges for labor law, especially concerning:

a. Uncertainty regarding employment status;
b. Limited social security and wage protection; and
c. Weak bargaining positions of workers within flexible yet potentially exploitative digital work systems (Ahmad Wildan, 2024).

Indonesia possesses a large human resource base, making it an ideal environment for the implementation of the digital industrial era. While technological progress offers numerous benefits to the industrial sector, it also has the potential to create challenges within labor law. Moreover, Indonesia is currently experiencing a demographic bonus period from 2020 to 2030, which further increases the importance of effective labor protection policies.

The Indonesian government has established a set of regulations governing employment matters, commonly referred to as labor law. Labor law regulates all matters related to workers before, during, and after employment. According to Mr. Soetikno, labor law encompasses all legal rules governing employment relationships in which a worker is placed under the direction or authority of another person, including conditions directly related to such employment relationships (Zainal Asikin, 2008).

Before discussing workers' rights guarantees in greater depth, it is essential to understand the obligations and rights of workers. Workers' obligations include:

a. Performing their duties properly;
b. Complying with applicable regulations; and
c. Compensating employers for damages caused by negligence or misconduct in carrying out their work.

Meanwhile, workers are entitled to the following rights, which employers are obligated to respect (Salma Elsa Anindya & Ratih Damayanti, 2024):

a. The right to work;
b. The right to fair wages;
c. The right to form and join labor unions;
d. The right to due legal process;
e. The right to equal treatment;
f. The right to occupational health and safety protection;
g. The right to freedom; and
h. The right to privacy.

With the rapid advancement of technology, the dynamic reality of digital work now faces labor regulations that remain largely conventional and rigid. Law Number 13 of 2003 concerning Manpower and its implementing regulations were designed based on the assumption that employment relationships are tied to a specific workplace. Consequently, these regulations do not adequately accommodate the unique characteristics of remote workers and digital employees.

This regulatory gap has created uncertainty regarding several fundamental aspects, including the legal status of employment relationships, the scope of work, effective working hours, and rest periods. Furthermore, specific rights and obligations associated with digital work arrangements such as responsibility for home-office operational expenses (electricity and internet costs) and employers' obligations to provide work equipment have not yet been explicitly regulated (Sodikin Dahlan, 2026).

Despite the flexibility offered by remote work, workers face significant vulnerabilities regarding basic protections traditionally guaranteed under labor law. Occupational Safety and

Health (OSH) risks, for example, have become increasingly complex because the workplace is located outside the direct supervision and control of employers. Legal complexities become even greater when digital employment relationships extend across districts, provinces, or even national borders.

One of the most prominent labor issues in the digital era is the increasing number of companies conducting large-scale layoffs as a consequence of technological advancement.
With regard to termination of employment, Indonesian labor law regulates this matter through Article 1 Paragraph 25 of the Manpower Law, which defines termination of employment as the ending of an employment relationship due to a particular circumstance resulting in the termination of rights and obligations between workers and employers (Abdul Rahmad Budiono, 2009). Since an employment relationship constitutes a legal relationship, termination of employment signifies the dissolution of that legal relationship between employer and employee.
Generally, termination of employment can be categorized into four types:

a. Termination due to the expiration of a contract;
b. Termination due to employee misconduct;
c. Termination due to unstable economic conditions; and
d. Termination due to technological development (Sendjun Manulang, 2001).

Layoffs resulting from industrial digitalization have become increasingly inevitable as companies adapt to technological developments. Such layoffs occur on a large scale as society transitions into the digital era.

Although layoffs caused by industrial digitalization are not specifically regulated under Indonesian labor legislation, they may be justified under efficiency measures undertaken by companies to remain competitive and avoid substantial financial losses. The legal basis for such actions can be found in labor regulations providing that:
“Employers may terminate employment because the company closes, not due to losses suffered for two consecutive years or force majeure, but as part of efficiency measures. In such cases, workers are entitled to severance pay amounting to twice the standard severance entitlement, a service appreciation award equivalent to one times the prescribed amount, and compensation for other employment rights.”

This legal protection allows companies to terminate employment relationships as part of efficiency efforts rather than because of prolonged financial losses or force majeure. However, employers are required to provide severance pay, service appreciation compensation, and reimbursement of workers' rights as stipulated by law.

These provisions serve as a legal foundation for addressing employment issues arising from digital transformation. Efficiency measures through digitalization represent a strategy for companies to survive and compete in an increasingly dynamic business environment (Kadek Agus Sadiwara, 2015).

CONCLUSION

Technological developments have had a profound impact on both industry and employment. One significant consequence is the reduction of labor demand through layoffs resulting from technological advancement. In cases where termination of employment occurs, workers remain entitled to the rights and protections guaranteed under Indonesian labor law.

In the digital era, legal protection for workers should focus particularly on Occupational Health and Safety (OHS) in relation to the use of technological devices and digital work systems. However, although occupational health and safety regulations already exist, they are primarily designed for workers engaged in conventional forms of employment and do not adequately address the needs of workers operating within digital-based sectors.

Therefore, the government should undertake comprehensive reforms of labor regulations to strengthen occupational health and safety protection and ensure adequate legal protection for workers in the digital era.

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CHARACTER-BASED LEADERSHIP IN EFFORTS TO INCREASE THE QUALITY OF VILLAGE HR TOWARDS A DIGITAL VILLAGE IN SOUTH SUMATRA

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Abstract

Village government is the level of government that has direct contact with the community and is responsible for implementing development programs initiated by the central government. The village head plays a crucial role in the administration of village governance, including the planning and implementation of village development. In the current digital era, where digital technologies have become increasingly integrated into government administration, the leadership of a village head significantly influences the success of village development and public service delivery. Therefore, effective leadership characteristics are essential to support good governance and community welfare. This study aims to contribute to the literature by identifying the ideal characteristics that should be possessed by village heads as leaders in village governance. The findings are expected to provide insights for policymakers, particularly the central government, in developing leadership capacity-building programs for village heads. Such efforts are important to ensure that village governments can deliver effective, efficient, and responsive public services in the digital era.

Keywords: *Village Government, Village Head Leadership, Leadership Characteristics, Digital Era, Public Service*

Introduction

Village government is one of the bureaucratic levels that is in direct contact with the interests of the community, of course the Village Government is obliged to implement development programs proclaimed by the Central Government. The success or failure of the program depends on the performance of village government officials, in this case the village head as the highest policy maker.

One of the main objectives of carrying out village government duties is to create good service to the community, produce development, and other matters related to village government duties and functions such as administration, administration, filing, management of village wealth inventories, management population administration, land administration, fostering peace and order in the village community. The success or failure of the village government in carrying out its duties and authorities is measured by the implementation of village administration. Village administration cangoes well if the quality of village government. can carry out as well as possible, meaning that village administration greatly determines the position of village government. Village administration is a benchmark for the success of village governance because it is the foundation for strengthening and developing village governance.

The village head (kades) is an important pillar in the administration of village governance, including in village development. The village head is a government manager who is in charge of making decisions in every policy and program at the village level and is a major part of the ruling elite class. Under these conditions, the village head becomes a strategic figure in governance and village development (Saefulrahman, 2015). The concept of digital village is not a new village development concept, but this concept has long been introduced through several research journals. Research conducted by Safitri (2019) suggests that the concept of a digital village has been introduced in the TaoBao village of China. In addition, research conducted by Hulu (2018) and Kusnandar (2020) states that in West Sumatra, the allocation of village fund budgets has emphasized empowering communities who are ready for technology.

According to Suyatna (2019) by entering this millennial era, information technology has penetrated massively into the central government sector to the regions to the villages. In this all-electronic era, technology plays a very strategic role in accelerating public services and increasing business opportunities. Maybe in the future there will be a shift in the mindset of services that were originally manual to digital. Likewise it will apply in the service sector and businesses in the villages. In the old bumdes concept, buying and selling was done manually, while in the millennial era buying and selling was done digitally. This digital village concept is a discourse that must continue to be voiced so that village communities become more empowered. Empowerment of village communities must be the main focus in allocating the village fund budget in order to be able to increase the village's original income. Thus, the digital village can become a catalyst in empowering village communities.

Seeing the rapid development of the digital world that has entered the ranks of government management, the important role of village leaders is very influential in the development of a village. The characteristics of a leader are one of the benchmarks that must be considered to be used as the basis for becoming a leader. According to Koo and Park (2017), stated that there are several types of characteristics that can affect the quality of decision making, namely: 1). 5 personality factors, 2) self-evaluation, 3) arrogance, 4). Excessive self-confidence, and 5) humility. Meanwhile, according to Klang (2012) states 5 personality factors are conscientiousness, neuroticism, openness, friendliness, and extraversion.

The rapid development of digital-based information technology at this time must be put to good use by every level of government, from the center to the villages. The purpose of this research is expected to be able to contribute to literature related to the right characteristics and must be possessed by a leader, especially the village head.

Literature Review

Traits Theory

According to Fleeson and Jayawickreme (2015) states that this theory places more emphasis on aspects of personality such as intellectualization, emotions, physical condition (age, height and weight) and other personal traits. This theory focuses on two aspects of leadership behavior and leadership styles.

Leadership Characteristics

Leadership theory develops in many directions such as transformational leadership. Transformational leadership is the style used depending on factors such as situation, employee, task, organization and other environmental variables. There are 4 (four) elements that underlie transformational leadership, namely: Charisma, Inspiration, Intellectual Stimulation, and Individualized Consideration. Nasyroh and Wikansari (2017) state that the leader's personality has an influence on the performance of human resources in the organization. this shows that the performance of an organization or institution is strongly influenced by the personality of

the leader. In addition, according to Koo and Park (2017) and Klang (2012), stated that there are several types of characteristics that can affect the quality of decision making, namely: 1). 5 personality factors, 2) self-evaluation, 3) arrogance, 4). Excessive self-confidence, and 5) humility. The other factors are the 5 personality factors, namely conscientiousness, neuroticism, openness, sociability, and extraversion.

Digitization of government information

Digitization can be interpreted as a process of storing all the properties and information of text, sound, images or multimedia in an electronic string of zero and one bit (Wuryanta, 2004). Digitalization makes it possible to change everything into a form that can be stored in various digital media, such as compact discs, hard discs, and flash discs, and can be transferred to various places around the world with only a very short time consuming through a telecommunications network in the form of the internet (Arifin et al., 2020). The presence of the internet, which has reached almost all parts of Indonesia, has had an impact on people's lives. Through the internet, people can exchange information without having to meet face to face (Imaniawan & Wati, 2017). Use of information systems to help village government performance become better, more efficient and easier. Supported by advances in information technology that enable the development of more reliable information systems (Pardani & Damayanthi, 2017; Paryanta et al., 2017).

Based on this understanding, it can be concluded that digitalization activities are closely related to the process of storing and transferring information electronically through computer media, regardless of time and place limitations. Any information can be stored relatively easily and quickly and transferred to various places in the world (Wijaya et al., 2013). This is what then becomes the extraordinary potential of internet media. Village administrative digitization activities are carried out with survey stages or inventory of digitization conditions that have been carried out by village officials, problem formulation, and problem solving efforts. Mardiyani et al (2020) in their research results show that the digitization of village information can improve the services provided to the community.

Research Methods

From the concept proposed by the author as well as a review of the literature, an analysis can be carried out that the digital village concept is a concept that captures opportunities for the use of information technology which is developing very rapidly to improve services to the public, especially empowering rural communities. As an example of empirical research conducted by Suyatna (2020), villages can be encouraged, through the existing village budget, to build digital market portals to be able to sell the business potential available in the village. This concept imitates Taobao Village in China which is able to alleviate poverty through this program. The South Tangerang city government did the same thing through a change project prepared by a supervisory official, namely Tangsel Market, whose concept refers to an existing digital market.

The concept of a digital village explained in Suyatna's research (2020) when viewed from a budgetary perspective, villages can build a Joint Village-Owned Enterprise (BUMDes) like a holding company but digital. Thus, it is enough for one district to build a digital market portal to accommodate local products from village entrepreneurs throughout the district. By applying the terms and conditions for the mandatory income limit as a monthly income threshold of a certain amount of rupiah, it can be ensured that the village has Village Original Income. Where does the village get it from, namely from fees for every transaction made by entrepreneurs and utilization

electronic money storage of every transaction made by the buyer.

In addition to the importance of digitizing village information, the main objective of this research is how characteristics can bridge the successful application of technology in village

government so that it can provide maximum service to the community. Of course this concept needs to continue to be discussed so that it becomes a reality.

Findings and Discussion

Entering the digital era, information technology has become increasingly integrated into all levels of government, from the central government to regional administrations and village governments. In this technology-driven age, digital innovation plays a strategic role in accelerating public services and expanding economic opportunities. As a result, there has been a gradual shift from traditional manual systems to digital-based services. This transformation also affects business activities in rural areas. Under the traditional Village-Owned Enterprise (BUMDes) model, buying and selling activities were conducted manually, whereas in the digital era, transactions can be carried out through digital platforms.

The concept of a digital village should continue to be promoted because it has the potential to empower rural communities and enhance local economic development. Community empowerment should be a primary consideration in the allocation of village funds, as it can contribute to increasing Village Original Revenue (PADes) and improving community welfare. Therefore, the digital village can serve as a catalyst for sustainable rural development and economic empowerment.

Based on village data collected by the researchers, approximately 3.7% of villages in Ogan Komering Ilir (OKI) Regency have not yet adopted digital technologies in public service delivery. This condition highlights the need to accelerate the digitalization of village services. Consequently, greater attention is required from both district and provincial governments. In addition to allocating budgets for infrastructure development and service-data migration, government support should also focus on leadership training and capacity building. Such efforts are necessary to ensure that village leaders possess the skills and characteristics required to manage digital transformation effectively.

Research Potential Contribution

As a public organization, the government is responsible for ensuring the effective and efficient administration of governance, public services, and development. In relation to these responsibilities, Rasyid (2000) identifies three essential functions of government: service, empowerment, and development. Public services contribute to social justice, empowerment promotes community independence, and development enhances societal prosperity.

The implementation of these functions is not solely the responsibility of the central government but also involves regional and village governments, which operate as integral parts of the national governance system. This responsibility is particularly relevant within the framework of decentralization, which requires regional and village governments to actively participate in governance and public administration. The successful implementation of these governmental functions serves as an important indicator of organizational effectiveness and governmental performance (Rasyid, 2000).

As part of the national governance structure, village administration in Indonesia is regulated by law. One of the key legal foundations for village governance is Law No. 32 of 2004 concerning Regional Government. Based on this regulation, village governance is primarily carried out by the Village Government under the leadership of the Village Head, who serves as both the formal and informal leader of the village community.

This study is expected to contribute to the existing literature by identifying the leadership characteristics that are most suitable for village heads in the digital era. The findings may provide valuable insights for policymakers, particularly the central government, in designing leadership development programs and capacity-building initiatives for village leaders. By fostering effective leadership characteristics, village governments can enhance the quality of

public services, improve the capacity of human resources, and successfully adapt to technological advancements. Ultimately, strong leadership can support the realization of effective, responsive, and digitally oriented village governance.

Conclusion

The rapid advancement of digital technology has created significant opportunities for improving village governance, public service delivery, and community empowerment. The concept of a digital village offers an innovative approach to utilizing information technology for enhancing administrative efficiency, expanding economic opportunities, and increasing community participation in development activities. However, the successful implementation of digital transformation at the village level depends not only on technological infrastructure but also on the quality of leadership demonstrated by village heads.

As the primary decision-makers in village governance, village heads play a crucial role in promoting innovation, managing change, and ensuring the effective adoption of digital technologies. Therefore, leadership characteristics such as conscientiousness, openness to experience, humility, self-awareness, and effective decision-making are essential for supporting village development in the digital era. Strengthening these leadership characteristics through training and capacity-building programs can help village governments improve public services, optimize the use of technology, and enhance community welfare. Consequently, collaboration among central, regional, and village governments is necessary to support both digital infrastructure development and leadership capacity enhancement in order to realize effective, responsive, and sustainable digital village governance.

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DISPUTE RESOLUTION OF FRANCHISE AGREEMENTS THROUGH ARBITRATION

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ABSTRACT

This study employs normative legal research, also known as library legal research, which examines the legal system through the analysis of legal materials. The research is conducted by reviewing secondary data consisting of primary, secondary, and tertiary legal materials. These materials are systematically compiled, analyzed, and subsequently used as the basis for drawing conclusions related to the legal issues under investigation. Government Regulation Number 35 of 2024 concerning Franchising stipulates in Article 1 paragraph (1) that a franchise is a special right owned by an individual or a business entity over a business system that fulfills predetermined criteria for the purpose of marketing goods and/or services that have been proven successful and may be utilized and/or operated by another party based on a franchise agreement. The establishment of a franchise agreement between a franchisor and a franchisee is based on Article 1320 of the Indonesian Civil Code concerning the validity requirements of agreements and Article 1338 of the Indonesian Civil Code concerning the binding force of agreements (pacta sunt servanda). Furthermore, Article 4 paragraph (4) of Government Regulation Number 35 of 2024 concerning Franchising stipulates that franchise agreements must be executed in writing and be governed by Indonesian law. With regard to dispute resolution, Article 6 paragraph (1) of Government Regulation Number 35 of 2024 concerning Franchising provides that disputes arising from franchise agreements may be resolved through litigation (court proceedings) or non-litigation mechanisms outside the court system, namely arbitration. In addition, Article 8 of Law Number 30 of 1999 concerning Arbitration and Alternative Dispute Resolution stipulates that disputes arising from franchise agreements may be resolved by submitting a written application to the Indonesian National Arbitration Board (Badan Arbitrase Nasional Indonesia/BANI). The written application must contain: The full names and addresses of the disputing parties; A description of the dispute; The legal basis of the claim or demand submitted; and The arbitration agreement serving as the basis for disute resolution.

Keywords: *Franchise dispute resolution, franchise agreements, arbitration*.

INTRODUCTION

Through the continuously evolving franchise concept, individuals who wish to start and develop a business no longer need to begin from scratch. The existence of franchising provides significant opportunities for prospective entrepreneurs, as the integrated franchise system offers potential and opportunities for franchisees to operate their businesses in a sustainable manner and achieve continued growth. Franchising is a business system for distributing goods or services by utilizing trademarks, logos, and operational systems owned by the franchisor.

Within this system, both the franchisor and the franchisee have the right to market the same goods or services within a specific geographical area and for a certain period of time. In practice, all rights and obligations between the franchisor and the franchisee are clearly stipulated in a franchise agreement.

The concept of franchising can be viewed from two perspectives, namely that of the franchisor and that of the franchisee. From the franchisor's perspective, franchising is defined as a business model based on intellectual property rights owned by the franchisor. Meanwhile, from the franchisee's perspective, franchising is understood as a contractual cooperation arrangement governed by specific standards and requirements. Under such an agreement, both parties are regarded as business partners whose relationship is interconnected and mutually dependent.

In its development, franchising has evolved into two forms: franchising as a business format and franchising in the form of a license associated with a product's trademark. In conducting business activities as partners, both the franchisor and the franchisee seek business certainty and legal protection. Such certainty and protection are essential to ensure the sustainability of the business relationship and the fulfillment of the rights and obligations of both parties.

Franchise businesses are highly attractive because the products and services offered are generally well-known and have established a strong presence in the market. The existence of franchising attracts many aspiring entrepreneurs who wish to own businesses that have already achieved substantial growth. Internationally recognized franchise businesses include McDonald's, Kentucky Fried Chicken (KFC), Pizza Hut, Ace Hardware, Carrefour, 7-Eleven, and Hilton Hotels. Well-known Indonesian franchises include Es Teler 77, Alfamart convenience stores, Primagama tutoring centers, and others.

The legal framework governing franchising in Indonesia was first introduced in 1997 through Government Regulation of the Republic of Indonesia Number 16 of 1997 concerning Franchising, issued on June 18, 1997. This was followed by the Decree of the Minister of Industry and Trade of the Republic of Indonesia Number 259/MPP/Kep/7/1997 dated July 30, 1997, concerning the Procedures for Franchise Business Registration. These regulations were subsequently amended and refined through Government Regulation Number 42 of 2007 concerning Franchising. Most recently, the franchising framework was revised through Government Regulation Number 35 of 2024 concerning Franchising, while its implementation continues to refer to the Regulation of the Minister of Trade of the Republic of Indonesia Number 31/M-DAG/PER/8/2008 concerning the Administration of Franchising.

Article 1 paragraph (1) of Government Regulation Number 35 of 2024 defines a franchise as a special right owned by an individual or business entity over a business system that satisfies established criteria for marketing goods and/or services that have been proven successful and may be utilized by other parties under a franchise agreement.

Furthermore, Article 1 paragraph (7) of Government Regulation Number 35 of 2024 stipulates that a franchise agreement is a written agreement between a franchisor and a franchisee, or between a master franchisor and a sub-franchisee, granting the right to enjoy the economic benefits of a franchise for a specified period and under certain conditions.

As a business contract, a franchise agreement is a written agreement between the franchisor and the franchisee. Like any commercial contract, the obligations contained therein may potentially be violated. Franchise disputes generally arise when one party breaches the terms of the agreement. In such circumstances, the aggrieved party may seek legal remedies in accordance with applicable law. Two areas commonly covered in franchise agreements that often give rise to legal disputes are quality control and the termination of franchise agreements.

Dispute resolution may be conducted through two mechanisms. The traditional method is litigation through the courts, while a more recent development involves cooperative dispute resolution outside the judicial system. Litigation often results in adversarial outcomes that may fail to accommodate the interests of all parties, potentially creating new conflicts and fostering hostility between disputing parties. In contrast, out-of-court dispute resolution tends to produce a "win-win solution," ensures confidentiality, avoids delays caused by procedural and administrative requirements, and promotes comprehensive problem-solving while preserving good business relationships between franchisors and franchisees.

Parties involved in franchise or business disputes are likely to incur greater losses when dispute resolution processes become lengthy and complicated. To obtain a final decision, maintain business relationships and credibility, and achieve a fair and satisfactory resolution for all parties involved, business actors generally prefer dispute resolution mechanisms that are simple, fast, flexible, and efficient. This preference has contributed to the development of Alternative Dispute Resolution (ADR) mechanisms, which provide methods of resolving disputes without resorting to litigation. In both domestic and international commercial agreements, Law Number 30 of 1999 concerning Arbitration and Alternative Dispute Resolution provides the legal basis for non-judicial dispute settlement.

Accordingly, if a dispute arises in the future, the parties may agree to resolve it through arbitration. Arbitration is a process in which parties to a legal dispute agree to settle their dispute through a neutral third party rather than through the traditional court system. The involvement of a neutral third party to adjudicate disputes between the parties is the essence of arbitration, which can simply be defined as an agreement between the parties to resolve disputes through an alternative forum. Arbitration offers numerous advantages, including confidentiality, expedited proceedings, cost-effectiveness, efficiency, private hearings, and procedural flexibility.

Based on the foregoing background, this study addresses the following research questions:

1. How is a franchise agreement implemented between a franchisor and a franchisee under Government Regulation Number 35 of 2024 concerning Franchising?
2. What is the procedure for resolving franchise disputes through arbitration under Law Number 30 of 1999 concerning Arbitration and Alternative Dispute Resolution?

The research method employed in this study is normative juridical research, which focuses on examining the application of legal principles and norms within positive law. This study utilizes a statutory approach by analyzing relevant legislation.

The statutory approach involves examining legislation that constitutes the primary focus of the research, particularly Government Regulation Number 35 of 2024 concerning Franchising and Law Number 30 of 1999 concerning Arbitration and Alternative Dispute Resolution.

DISCUSSION

1. Franchise Agreements Between Franchisors and Franchisees Under Government Regulation Number 35 of 2024 on Franchising

A franchise agreement is a special type of contract that is not explicitly regulated under the Indonesian Civil Code (KUH Perdata). Nevertheless, its existence is recognized and considered legally valid within the Indonesian legal system because it is based on the principle of freedom of contract. This principle is reflected in Article 1338 of the Civil Code, which provides that all legally concluded agreements shall bind the parties as law. The validity of an agreement is determined by the fulfillment of the legal requirements stipulated in Article 1320 of the Civil Code, namely: mutual consent of the parties, legal capacity to enter into an agreement, a certain object, and a lawful cause. Consequently, Indonesian contract law adopts an open system, granting individuals the freedom to create various types of agreements provided that they do not conflict with statutory regulations, public order, or morality.

Although franchise agreements are not specifically regulated in the Civil Code, they remain subject to the general provisions governing contracts, particularly the requirements for the validity of agreements contained in Book III of the Civil Code. This ensures that franchise agreements possess a clear legal basis and are recognized as valid under Indonesian civil law

Franchising, as a business activity, is conducted within the framework of contractual law, similar to other business activities. The implementation of a franchise relationship is governed by a franchise agreement, which serves as the legal basis for the rights and obligations of the parties involved. A franchise agreement is a type of contract that exists outside the provisions of the Indonesian Civil Code (*Kitab Undang-Undang Hukum Perdata*), commonly referred to as an innominate contract (*kontrak innominaat*). This type of contract is not specifically regulated under the Civil Code but rather emerges, develops, and evolves through business practices within society. Therefore, the existence of innominate contracts is based on the dynamic legal needs of the contracting parties and is founded upon the principle of freedom of contract, which is recognized under Indonesian civil law.

Although franchise agreements exist outside the Civil Code, they are subject to specific regulations. Initially governed by Government Regulation Number 16 of 1997 concerning Franchising, the legal framework was subsequently replaced by Government Regulation Number 42 of 2007 and later amended by Government Regulation Number 35 of 2024 concerning Franchising. Its implementation is supported by the Decree of the Minister of Industry and Trade Number 259/MPP/Kep/7/1997 concerning the Procedures for Franchise Business Registration and further clarified through Minister of Trade Regulation Number 53 of 2012 concerning the Administration of Franchising in Indonesia. These regulations were enacted to provide legal certainty, guidance, and supervision for franchise businesses.

Normatively, the implementation of a franchise agreement must be preceded by the fulfillment of the legal requirements for a valid contract as stipulated in Article 1320 of the Indonesian Civil Code (*Kitab Undang-Undang Hukum Perdata*). These requirements include the mutual consent of the parties, legal capacity to enter into an agreement, a specific subject matter, and a lawful cause. When these four requirements are fulfilled, the franchise agreement becomes legally valid and binding upon the parties. Consequently, from the moment the agreement is signed, a legal relationship arises, creating reciprocal rights and obligations between the franchisor and the franchisee.

Furthermore, the implementation of a franchise agreement is based on the principle of freedom of contract, as reflected in Article 1338 paragraph (1) of the Indonesian Civil Code, which provides that all legally executed agreements shall have the force of law for the parties who enter into them. This principle grants the parties the freedom to determine the content, form, and clauses of the agreement, provided that they do not contravene statutory regulations, public order, or morality. In the context of franchising, this freedom is manifested in provisions concerning the granting of trademark usage rights, business systems, operational standards, business territories, royalty payments, training and assistance, as well as the duration of the agreement.

In addition, Article 1338 paragraph (3) of the Indonesian Civil Code emphasizes that agreements must be performed in good faith. The principle of good faith plays a crucial role in the implementation of franchise agreements, considering that the legal relationship between the parties is continuous in nature and requires mutual trust. The franchisor is obligated to provide managerial support, training, and maintain the consistency of the franchised business system. Conversely, the franchisee is required to operate the business in accordance with established standards, uphold the reputation of the trademark, and fulfill royalty payments and other contractual obligations as agreed upon by the parties. Failure to perform the agreement

in good faith may give rise to disputes and may potentially be classified as a breach of contract (*wanprestasi*).

The operation of a franchise is conducted through a legal relationship regulated by a franchise agreement, which constitutes the legal foundation for the rights and obligations of the contracting parties.

Franchise agreements, as a form of business activity, are conducted within the framework of contractual relationships, similar to other commercial activities. Pursuant to Article 1 paragraph (1) of Government Regulation Number 35 of 2024, the implementation of franchising is formulated and governed through a franchise agreement, which serves as the basis for the rights and obligations of each party.

Chapter III of Government Regulation Number 35 of 2024 concerning Franchise Criteria, particularly Article 4, stipulates the following:

1. Franchisors and master franchisors in conducting franchise activities must satisfy the franchise criteria.
2. The franchise criteria referred to in paragraph (1) include:
a. Having an established business system;
b. The business has generated profits;
c. Possessing recorded or registered intellectual property rights; and
d. Providing continuous support from the franchisor and/or master franchisor to the franchisee and/or sub-franchisee.
3. The business system referred to in paragraph (2)(a) shall consist of standard operating procedures (SOPs) that at a minimum cover:
a. Human resource classification;
b. Administration;
c. Operational management;
d. Standard operating methods;
e. Business location selection;
f. Business premises design;
g. Employee requirements; and
h. Marketing strategies.
4. The business system referred to in paragraph (3) must:
a. Be documented in writing and offered by the franchisor or master franchisor to the franchisee or sub-franchisee;
b. Be easy to teach and implement; and
c. Have a clear and uniform framework between the franchisor or master franchisor and the franchisee or sub-franchisee.
5. The criterion that the business has generated profits, as referred to in paragraph (2)(b), shall be evidenced by:
a. The franchised business having operated for at least three (3) consecutive years; and
b. Financial statements for the previous two (2) years demonstrating profitability and audited by a public accountant with an unqualified opinion.
6. The requirement for audited financial statements by a public accountant, as referred to in paragraph (5)(b), is exempted for franchisors or master franchisors operating as Micro and Small Enterprises.

Based on Article 4 paragraph (4) of Government Regulation Number 35 of 2024 on Franchising, franchising activities must be conducted pursuant to a written agreement between the franchisor and the franchisee, with due regard to the applicable laws of Indonesia.

Pursuant to Article 4 paragraph (4) of Government Regulation Number 35 of 2024 concerning Franchising, franchising activities must be conducted on the basis of a written agreement between the franchisor and the franchisee in accordance with Indonesian law.

Furthermore, Article 6 of Government Regulation Number 35 of 2024 concerning Franchise Agreements provides as follows:

1. Franchise activities shall be based on a franchise agreement entered into between:
a. A franchisor and a franchisee; or
b. A master franchisor and a sub-franchisee,
both of whom possess equal legal standing and are subject to Indonesian law.
2. The franchise agreement referred to in paragraph (1) shall contain at least the following provisions or clauses:
a. The names and addresses of the franchisor or master franchisor and the franchisee or sub-franchisee;
b. Intellectual property rights that remain under legal protection;
c. Business activities;
d. The business system;
e. The rights and obligations of the franchisor or master franchisor and the franchisee or sub-franchisee;
f. Assistance, facilities, operational guidance, training, and marketing support provided by the franchisor or master franchisor to the franchisee or sub-franchisee;
g. The business territory;
h. Guarantees from the franchisor or master franchisor to the franchisee or sub-franchisee regarding compensation and/or the granting of franchise rights in the event that the franchisor or master franchisor ceases business operations;
i. The duration of the franchise agreement;
j. Procedures for payment of fees or royalties;
k. Ownership and transfer of franchise ownership;
l. Dispute resolution mechanisms;
m. Procedures for amendment and termination of the franchise agreement;
n. Guarantees from the franchisor or master franchisor to continue fulfilling their obligations toward the franchisee or sub-franchisee; and
o. The number of outlets or business premises to be managed by the franchisee or sub-franchisee.
3. In addition to the provisions referred to in paragraph (2), a franchise agreement may also include a clause granting the franchisee the right to appoint a sub-franchisee.

From a juridical perspective, Article 6 paragraph (2) of Government Regulation Number 35 of 2024 concerning Franchising demonstrates that a franchise agreement possesses the following characteristics:

A bilateral contract, as it creates reciprocal rights and obligations for both parties;
An innominate contract within modern business practice, which, although not expressly regulated under the Indonesian Civil Code, is recognized under the principle of freedom of contract; and
A continuing contract, as its implementation extends over a specified period of time.

Government Regulation Number 35 of 2024 further emphasizes that a franchise constitutes a special right over a business system possessing distinctive characteristics, proven commercial success, and the ability to be utilized by other parties pursuant to a written agreement. Consequently, intellectual property rights (IPRs) constitute a central element of the legal relationship in franchising.

Accordingly, franchise agreements between franchisors and/or master franchisors and franchisees and/or sub-franchisees must contain written clauses as stipulated in Article 6 paragraph (2). At a minimum, a franchise agreement shall include:

a. Identification of the parties;
b. The types of intellectual property rights involved;
c. The rights and obligations of the parties;
d. Assistance and training;
e. The business territory;
f. The duration of the agreement;
g. Procedures for payment of fees or royalties;
h. Dispute resolution mechanisms; and
i. Provisions concerning termination and renewal.

Juridically, these clauses give rise to the rights and obligations of the parties in a franchise agreement, as stipulated in Article 7 of Government Regulation Number 35 of 2024 concerning Franchising, as follows:

a. Rights and Obligations of the Franchisor

The franchisor has the right to receive compensation (royalties and/or fees) and to supervise the implementation of the business system. On the other hand, the franchisor is obligated to:

1. Grant the right to use the trademark and business system;
2. Provide training and business guidance;
3. Ensure the continuity of operational support; and
4. Provide accurate and transparent information.

b. Rights and Obligations of the Franchisee

The franchisee has the right to receive business support and to utilize the franchisor's business system. The obligations of the franchisee include:

1. Paying royalties, fees, or other compensation in accordance with the agreement;
2. Maintaining the quality standards and reputation of the trademark; and
3. Complying with the established business system and operational procedures.

These rights and obligations form the legal foundation of the franchise relationship and are intended to ensure legal certainty, fairness, and the sustainable operation of the franchised business.

The existence of franchise agreements within the Indonesian law of contracts is essentially classified as an innominate contract, namely a type of agreement that is not specifically regulated under the Indonesian Civil Code (Kitab Undang-Undang Hukum Perdata). Instead, it emerges and develops based on the principle of freedom of contract. Consequently, franchise agreements are subject to the general provisions of contract law as well as to specific statutory regulations governing franchising.

Based on the above explanation, it can be concluded that the concept of implementing a franchise agreement according to the Civil Code is rooted in the general principles of the law of obligations, namely the principle of freedom of contract, the principle of *pacta sunt servanda*, and the principle of good faith. These principles serve as the juridical foundation in regulating and assessing the legal relationship between the franchisor and the franchisee. A franchise business agreement is an innominate contract, namely a contract in written form, which arises, grows, and develops in practice due to the principle of freedom of contract. However, although it may be freely made and agreed upon by the parties, the substance of a franchise business agreement has been clearly stipulated in Government Regulation No. 35 of 2024 concerning Franchisin.

A franchise agreement may also regulate a provision that allows the franchisee to grant a sub-franchise to another party, provided that the franchisee has operated at least one franchise outlet and that the sub-franchise agreement is made with the knowledge of the franchisor. In granting a sub-franchise, the principal franchisee is required to prove to the sub-franchisee that he or she has the authority to do so. This is in accordance with Article 6 of the Minister of Trade Regulation No. 53/M-DAG/PER/8/2012 concerning the Implementation of Franchising and Minister of Trade Regulation No. 07/M-DAG/PER/2/2013 concerning the Development of Franchise Partnerships, which contain mandatory provisions regarding the minimum clauses that must be stipulated in a franchise agreement. The minimum term of the agreement is 10 years for a franchise agreement between the franchisor and/or sub-franchisor and the franchisee and/or sub-franchisee; and a minimum of 5 years for a franchise agreement between the franchisee and the sub-franchisee.

The legal provisions regarding franchising as a form of agreement in the business world also adhere to and are subject to the provisions applicable to the validity of an agreement. Franchising or a franchise is a form of agreement that grants special rights and authority to the franchisee, which may take the form of.

forms: the right to sell products in the form of goods and/or services by using a particular trade name or trademark, and the right to conduct business activities with or based on a business format determined by the franchisor. A franchise business agreement must be carefully drafted so that the business cooperation carried out benefits both parties equally

Dispute Resolution of Franchise Agreements Under Law Number 30 of 1999 on Arbitration and Alternative Dispute Resolution

Based on Government Regulation No. 16 of 1997 concerning Franchising, which was subsequently replaced by Government Regulation No. 42 of 2007 and amended by Government Regulation No. 35 of 2024 concerning Franchising, and its implementation based on the Decree of the Minister of Industry and Trade Number 259/MPP/Kep/7/1997 concerning Provisions and Procedures for the Registration of Franchise Businesses, and further clarified in Minister of Trade Regulation No. 53 of 2012, these regulations govern the implementation of franchising in Indonesia.

A franchise agreement is a set of requirements, terms, and commitments formulated and established by the franchisor to be implemented by the franchisee. The franchise agreement regulates various provisions relating to the rights and obligations of each party, both the franchisor and the franchisee. Legally, franchising as one of the forms of agreements in the business sector is guided by and subject to the applicable legal provisions governing contracts. A franchise agreement is a type of agreement that grants specific rights and authority from the franchisor to the franchisee to conduct business activities by using the franchise system.

A franchise agreement generally regulates various matters, including the object of the agreement, the business location or place of business, the granting of a business territory by the franchisor to the franchisee, building lease arrangements, training and technical assistance from the franchisor, operational business standards, financial considerations, confidentiality clauses, clauses regulating business competition, responsibilities in advertising and marketing strategies, pricing and purchasing systems, business entity status, the right to use trade names and trademarks, the duration of the agreement and the possibility of renewal or extension, provisions regarding the termination of the agreement, interpretation of the contents of the agreement, as well as the applicable choice of law.

Two aspects that are usually included in a franchise agreement and often give rise to potential legal issues are quality control and termination of the franchise agreement. Quality control is important for the franchisor or sub-franchisor because, by maintaining uniform quality standards and business appearance, the reputation of the franchise system can be preserved. In addition, such uniform standards also play a role in increasing public confidence in the products offered.

Based on the foregoing, the franchisor or sub-franchisor generally requires the franchisee or sub-franchisee to purchase certain products and supplies from the franchisor at predetermined prices, or from suppliers capable of meeting the specifications and standards determined by the franchisor. However, if the franchisee is required to purchase products solely from the franchisor without any alternative suppliers that meet such standards, such practice may potentially violate the provisions of the Law on the Prohibition of Monopolistic Practices and Unfair Business Competition**.**

The termination of a franchise agreement may also give rise to legal issues if it is not carried out carefully and prudently. Generally, a franchise agreement stipulates the duration of the agreement, for example five years or ten years, and also contains provisions regarding the possibility of extension after the expiration of such period. As part of the contents of the agreement (covenants), various conditions that must be complied with by the parties are usually included. One of these conditions is the provision that the franchisee agrees not to engage in competing business activities for a certain period after the expiration of the franchise agreement. In addition, certain conditions such as the bankruptcy of the franchisee or delays in the payment of monthly or semi-annual royalties when due may serve as grounds for the termination of the franchise agreement.

Therefore, the resolution of issues arising from a franchise agreement needs to be regulated more carefully and comprehensively. Generally, the franchisor or master franchisor provides an opportunity for the franchisee or sub-franchisee, for example, within fifteen working days, to remedy or resolve the failure or default that has occurred. Most franchise agreements also contain provisions regarding the termination of the franchise agreement. This indicates that a dispute is a continuation of a conflict; a conflict can only be categorized as a dispute when it cannot be resolved through internal mechanisms.

Based on the above explanation, a franchise agreement constitutes a legal relationship that regulates the rights and obligations between legal subjects, which must be fulfilled in accordance with statutory provisions. In practice, many problems arise because one of the parties fails to perform its rights and obligations as agreed in the agreement, which in turn causes losses. With regard to franchise agreements, various factors may give rise to disputes between the parties. These factors include business risks that arise, improper supervision by the franchisor or sub-franchisor over the implementation of the agreement, and termination of the agreement that is considered detrimental to the franchisee or sub-franchisee.

As a business contract, a franchise agreement often gives rise to differences of interest among business actors. These differences of interest may lead to disputes. Franchise disputes may be resolved through litigation or non-litigation procedures. As a business contract, a franchise agreement usually contains confidential arrangements that are not intended to be disclosed to the public. Therefore, litigation should be the last resort in dispute resolution. Prior to that, the parties are expected to conduct direct negotiations or negotiations through legal representatives in order to reach a mutually beneficial agreement. If such negotiations do not produce results, the dispute may then be submitted to arbitration or to the court/litigation process for resolution. In particular,

Dispute resolution through arbitration is preferred more than litigation, especially for international business and commercial contracts.

Dispute resolution is generally carried out through adjudication procedures. However, considering that franchising is a business contract between the franchisor and the franchisee containing agreements mutually approved by the parties, there is concern that the adjudication process may disclose the contents of the contract, which should remain confidential between the parties. Therefore, alternative dispute resolution becomes a more effective and efficient method for handling conflicts of interest and meeting the needs of the parties. Nevertheless, in some countries, judicial proceedings may be conducted more quickly. One of the advantages of non-litigation dispute resolution is its confidentiality, whereby both the proceedings and the resulting decisions are not made public. This out-of-court dispute resolution is commonly known as Alternative Dispute Resolution (ADR). At present, dispute resolution through the courts is often subject to strong criticism, both from practitioners and from the perspective of legal theory.

The process of Alternative Dispute Resolution (ADR) is more flexible than court proceedings and has a greater ability to produce agreements that reflect the interests and needs of the parties. The disputing parties may sit together to formulate solutions capable of resolving the existing problems. The chosen solution is the result of a mutual agreement between the two disputing parties.

According to Erman Rajagukguk, society, particularly business actors, tends to prefer dispute resolution outside the courts for three reasons. First, court proceedings are open to the public, whereas business actors generally prefer their disputes to be resolved privately without public knowledge. Second, some business actors believe that judges do not always possess specialized expertise in handling complex dispute matters. Third, court-based dispute resolution tends to determine which party is right and which party is wrong, whereas out-of-court dispute resolution emphasizes reaching an agreement through compromise.

Alternative dispute resolution outside the court process is currently known as Alternative Dispute Resolution (ADR). Franchise agreement disputes/business disputes generally require a dispute resolution mechanism that is simple, fast, and cost-efficient.

In franchise business activities, the legal relationship between the franchisor and the franchisee is set forth in a franchise agreement containing the rights and obligations of the parties. In practice, the implementation of such agreements often gives rise to disputes, for example regarding breach of contract, trademark use, royalty payments, or the implementation of operational business standards. Based on Government Regulation Number 35 of 2024 concerning Franchising, Article 6 paragraph (2) letter i explains that, in the settlement of franchise agreement disputes, the parties are free to choose and determine in the franchise agreement the dispute resolution mechanism that may arise between them, whether through litigation before judicial institutions or through non-litigation procedures by means of arbitration. One of the arbitration institutions frequently used in the settlement of business disputes in.

Indonesia is the Indonesian National Arbitration Board (Badan Arbitrase NasionalIndonesia/BANI)**.** This institution provides an independent and professional forum for dispute resolution for business actors. The legal basis for dispute resolution through arbitration, including that conducted through BANI, is regulated under Law Number 30 of 1999 concerning Arbitration and Alternative Dispute Resolution.

Law Number 30 of 1999 provides a legal basis for parties to resolve civil disputes outside the courts through arbitration. Several provisions that serve as the legal basis for the settlement of franchise disputes through BANI include:

a. **Article 1 point 1 states that**

Arbitration is a method of resolving a civil dispute outside the general courts based on a written arbitration agreement made by the disputing parties. Based on this definition, there are several important elements of arbitration, namely:

a. The existence of a civil dispute

Disputes that may be resolved through arbitration are disputes in the field of private or civil law, including business and commercial disputes such as franchise contracts.

a. **Settlement outside the courts (non-litigation)**

Arbitration is a dispute resolution mechanism outside the general courts that aims to provide a faster and more efficient resolution while maintaining the confidentiality of the parties.

b. The existence of a written arbitration agreement

Arbitration may only be conducted if there is a written agreement between the parties.
Article 3 states that:

The District Court has no authority to adjudicate disputes between parties who are bound by an arbitration agreement.

According to the meaning of the above article, the District Court does not have the authority to adjudicate disputes between parties who are bound by an arbitration agreement. Therefore, if a franchise agreement contains an arbitration clause appointing BANI as the dispute resolution institution, the dispute must be resolved through BANI and may not be submitted to the District Court. The legal relationship in a franchise business is based on a franchise agreement between the franchisor and/or sub-franchisor and the franchisee and/or sub-franchisee, in accordance with Government Regulation Number 35 of 2024 concerning Franchising.

Article 4 provides that an arbitration agreement may be divided into two main forms, namely:

a. Arbitration Clause

An arbitration clause is an agreement included in a contract before a dispute arises. In business practice, this clause is usually found in cooperation agreements, commercial contracts, or franchise agreements. An example of an arbitration clause in a franchise agreement is as follows: “If a dispute arises from the implementation of this agreement, the parties agree to resolve it through arbitration at the Indonesian National Arbitration Board (BANI).” With the inclusion of this clause, if a dispute arises, the parties are obliged to resolve the dispute through arbitration.

b. Deed of Submission (Akta Kompromis)

A deed of submission is an arbitration agreement made after a dispute has arisen. In this case, the disputing parties agree not to bring the matter before the court, but instead to resolve it through arbitration.

According to the explanation above, an arbitration agreement must be made in writing and may take the form of an arbitration clause in the principal agreement or a separate arbitration agreement made after the dispute has arisen. In franchise business practice, an arbitration clause is usually included in the franchise contract as a dispute resolution mechanism in the event that a dispute arises in the future.

In practice, franchise agreements often contain arbitration clauses as a dispute resolution mechanism. This is because franchising involves long-term business relationships and complex commercial interests. Disputes that frequently arise in franchise relationships include:

a. Violation of the operational standards of the franchise system;
b. Delay in royalty payments;
c. Infringement of intellectual property rights or trademarks;
d. Unilateral termination of the agreement; and
e. Disputes concerning business territories.

If the franchise agreement contains an arbitration clause as regulated in Article 4, then the dispute may be resolved through arbitration.

Article 8 regulates the procedures for submitting a dispute for resolution through arbitration. This article governs the submission of an arbitration request by a party who feels aggrieved. The request shall be submitted in writing to the arbitrator or the selected arbitration institution, including BANI. The request shall contain at least:

a. The full names and addresses of the disputing parties;

b. An explanation of the dispute that has arisen;

c. The basis of the claim or demand submitted;

d. The arbitration agreement serving as the basis for dispute resolution.

After the arbitration request has been submitted to the Indonesian National Arbitration Board, the dispute resolution process generally includes the following stages:

a. Notification to the respondent

The BANI Secretariat will deliver a copy of the arbitration request to the respondent so that the respondent may provide a response or answer.

b. Appointment of arbitrators

The parties may appoint arbitrators directly or delegate the appointment to BANI.

c. Examination of the dispute

At this stage, the examination process is conducted, including the submission of claims, responses from the respondent, documentary evidence, and the examination of witnesses or experts.

d. Arbitral award

After the examination process is completed, the arbitrator will issue an arbitral award that is final and binding upon the parties.

1. Article 27 regulates the nature of case examinations in arbitration proceedings, which in principle states that the examination of disputes by an arbitrator or arbitral tribunal shall be conducted in private unless the parties determine otherwise. This provision emphasizes that the arbitration process has characteristics different from litigation proceedings in court, which are generally open to the public. In arbitration, confidentiality is one of the principal principles maintained to protect the interests of the disputing parties. This principle of confidentiality has several important objectives, namely protecting the business interests of the parties, maintaining the reputation of the parties, and providing comfort in the dispute resolution process.

2. Article 48 regulates the time limit for dispute resolution through arbitration. This provision essentially states that the examination of a dispute by an arbitrator or arbitral tribunal must be completed within a maximum period of 180 days from the date the arbitrator or arbitral tribunal is constituted, unless the parties agree to an extension of time.Pasal 54 mengatur mengenai unsur-unsur yang harus dimuat dalam putusan arbitrase. Sementara itu, Pasal 60 menyatakan bahwa putusan arbitrase bersifat final dan mengikat (*final and binding*) bagi para pihak, sehingga tidak dapat diajukan banding atau kasasi.

3. Article 54 regulates the elements that must be included in an arbitral award. Meanwhile, Article 60 states that an arbitral award is final and binding upon the parties (*final and binding*), and therefore cannot be appealed or challenged through cassation.

4. Articles 59 to 64 regulate the enforcement of arbitral awards. An arbitral award must be registered with the District Court within a maximum period of 30 days from the date the award is rendered in order to obtain executorial force.

In Law Number 30 of 1999 concerning Arbitration and Alternative Dispute Resolution, Article 1 point (10) provides a definition of Alternative Dispute Resolution (ADR). The provision states that:

Alternative dispute resolution is an institution for the settlement of disputes or differences of opinion through procedures agreed upon by the parties, namely settlement outside the court by means of consultation, negotiation, mediation, conciliation, or expert appraisal.

Several forms of alternative dispute resolution referred to in the article include:

1. Consultation

Consultation is a process in which the parties seek opinions or advice from a person who is an expert in a particular field to assist in resolving the problem that has arisen.

2. Negotiation

Negotiation is a process of direct discussion between the disputing parties to reach a mutual agreement without the involvement of a third party.

3. Mediation

Mediation is a dispute resolution process with the assistance of a neutral third party (mediator) whose role is to help the parties reach an agreement.

4. Conciliation

Conciliation is a dispute resolution process in which a third party assists the disputing parties in formulating a solution to resolve the dispute.

5. Expert Appraisal

Expert appraisal is conducted by seeking the opinion of an expert regarding a particular issue that constitutes the subject matter of the dispute.

Arbitration is essentially intended to avoid court proceedings because, compared to public adjudication, arbitration provides greater freedom, choice, autonomy, and confidentiality to the disputing parties. In arbitration, the parties may choose the judge they desire, thereby ensuring neutrality and expertise appropriate to their dispute. The parties may also choose the law they wish to apply as the basis for resolving the dispute. The costs are lower and the process tends to be more informal. Based on this definition, arbitration may be understood as one method of dispute resolution outside the general courts (non-litigation) in the form of a written agreement between the disputing parties, where the settlement process involves a third party, namely an arbitrator or arbitral tribunal, as the decision-maker in resolving the dispute in order to achieve a win-win solution for the parties.

CONCLUSION

The formation of a franchise agreement between the franchisor and the franchisee is governed by Article 1320 of the Indonesian Civil Code concerning the requirements for the validity of an agreement and Article 1338 of the Indonesian Civil Code concerning the binding force of an agreement (*the principle of pacta sunt servanda*). Furthermore, Government Regulation No. 35 of 2024 concerning Franchising, Article 4 paragraph (4), states that a franchise agreement shall be executed in writing and shall be governed by the laws applicable in Indonesia.

The settlement of franchise disputes according to Article 6 paragraph (1) of Government Regulation No. 35 of 2024 concerning Franchising states that disputes arising from franchise agreements may be resolved through litigation (court proceedings) or non-litigation methods (outside the courts through arbitration). Furthermore, Article 8 of Law No. 30 of 1999 concerning Arbitration and Alternative Dispute Resolution states that disputes arising from

franchise agreements may be resolved by submitting a written application to the Indonesian National Arbitration Board (BANI). The written application shall contain:
a. The full names and addresses of the disputing parties;
b. An explanation of the dispute that has arisen;
c. The basis of the claim or demand submitted;
d. The arbitration agreement serving as the basis for the settlement of the dispute.

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JUDICIAL CONSIDERATIONS OF JUSTICE IN CLASS ACTION LAWSUITS AGAINST CORPORATE ACTIVITIES CAUSING ENVIRONMENTAL POLLUTION (A CASE STUDY OF SUKOHARJO RESIDENTS VS PT RAYON UTAMA MAKMUR)

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Abstract

This thesis examines the environmental impacts of the business activities of PT Rayon Utama Makmur (PT RUM) on the surrounding community, which led to the filing of a class action lawsuit, and analyzes whether the judicial considerations at each level of the judiciary in adjudicating the class action between the residents of Sukoharjo and PT RUM reflected principles of justice. This study employs a normative legal research method using secondary data collected through library research.

The findings reveal that PT RUM's waste management activities generated air pollution containing Hydrogen Sulfide (H_2S), which caused widespread respiratory disorders and other health problems among local residents. Regarding judicial considerations, the decisions rendered by the courts at the first-instance and cassation levels did not fully provide justice to the affected community. However, at the cassation level, the court ultimately ruled that PT RUM had committed an unlawful act and ordered the company to compensate the plaintiffs for material damages and undertake measures to restore the rights of the affected residents. Therefore, this decision can be regarded as providing justice for the community members who suffered the adverse impacts of the pollution.

Keywords: *Class Action; Justice; Environmental Pollution.*

A. Introduction

There are two methods for filing claims arising from violations of civil legal relationships. First, a claim may be filed by the concerned individual or his/her heirs (ordinary civil lawsuit). Second, it may be filed by a group of persons sharing the same interest (class action). Class actions, or representative group lawsuits, have long been recognized and implemented in countries adhering to the Common Law legal system, such as England and countries that were formerly its colonies. Law Number 23 of 1997 concerning Environmental Management was the first legislation in Indonesia to recognize this form of lawsuit. To ensure that class action lawsuits could be examined, adjudicated, and decided more efficiently, systematically, and effectively, the Supreme Court issued Supreme Court Regulation Number 1 of 2002 concerning Procedures for Class Action Lawsuits.

A class action is a civil lawsuit filed by one or more individuals on behalf of a group of people having identical claims against a defendant. The individual acting as the representative represents both his or her own interests and those of other class members. Class members and representatives alike are parties who have suffered losses or harm. Plaintiffs in a class action consist of class members and class representatives. Both class representatives and class members must be victims of the same conduct by the defendant, arising from the same facts or events, legal grounds, and type of claim. Another important aspect in class action litigation concerns the distribution of compensation. If a claim for damages is granted, the judge bears the responsibility of determining the amount of compensation, identifying the groups and sub-groups entitled thereto, determining the method of distribution, and establishing the measures to be undertaken by the class representatives during the distribution process. Law may serve as a guideline for behavior over a relatively long period because its principles are open, generally applicable, principled in nature, and characterized by consistency and legal certainty. This reflects the explicit nature of law.

In practice, communities have initiated class actions against corporations due to air and water pollution resulting from corporate activities. On the one hand, the existence of corporations or companies within society creates positive impacts, including employment opportunities, fulfillment of public needs for goods and services, and the development of a stable and growing economy. On the other hand, environmental pollution and degradation have become serious issues caused by industrial activities, particularly those of large corporations. Air, water, and soil pollution have become increasingly prevalent due to improperly managed industrial waste. Industrial companies therefore bear responsibility for environmental damage and pollution resulting from their activities. Such responsibility constitutes an obligation to bear the consequences of unforeseen events and may give rise to claims, disputes, and legal proceedings.

One example is the environmental pollution case resulting from the negligent waste disposal practices of PT Rayon Utama Makmur (PT RUM), whose manufacturing operations generated production waste in the form of a highly pungent foul odor that disturbed surrounding residents. Residents had submitted complaints to the Environmental Agency of Sukoharjo Regency but never received the response they expected. Ideally, the Environmental Agency should play a significant role in addressing environmental pollution issues. PT RUM's non-compliance with environmental regulations ultimately resulted in sanctions imposed by the Minister of Environment and Forestry in relation to the implementation of government administrative coercive measures.

PT RUM also received administrative sanctions twice from the Regent of Sukoharjo in 2018 and 2019. However, according to the affected residents, such sanctions did not satisfy their demand for material and immaterial compensation under the Indonesian Civil Code. Consequently, residents filed a class action lawsuit concerning environmental pollution and environmental degradation beginning in 2017.

The class action against PT RUM underwent a lengthy civil law enforcement process up to the cassation level because the residents did not obtain justice at the first-instance and appellate levels. Therefore, it is necessary to further analyze the legal reasoning of judges at each stage of legal remedies and whether such considerations have delivered justice to communities severely affected by PT RUM's operations, particularly regarding air and water pollution. Accordingly, the author is interested in examining this issue under the title mentioned.

B. Statement of Problems

The principal issues examined in this study are:

1. What impacts have PT Rayon Utama Makmur's business activities had on the surrounding environment that resulted in a class action lawsuit ?
2. Have the judicial considerations at each level of adjudication examining and deciding the class action between the residents of Sukoharjo and PT RUM reflected justice ?

C. Research Method

This study employs normative legal research through both the statutory approach and the sociological approach. The data utilized consist of secondary data collected through library research. Data processing was conducted through editing, coding, reconstructing, and systematizing. Data analysis was performed qualitatively, and conclusions were drawn using deductive reasoning.

D. Findings and Analysis

1. **The Impact of PT Rayon Utama Makmur's Business Activities on the Surrounding Environment Resulting in a Class Action Lawsuit**

The low level of legal compliance and the relatively high costs associated with waste management, as previously explained, are suspected to be among the principal causes of waste treatment problems. This situation contributed to the worsening conflict between PT RUM and residents of Gupit and Ngrapah villages located north of the factory, as well as several other affected villages in Nguter District, Sukoharjo Regency. Since 2017, PT RUM, a subsidiary of PT Sri Rejeki Isman Tbk engaged in the production of synthetic-fiber-based materials, has generated waste causing air pollution in the form of a highly offensive foul odor affecting nearby residents. More severely, the odor generated from PT RUM's waste was reportedly detectable within a radius of up to 60 kilometers. This indicates PT RUM's inability to properly manage industrial residues, resulting in factory waste producing persistent unpleasant odors.Furthermore, the waste generated by PT RUM caused respiratory disorders among local residents as well as other illnesses, including acute respiratory infections (ARI), dyspepsia, and dermatitis.

PT RUM commenced production operations around October 2017. Since that time, its manufacturing activities have generated a pungent odor causing residents to experience headaches, dizziness, nausea, shortness of breath, and sleeping difficulties, thereby negatively affecting their comfort and quality of life. The Environmental Agency (Dinas Lingkungan Hidup/DLH) of Sukoharjo Regency issued a Warning Letter dated 1 November 2017 to PT RUM based on field findings obtained on 25 October 2017. The warning letter stated that a strong odor originating from PT RUM's production activities had caused residents to suffer dizziness, nausea, and vomiting after exposure to the odor. On 27 November 2017, representatives of affected residents submitted a protest letter to PT RUM regarding the air and water pollution allegedly caused by the company.

Additional evidence emerged from a study conducted by the Muhammadiyah Regional Leadership through Report Number 20.37/III.O/A/2018 concerning the Performance Report of

the Independent Muhammadiyah Team dated 18 February 2018. The report found that local water sources had been contaminated and that the air contained Hydrogen Sulfide (H_2S). Exposure to this substance caused irritation of the eyes, nose, and throat, respiratory system disorders, shortness of breath, nausea, and dizziness, and prolonged exposure could potentially result in death.

As a consequence, residents surrounding the factory rejected all PT RUM activities. Based on two rounds of free medical examinations, local residents were diagnosed with severe acute respiratory infections, mild acute respiratory infections, dyspepsia, and dermatitis.

2. **Analysis of Equitable Judicial Considerations at Each Level of Adjudication Examining and Deciding the Class Action Between Sukoharjo Residents and PT RUM**

The class action lawsuit was adjudicated in Decision Number 29/Pdt.G/2023/PN Skh. However, the claims filed by Sarmi and Slamet Riyanto as representatives of the affected community against PT RUM were dismissed, and the plaintiffs were jointly ordered to pay court costs.

The court's principal reasons for dismissing the claim were as follows:

1. The plaintiffs failed to prove the loss of peace and comfort suffered by residents due to the foul odor allegedly caused by PT RUM;
2. The plaintiffs did not leave their residences and continued living near PT RUM;
3. PT RUM's presence was viewed as a manifestation of the Sukoharjo Regency Government's efforts to improve public welfare;
4. The lawsuit was considered merely to represent a particular group interest;
5. Laboratory results indicated that PT RUM had not exceeded the applicable water and air quality standards;
6. Witness testimony did not establish that PT RUM had committed environmental pollution.

According to the author, these considerations demonstrate that the first-instance court failed to provide justice to the plaintiffs. It is entirely reasonable that residents remained in their homes despite experiencing air pollution, as relocation is neither simple nor economically feasible. Therefore, the first and second considerations were irrelevant and failed to reflect both judicial conscience and the social realities explaining why residents remained in place.

Likewise, PT RUM's contribution to local employment opportunities should not negate its responsibility for environmental pollution. Economic benefits and environmental contamination are distinct issues with separate legal consequences. The court also characterized the class action as merely a legal effort undertaken by a limited group of residents. This reasoning is equally irrelevant and inconsistent with sociological realities, given that the plaintiffs were acting as representatives of the broader community residing around the factory.

The author further argues that the court's judgment was inappropriate and insufficiently fair because it appeared to favor only one side. This conclusion is supported by the fact that during the judicial site inspection, members of the judicial panel, together with both plaintiffs and defendants, directly detected the foul odor emanating from the factory, even when the factory was not operating at the time. Moreover, documentary evidence and witness testimony—including testimony from PT RUM's own side—confirmed indications of environmental pollution resulting from the emission of offensive odors.

This conclusion is reinforced by sanctions imposed prior to trial by both the Minister of Environment and Forestry and the Regent of Sukoharjo through Decision Number 4047/Menlhk-PHLHK/PPSGA/GKM.016/2018 concerning the implementation of administrative coercive measures and Sukoharjo Regent Decree Number 660.1/2017 of 2018, which granted PT RUM eighteen months to address the gas odor problem generated by its operations. A further sanction was imposed in October 2019 due to a decline in production output.

The foregoing facts revealed PT RUM's wrongdoing during the trial process and reinforced the perception that the competent authorities had failed to provide justice in addressing this environmental pollution case. Consequently, the judgment not only allowed PT RUM to continue polluting the environment but also released the company from its legal responsibility, which should have included compensation for losses suffered by the community and environmental restoration measures. This situation generated concerns regarding the continuing negative impacts on public health and environmental sustainability due to inadequate enforcement of environmental law, which should have been implemented firmly and fairly.

Following the first-instance judgment, which the plaintiffs regarded as unjust, they pursued an appeal. However, the appeal was also declared inadmissible as premature pursuant to the Decision of the Semarang High Court Number 43/Pdt/2024/PT Smg. The High Court based its reasoning, among other things, on Letter P-21 of the Deputy Attorney General for Special Crimes of the Republic of Indonesia Number B-2712/E.3/Eku.1/07/2023 dated 7 July 2023 concerning the results of the criminal investigation against PT Rayon Utama Makmur. The investigation concerned alleged violations of Article 98 paragraph (1) in conjunction with Article 116 paragraph (1) letter (a) of the Environmental Protection and Management Law, and Article 100 paragraph (2) in conjunction with Article 118 of the same law. On 20 July 2023, the suspect and evidence were transferred to the Public Prosecutor of the Sukoharjo District Attorney's Office, and the matter was awaiting criminal trial proceedings.

The appellate court further referred by analogy to Article 25 of Law Number 31 of 1999 concerning the Eradication of Corruption Crimes, which requires corruption cases to be prioritized in investigation, prosecution, and adjudication. The High Court considered environmental pollution offenses to constitute special crimes similar to corruption offenses and therefore concluded that such criminal proceedings should take precedence over other proceedings to avoid contradictory decisions. The court further emphasized that the case at hand did not concern property ownership rights.

According to the author, this reasoning was flawed because the criminal proceedings concerned criminal liability, whereas the class action lawsuit concerned compensation for damages. The purpose of criminal proceedings is punishment and criminal accountability, while the purpose of a class action is the recovery of losses suffered by affected individuals.

Accordingly, the civil class action should have proceeded to substantive adjudication regardless of the existence of ongoing criminal proceedings. The civil lawsuit should not have been dismissed as premature merely because criminal charges were pending. The appellate decision therefore failed to provide justice to the affected residents suffering from PT RUM's pollution. Although Indonesian law provides administrative, civil, and criminal sanctions against environmental polluters, governmental protection for victims remains ineffective. The principal obstacles identified include the inadequate responsiveness of local authorities in addressing environmental pollution and the lack of commitment to enforcing environmental laws against polluters.

As a result, pollution caused by PT RUM continued, causing prolonged suffering among surrounding communities and creating dissatisfaction with existing legal protection mechanisms.The plaintiffs' pursuit of justice ultimately yielded success. At the cassation level, the Supreme Court granted the cassation petition through Supreme Court Decision Number 4441 K/Pdt/2024. The Supreme Court granted the cassation appeal and annulled the Decision of the Semarang High Court Number 43/Pdt/2024/PT Smg, which had effectively upheld the dismissal of Decision Number 29/Pdt.G/2023/PN Skh.

In adjudicating the merits of the case, the Supreme Court ruled, among other things, as follows:

1. To partially grant the Plaintiffs' claim;

2. To declare that the Defendant committed an Unlawful Act;
3. To order the Defendant to pay material damages suffered by the Plaintiffs and Class Members totaling 185 persons, consisting of:
    a. Compensation for the purchase of masks intended to reduce the impact of foul odors generated by the Defendant's operational activities in the amount of IDR 277,500,000 (two hundred seventy-seven million five hundred thousand rupiah);
    b. Compensation for the purchase of medicines to alleviate physical effects caused by prolonged exposure to the odor in the amount of IDR 222,000,000 (two hundred twenty-two million rupiah);

    such compensation to be distributed to the Plaintiffs and Class Members by a compensation distribution team through a gathering at the residence of Plaintiff I located in Ngrapah Hamlet, RT 002/RW 009, Gupit Village, Nguter District, Sukoharjo Regency;
4. To order the Defendant to undertake measures restoring the Plaintiffs' rights to their original condition by preparing a restoration plan containing the substance required under Article 55 paragraph (1) of Supreme Court Regulation Number 1 of 2023 concerning Guidelines for Adjudicating Environmental Cases, under the supervision and approval of the Sukoharjo Environmental Agency and approval of the Chief Judge of the Sukoharjo District Court, including:
    a.Eliminating foul odors resulting from the Defendant's operational activities;
    b. Installing and/or repairing air and liquid waste treatment facilities;
    c. Eliminating the causes of air and water pollution;
5. To order the Respondent in Cassation to pay court costs at all levels of proceedings, including cassation costs in the amount of IDR 500,000 (five hundred thousand rupiah).

Aristotle viewed justice as the granting of equal rights, though not necessarily identical treatment. He distinguished equality based on proportional rights. According to Aristotle, equality means that all persons or citizens possess equal rights, while proportional equality grants each person rights corresponding to their capacities and actions.

Justice therefore emphasizes balance and proportionality. On one hand, justice entails equality of rights; on the other hand, it also recognizes differences in rights according to relevant circumstances. Accordingly, justice requires not only equal treatment but also balanced and proportional treatment.

Viewed through this theory of justice, the Supreme Court's decision granting the class action claim against PT RUM constituted a realization of justice. The residents of Sukoharjo obtained balanced and proportional justice because they suffered environmental harm, while PT RUM was held civilly accountable and required to compensate for the losses caused by its conduct. The affected residents ultimately prevailed in their struggle against environmental pollution after their class action lawsuit concerning PT RUM's foul odor emissions was granted. Their efforts were neither immediate nor easy. The environmental rights taken away by PT RUM had to be restored to the affected residents. The Supreme Court's cassation decision significantly strengthened the residents' efforts to protect the environment from PT RUM's pollution. The judgment confirmed the existence of environmental pollution harming the people of Sukoharjo and contributed to protecting the Bengawan Solo River from environmental degradation.

To ensure continuing justice for the people of Sukoharjo and the preservation of a clean environment, implementation of the Supreme Court's decision must continue to be monitored. The cassation judgment did not end the residents' struggle; rather, it became an important milestone in the ongoing effort to protect the environment. Through this decision, the

environment was safeguarded from irresponsible polluters, and the residents' movement for environmental protection gained renewed strength.

E. Conclusions and Recommendations

1. Conclusions

Based on the research findings, the following conclusions may be drawn:

a. The impact of PT Rayon Utama Makmur's (PT RUM) business operations on the surrounding environment, which ultimately gave rise to the class action lawsuit, consisted of factory waste processing activities that generated air pollution containing Hydrogen Sulfide (H_2S). This pollution caused widespread respiratory disorders, headaches, dizziness, nausea, eye irritation, and disruption of residents' daily activities.

b. The judicial considerations at the first-instance and appellate levels did not provide justice because the residents' claims were rejected and declared premature on the grounds that the plaintiffs failed to prove their allegations and because PT RUM was simultaneously undergoing criminal proceedings. In reality, however, site inspections clearly demonstrated the existence of a strong odor affecting a broad geographical area. Furthermore, criminal proceedings, which concern criminal sanctions, should not impede civil proceedings seeking compensation for damages. Justice was ultimately achieved at the cassation level when PT RUM was declared to have committed an unlawful act and was ordered to compensate material losses and undertake measures to restore the rights of the affected residents.

2. Recommendations

Based on the foregoing conclusions, the following recommendations are proposed:

a. Local government authorities, particularly the Environmental Agency, should promptly respond to public complaints concerning waste management and factory production activities that result in air or water pollution. Such authorities should conduct inspections and impose administrative measures where necessary so that environmental problems can be resolved without requiring affected communities to pursue costly and time-consuming class action litigation in order to obtain justice and environmental protection.

b. Judges adjudicating environmental pollution class action cases should formulate legal reasoning grounded in justice and supported by factual evidence demonstrating the existence of environmental pollution. In doing so, judicial decisions will better promote legal certainty, justice, and social benefit.

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Kitab Undang-Undang Hukum Perdata

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Peraturan Mahkamah Agung Nomor 1 Tahun 2002 tentang Acara Gugatan Perwakilan Kelompok

E. **Internet**

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CROSS BORDER PENALTIES TO INTERNATIONAL CORPORATION IN INDONESIA JURISDICTION BY BRIBERY CASE: A CASE STUDY OF CHROMEBOOK PROCUREMENT BY NADIEM MAKARIM

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Abstract. In the era of digital transformation, the education digitalization program has become a priority policy of the Indonesian government to improve the quality and equality of access to education across all regions. Various education digitalization programs, both those supporting academic and non-academic activities, have proven effective in expanding and accelerating access to education. Education is one of the steps in supporting the Freedom to Learn program initiated by the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek). However, the implementation of education digitalization programs that involve large budgets for the procurement of information and communication technology devices opens new opportunities for corruption. In the 2021 Chromebook laptop procurement program by Kemendikbudristek with a value of nearly IDR 10 trillion, corruption is suspected in the procurement process, which is currently under investigation by the Attorney General's Office. Nadiem is suspected of abusing his authority in the procurement process by directing technical specifications to match Chromebook products before the procurement process begins. Nadiem's role was also evident in his meeting with Google Indonesia to discuss the Google for Education program, as well as the issuance of Minister of Education and Culture Regulation Number 5 of 2021, which specifically locks the use of Chrome OS in Information and Communication Technology (ICT) procurement. These actions served as a strong basis for the suspect's determination, as they were deemed to contain indications of a conflict of interest and policy manipulation that harmed state finances. The type of research used in this study was normative. The results of the discussion showed that the Public Prosecutor did not indict Google Asia Pacific because it did not find any malicious intent; Google's investment was directed to PT Aplikasi Karya Anak Bangsa which later became PT GoTo Gojek Tokopedia. The prosecutor suspected Nadiem of using an investment of US$786.99 million and internal transactions of Rp809.59 billion for personal gain in the procurement of Chromebook laptops 2019 2022. Nadiem rejected the accusation, stating that Google's investment in Gojek occurred before he became a minister, did not enrich Google, and criticized the prosecutor's rejection of the testimony of three former Google executives. Corporations such as Google can be prosecuted as suspects for giving bribes based on Article 20 of Law Number 31 of 1999 in conjunction with Law Number 20 of 2001 concerning the Eradication of Criminal Acts of Corruption (Corruption Law). This corporate criminal liability is operationalized through the guidelines for investigation and trial procedures in Supreme Court Regulation (PERMA) Number 13 of 2016. To determine Google as a suspect corporation, investigators (such as the Corruption Eradication Commission or the Prosecutor's Office) must fulfill the following specific elements: (1) Actions Carried Out by Corporate Organs; (2) Profits for the Corporation; and (3) Corporate Misconduct. In his personal defense, Nadiem rejected all of the prosecutor's charges and requested an acquittal. Nadiem claimed that the use of Chrome OS was actually an effort to save state funds and there was no evidence of illegal funds flowing into his personal account.
Keywords: Chromebook Laptop, Corruption Crime, Conflict of Interest, Google

INTRODUCTION

The problem of corruption stems not only from weak oversight systems but also from a lack of individual integrity in the performance of duties and responsibilities. Furthermore, bureaucratic complexity and a lack of transparency in budget management exacerbate the risk of corrupt practices. The education sector is not immune to such corruption. This is particularly concerning given the strategic role education plays in shaping the quality of human resources and the character of the nation's youth. Corruption in the education sector results not only in financial loss for the state but also directly impacts the quality of learning, the availability of facilities, and equitable access to education. In some instances, funds intended to improve educational quality are misappropriated, rendering the planned programs ineffective.

One case attracting public attention involves alleged corruption in the procurement of Chromebook laptops—valued at IDR 9.9 trillion—under an education digitalization program involving the former Indonesian Minister of Education and Culture, Nadiem Makarim. While the program initially aimed to support technology-based learning, its implementation was allegedly marred by irregularities, such as discrepancies between product specifications and actual field requirements, as well as inadequate supporting infrastructure—particularly regarding internet access in various regions. Nadiem is also accused of receiving funds totaling IDR 809.59 billion, allegedly originating from PT AKAB via PT Gojek Indonesia; the bulk of PT AKAB's funds reportedly came from a Google investment valued at USD 786.99 million. Prosecutors have linked these alleged fund transfers to Nadiem's 2022 State Official Wealth Report (LHKPN), which declared securities holdings worth IDR 5.59 trillion. Consequently, the indictment charges Nadiem with violating Article 2, Paragraph (1) or Article 3—in conjunction with Article 18 of the Corruption Eradication Law and Article 55, Paragraph (1), Item 1 of the Criminal Code.

In his view, Baharuddin Lopa stated that corruption is a criminal offense linked to bribery, manipulation, and other unlawful acts that harm the state's economy and finances, as well as the public welfare and interest. Furthermore, Law No. 31 of 1999 regarding corruption defines it as an unlawful act that causes financial and economic loss to the state. Based on this explanation, corruption involves any person who, in violation of the law, engages in acts to enrich themselves, another person, or a corporation, thereby causing financial and economic loss to the state.

The study of cross-border sanctions and corporate jurisdiction regarding bribery cases in Indonesia is governed by the Corruption Eradication Law (Law No. 31 of 1999, as amended by Law No. 20 of 2001) and the territoriality principle of the Criminal Code. Although extraterritorial jurisdiction over foreign corporations remains limited, this principle allows for the prosecution of criminal acts occurring—either in whole or in part—within Indonesian territory. The corruption case involving the procurement of Chromebook laptops for the Ministry of Education, Culture, Research, and Technology has been processed in Indonesian courts, with several suspects named—ranging from government officials to private consultants and contractors. In the context of both international and national law, the enforcement of sanctions and jurisdiction in this case faces several key challenges: (1) Jurisdictional Principles; National Jurisdiction: Based on the territoriality principle adopted by Indonesia (Articles 2 and 3 of the Criminal Code), Indonesian law applies to anyone committing a crime within Indonesian territory, including multinational corporations operating or conducting transactions here; Extraterritorial Jurisdiction: If bribery or the planning of corruption occurs abroad—involving a foreign entity bribing a public official in Indonesia—Indonesian law enforcement relies on the ratification of the UNCAC (United Nations Convention against Corruption), which addresses foreign bribery; (2) Corporate Criminal Liability; Indonesian Regulations: Under the Corruption Eradication Law, corporations can be prosecuted and fined, while their executives or directors may face custodial sentences (imprisonment) and orders to pay restitution; Cross-Border Obstacles: If a parent company is located abroad (in a foreign jurisdiction), law enforcement agencies often must utilize international cooperation mechanisms—such as Mutual Legal Assistance (MLA)—for asset tracing, the examination of witnesses or experts, or the extradition of perpetrators. (3) Analysis of the Chromebook Procurement Case; Alleged Irregularities: This case highlights alleged price mark-ups and abuse of authority in the procurement of information and communication technology, resulting in state financial losses amounting to trillions of rupiah. The procurement process was deemed to be steered—via specification locking—toward specific products and licensing systems; Vendor Awards: During the proceedings at the Central Jakarta Corruption Court, trial evidence revealed the provision of money and perks to relevant parties, sparking debates regarding jurisdiction and the substantiation of elements such as malicious intent (mens rea) and illicit gratuities.

RESEARCH METHODOLOGY

This study employs a normative-juridical research method, relying on prevailing laws and regulations. The analysis utilizes primary legal materials—specifically relevant legislation, such as the new Criminal Code—and secondary legal materials, including journal articles, books, and websites, which were collected and analyzed. The analysis was conducted through a descriptive examination of these legal materials.

RESEARCH FINDINGS AND DISCUSSION

A. Legal Rationale: The Public Prosecutor (JPU) did not Prosecute the Google Corporation—The Entity Alleged to have provided the Bribe—Contrary to the Arguments presented by the JPU in the Nadiem Makarim Case

Allegations of corruption regarding the procurement of Chromebook laptops at the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) between 2019 and 2022 also implicated the former minister, Nadiem Makarim. Nadiem stated that prior to his tenure, there had indeed been a pilot program for Chromebook usage in schools located in 3T regions (disadvantaged, frontier, and outermost areas). However, once he assumed office, the Chromebooks were allocated to non-3T regions that already had internet access. "I wish to clarify that the laptop procurement process during my tenure was not targeted at 3T regions. Only schools with internet access were eligible to receive laptops from this procurement," Nadiem said. In 2023, monitoring results from the 77,000 schools that received the Chromebooks showed that 97 percent of the laptops were being used for learning activities. Meanwhile, for 3T regions, Nadiem established the *Awan Penggerak* (Driving Cloud) program. Notably, the Attorney General's Office (Kejagung) initiated an investigation into this case in late May 2025. The budget for the Chromebook procurement reportedly reached IDR 9.9 trillion. Authorities searched two apartments belonging to a Kemendikbudristek employee in South Jakarta. Harli Siregar, Head of the Legal Information Center (Kapuspenkum) at the Attorney General's Office, stated there were allegations of collusion or criminal conspiracy among various parties to steer the technical team toward producing a technical assessment favoring the procurement of Chromebook-based information and communication technology equipment. Yet, at that time, Indonesia was deemed not to require Chromebooks, as internet network coverage was not yet evenly distributed.

As of early September 2025, the case remains in the investigation or preliminary prosecution stage. The court will serve as the forum to determine whether the policy in question amounted to mere mismanagement or an abuse of authority intended to benefit specific vendors at the expense of the state. This case exemplifies "decision-based corruption": a large-scale policy ostensibly serving the public interest that is under scrutiny for alleged corrupt implementation—specifically, the manipulation of processes resulting in financial loss. The defense's focus on the absence of personal gain raises a pivotal legal question: can a flawed decision made without personal motive be classified as corruption? The answer hinges on evidence regarding intent, process, and consequences.

Prosecutors characterize the Chromebook and CDM license procurement case (2020–2022)—which implicates Nadiem Makarim—as a form of "state-corporate crime," involving collusion between the state and a corporation through public policy. This pandemic-era education digitalization project is alleged to be more than a routine policy; it is accused of being a structured scheme that created "vendor lock-in," effectively turning Indonesia's education system into a captive market for a single global company. Through this policy, which facilitated a monopoly, the state allegedly suffered financial losses amounting to IDR 5.68 trillion.

During proceedings at the Central Jakarta Corruption Court, prosecutors argued that the policy violated transparency principles and contradicted the government's commitment to eradicating corruption. They also highlighted the decision to purchase Chromebooks, noting that since 2018, the ministry had deemed the devices unsuitable for regions with limited internet access. Prosecutors added that the decision to proceed with the procurement was made after Nadiem held several meetings with representatives from Google Asia Pacific and Google Indonesia in 2020. Conversely, Nadiem denied all allegations. He has been detained since September alongside other ministry officials, while his lawyers maintain that the charges lack significant new evidence.

Public prosecutors did not charge Google as a corporation, as the company was deemed to lack criminal intent (mens rea) regarding the Chromebook procurement case. Prosecutors emphasized that Google acted purely as an investor. Instead, prosecutors argued that the criminal intent lay entirely with Nadiem Makarim, who allegedly exploited Google's investment for personal gain. Under Indonesian criminal law, the doctrine of criminal intent is a prerequisite for prosecuting an individual or a corporation. Based on the facts and arguments presented by the prosecution, the underlying legal reasoning regarding Google and the charges against Nadiem Makarim is as follows: (1) Google: Acted as a multinational technology company making a business investment. Prosecutors found no evidence of a direct bribery agreement between Google and the ministry; the funds in question represented a purely corporate investment activity.

Nadiem Makarim: Charged with abusing his authority as the former Minister of Education, Culture, Research, and Technology. Prosecutors alleged that Nadiem used his position to steer procurement specifications, thereby benefiting specific parties as well as himself. (2) In Indonesia's corruption judicial system, criminal liability is personal (attaching to the individual perpetrator). As Google acted purely as an investor and had no plan or agreement to engage in bribery, it cannot be classified as a perpetrator of the alleged corruption. The corruption charges focus on the abuse of authority and criminal conspiracy allegedly committed by state officials.

B. Current Regulations Regarding the Potential Prosecution of Google as a Suspect for Bribery in the Nadiem Makarim Case

The alleged corruption case involving the procurement of Chromebook laptops at the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) stands out as a major scandal within Indonesia's education sector. The Attorney General's Office revealed that the procurement of these devices allegedly caused state financial losses amounting to IDR 1.98 trillion between 2019 and 2022. This case involves not only legal issues but also has serious repercussions for the effectiveness of education digitalization policies and public trust. This alleged corruption unfolded through several mechanisms. First, technical specifications in the operational guidelines were restricted so that only the Chrome OS operating system could meet the requirements. Second, the planning process was allegedly "rigged" from the outset through communication between the Minister of Education and Google Indonesia, even though the ministry's technical team had initially recommended other options. Furthermore, the distribution of devices to schools in 3T regions (frontier, outermost, and underdeveloped areas) was deemed ineffective because Chromebooks rely heavily on a stable internet connection, rendering many of the devices potentially useless. This combination of factors suggests price mark-ups and an abuse of authority that resulted in significant state financial losses. The impact of this case is far-reaching. From a fiscal perspective, the state loss of nearly IDR 2 trillion means that public funds—which should have been allocated to improving education quality, teacher welfare, or school infrastructure—were squandered. From an educational standpoint,

distributing devices without regard for existing infrastructure conditions exacerbated the digital divide between urban and rural schools. Schools in areas with limited internet access could not utilize the devices optimally, thereby failing to achieve the goals of education digitalization. Moreover, the involvement of the Minister of Education in this case has eroded public confidence in the integrity of education policies.

Corporations such as Google can be prosecuted as suspects for bribery under the Corruption Eradication Law. The primary provision is Article 20 of the Law, which establishes corporations as legal subjects capable of being held criminally liable for acts committed for the corporation's benefit. Articles 5 and 13 of the Law govern the act of giving or promising something to a civil servant or state official.Under Article 20, a criminal act of corruption is deemed to have been committed by a corporation if the act was performed by an individual with an employment or other relationship—acting either independently or jointly—for the corporation's interest. Technical guidelines for the examination and adjudication of corporate cases are set forth in Supreme Court Regulation (PERMA) No. 13 of 2016. This regulation assists law enforcement officials in establishing liability and imposing sanctions (such as fines or dissolution) on corporate entities. Investigators must prove that the bribe was intended to influence policy or to benefit the company, whether directly or indirectly.

The public, teachers, and students have grown skeptical of technology-based government programs.This case highlights the risks inherent in technology-based public procurement—particularly when lacking adequate oversight and transparency mechanisms—which can create loopholes for misconduct. In this context, the role of online mass media is crucial, as media coverage serves as a primary source of public information regarding the processes, actors, and dynamics of the case in question.

Criminal law enforcement in Indonesia places a strong emphasis on judges examining facts objectively and meticulously and applying the law correctly; the ultimate goal is to ensure that the resulting verdict is fair, lawful, and convincing. This situation presents a challenge for the application of criminal law—specifically the process of replacing old regulations with new criminal statutes to address the country's social and political dynamics, such as the need to protect human rights; yet, the drafting of the new Criminal Code has sparked uncertainty regarding how to balance the preservation of local values with universal human rights principles.

CONCLUSIONS AND RECOMMENDATIONS

In a global context, corporate corruption exhibits increasingly complex, cross-border characteristics. Practices such as transnational bribery, regulatory evasion, and the exploitation of international legal structures have become common patterns among corporations. Consequently, corporate corruption is classified as a form of transnational economic crime that cannot be addressed piecemeal by a single nation; thus, anti-corruption education is crucial as a long-term preventive measure. The case involving Nadiem Makarim demonstrates that officials can be held accountable for their decisions—even in the absence of evidence of personal bribery—provided the elements of abuse of authority, benefit to a third party, and resulting loss are established. This reinforces the principle that public office is a position of trust, not a license to act arbitrarily.

For Indonesia, a key priority is to clarify guidelines so that the exercise of honest discretion remains safe, while abuse is met with firm enforcement. By adhering to proper processes, maintaining meticulous documentation, and upholding integrity, officials can confidently make innovative decisions within the bounds of the law. The ultimate goal is to ensure that public decisions consistently serve the common good rather than narrow interests.

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ENVIRONMENTAL CRIMINAL LAW ENFORCEMENT BASED ON INFORMATION TECHNOLOGY

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Abstract

The development of information technology has significantly influenced environmental criminal law enforcement in Indonesia. Digital technology has become an important instrument in monitoring, preventing, and proving environmental crimes such as illegal logging, forest fires, waste pollution, and illegal mining. This article aims to analyze the role of information technology in environmental criminal law enforcement and examine the challenges faced in its implementation. The research method used is normative juridical research with statutory and conceptual approaches. The study shows that information technology, including satellite imagery, drones, electronic reporting systems, and digital evidence, has strengthened the effectiveness of environmental law enforcement. Electronic evidence has also gained legal recognition under Indonesian law, particularly through the Law on Electronic Information and Transactions. However, challenges remain, including limited technological infrastructure, lack of digital expertise among law enforcement officers, and weak inter-agency coordination. Therefore, strengthening regulations, improving digital literacy, and enhancing technological facilities are necessary to support effective environmental criminal law enforcement in the digital era.

Keywords: *environmental criminal law; information technology; digital evidence; environmental crimes; law enforcement*

INTRODUCTION

Indonesia is endowed with abundant natural resources and possesses the world's third-largest tropical rainforest, making environmental crime one of the most significant challenges to national law enforcement. Illegal logging, forest and land fires, industrial waste pollution, and illegal mining continue to occur annually, causing substantial ecological, economic, and social losses. Environmental law enforcement is fundamentally understood as the application of legal instruments to ensure compliance with environmental protection and management regulations through administrative, civil, and criminal mechanisms (Niniek, 1994).

Environmental criminal law in Indonesia is specifically regulated under Chapter XV of Law Number 32 of 2009 concerning Environmental Protection and Management, which stipulates criminal offenses and sanctions for perpetrators of environmental pollution and

destruction. Nevertheless, environmental criminal law enforcement continues to face persistent challenges, particularly in the evidentiary process, because environmental crimes are generally latent in nature, occur across extensive and difficult-to-access areas, and involve increasingly sophisticated methods of operation (Januari & Muaz, 2015).

The rapid development of information and communication technology has significantly transformed the manner in which law enforcement agencies detect, monitor, investigate, and prosecute environmental crimes. Digital technologies—including satellite imagery, unmanned aerial vehicles (drones), artificial intelligence, electronic reporting systems, and digital evidence—have become indispensable components of contemporary law enforcement. This digital transformation has substantially improved the administration of justice, although legal regulations frequently lag behind the rapid pace of technological innovation (Yunita & Iskandar, 2024).

From the perspective of procedural law, electronic evidence has obtained formal legal recognition through Law Number 11 of 2008 concerning Electronic Information and Transactions (EIT Law), as amended by Law Number 19 of 2016 and most recently by Law Number 1 of 2024. Electronic information, electronic documents, and their printed versions constitute an extension of the evidentiary instruments recognized under Article 184 of the Indonesian Criminal Procedure Code (KUHAP), thereby providing a legitimate legal basis for their application in environmental criminal proceedings (Permana, Arjaya, & Karma, n.d.).

Based on these considerations, this study is important to examine comprehensively the role of information technology in environmental criminal law enforcement in Indonesia and to identify the challenges encountered in its implementation. The findings are expected to contribute to the development of strategic policies aimed at strengthening environmental law enforcement in the digital era.

This study examines two principal issues: first, the role of information technology in environmental criminal law enforcement in Indonesia; and second, the challenges associated with the implementation of information technology in environmental criminal law enforcement in Indonesia. This study aims to analyze the role of information technology in environmental criminal law enforcement in Indonesia and to examine the challenges encountered in its implementation. Furthermore, it seeks to provide recommendations for strengthening environmental law enforcement policies and practices in the digital era.

METHOD

This study employs normative legal research (doctrinal legal research), which examines law as a system of written legal norms by analyzing primary, secondary, and tertiary legal materials. The research adopts both a statutory approach and a conceptual approach.

The statutory approach is utilized to examine relevant legislation, including Law Number 32 of 2009 concerning Environmental Protection and Management, Law Number 8 of 1981 concerning the Indonesian Criminal Procedure Code, and Law Number 11 of 2008 concerning Electronic Information and Transactions, together with its subsequent amendments.

Meanwhile, the conceptual approach is employed to analyze legal concepts relating to electronic evidence and technology-based environmental law enforcement. The legal materials are analyzed qualitatively using a descriptive-analytical method to obtain a comprehensive understanding of the legal issues under investigation.

DISCUSSION

A. The Role of Information Technology in Environmental Criminal Law Enforcement

Conventional environmental criminal law enforcement primarily relies on field patrols and public reports, both of which have limitations in terms of geographical coverage, operational costs, and response time (Rao et al., cited in Aksaraglobal, 2024). These limitations have encouraged the adoption of information technology as a key supporting instrument in three principal aspects of law enforcement: monitoring, prevention, and criminal investigation and prosecution.

1. Satellite Imagery and Remote Sensing

   Remote sensing technology through satellite imagery has long been utilized to monitor land-cover changes and detect hotspots as indicators of forest and land fires. Polar-orbiting satellite systems such as MODIS and VIIRS provide hotspot information, although their temporal resolution remains relatively limited. Consequently, the development of next-generation satellite systems, such as Himawari-8, has significantly improved hotspot detection by offering much higher temporal resolution (Amalia, 2021). Remote sensing data play an essential role as an early warning system, enabling law enforcement agencies to conduct preliminary investigations before carrying out field verification and further criminal investigations into suspected environmental offenses.

2. Unmanned Aerial Vehicles (Drones)

   In addition to satellite imagery, unmanned aerial vehicles (UAVs), commonly known as drones, are increasingly employed by forestry and environmental authorities

to monitor forest areas with greater accuracy and efficiency. Drones are capable of detecting indications of illegal logging, unauthorized land clearing, illegal mining activities, and wildfire hotspots much faster than conventional patrol methods. The collected data can be transmitted directly to law enforcement agencies for immediate follow-up (Ministry of Forestry of the Republic of Indonesia, cited in *Media Indonesia*, 2025).

The primary advantage of drones lies in their ability to access remote and difficult terrain, including peatland ecosystems, where conventional inspections are often impractical. Furthermore, drones equipped with thermal sensors can detect heat sources and smoke at an early stage, thereby accelerating emergency response while simultaneously providing visual evidence to support criminal investigations.

3. Artificial Intelligence (AI)

Artificial Intelligence (AI) plays an important role in processing satellite and drone monitoring data into more accurate and actionable information for law enforcement purposes. The integration of drones, thermal sensors, satellite imagery, and AI-based analytical systems enables the development of highly accurate early warning systems capable of detecting potential forest fires and illegal activities within forest areas (Saromben, 2025).

AI-driven digital transformation has also contributed to a paradigm shift in law enforcement. As legal and technology scholars have argued, technological systems increasingly regulate and shape legal behavior through the principle of "code is law," although legal regulations frequently struggle to keep pace with rapid technological innovation (Yunita & Iskandar, 2024).

4. Electronic Reporting Systems

Electronic reporting systems have become an essential instrument for enhancing public participation in environmental monitoring. These systems enable citizens and field officers to report suspected environmental crimes in real time through mobile applications and digital platforms connected directly to environmental law enforcement agencies.

The utilization of information technology has significantly expanded public access to justice, particularly for communities in remote areas that previously had limited access to conventional environmental monitoring and complaint mechanisms (Yunita & Iskandar, 2024).

5. Electronic Evidence and Digital Forensics

Information technology also plays a crucial role during the evidentiary stage through the use of electronic evidence and digital forensic techniques. Electronic evidence possesses unique characteristics—it exists in digital form, can be easily duplicated, and is susceptible to alteration. Consequently, digital forensic examinations are required to verify the authenticity and integrity of electronic information and documents before they can be admitted as lawful evidence in court (Marsilindo et al., n.d.).

Satellite imagery, drone recordings, GPS metadata, environmental monitoring data, and electronic environmental licensing documents may all serve as supporting evidence that strengthens the prosecution of environmental criminal cases.

B. Legal Recognition of Electronic Evidence in Environmental Criminal Law Enforcement

The legal status of electronic evidence within the Indonesian criminal justice system has undergone significant development since the enactment of Law Number 11 of 2008 concerning Electronic Information and Transactions (EIT Law). Electronic information, electronic documents, and their printed versions constitute an extension of the evidentiary instruments recognized under Article 184 of the Indonesian Criminal Procedure Code (KUHAP). Consequently, criminal proceedings are no longer limited to the five conventional categories of evidence but also recognize electronic evidence as an independent evidentiary category (Hiariej, cited in *OJS Daarul Huda*, n.d.).

This legal recognition was further strengthened through the first amendment to the EIT Law by Law Number 19 of 2016, and subsequently by Law Number 1 of 2024, both of which reaffirm the legal validity and evidentiary force of electronic information and electronic documents. In environmental cases, Article 96 of Law Number 32 of 2009 concerning Environmental Protection and Management also provides legal grounds for the admission of evidence beyond those expressly regulated under the Criminal Procedure Code, including scientific and electronic evidence, provided that such evidence is obtained in accordance with applicable procedural law.

Despite its formal legal recognition, electronic evidence must satisfy both procedural and substantive legal requirements under the EIT Law because digital data remain vulnerable to manipulation and unauthorized modification. Therefore, digital forensic examination constitutes a critical process for preserving the authenticity, integrity, and reliability of

electronic evidence before it is presented and examined before the court (Marsilindo et al., n.d.).

C. Challenges in the Implementation of Information Technology in Environmental Criminal Law Enforcement

Although information technology offers numerous advantages, its implementation in environmental criminal law enforcement in Indonesia continues to face several fundamental challenges.

1. Limited Digital Infrastructure

   Technology-based environmental monitoring through satellites and drones requires adequate digital infrastructure, including reliable internet connectivity, advanced data-processing facilities, and specialized equipment. However, such infrastructure remains unevenly distributed across Indonesia, particularly in remote forest regions that are most vulnerable to environmental crimes.

2. Limited Human Resource Capacity

   The effectiveness of technology-based law enforcement largely depends on the competence of law enforcement personnel in operating advanced technological equipment and interpreting digital data as legal evidence. Nevertheless, digital forensic training and technological literacy among environmental investigators remain relatively limited.

3. Weak Inter-Agency Coordination

   Environmental criminal law enforcement involves multiple governmental institutions, including the Ministry of Environment, the Ministry of Forestry, the Indonesian National Police, the Attorney General's Office, and regional governments. In practice, technological monitoring data are often fragmented across different institutions without standardized mechanisms for data integration and information sharing, thereby reducing the overall effectiveness of law enforcement.

4. Inadequate Technical Regulations

   Technical regulations governing the use of satellite imagery, drones, artificial intelligence, and other digital technologies as evidence in environmental criminal proceedings remain insufficiently developed. Consequently, the admissibility and evidentiary weight of such technologies often depend on judicial discretion on a case-by-case basis. This situation reflects the broader reality that digital transformation

within the justice system frequently advances more rapidly than the legal framework designed to regulate it (Yunita & Iskandar, 2024).

CONCLUSION

Information technology plays a strategic role in environmental criminal law enforcement in Indonesia, particularly in the areas of monitoring, prevention, and evidentiary processes. The utilization of satellite imagery and unmanned aerial vehicles (drones) has significantly enhanced the early detection of forest and land fires, illegal logging, and illegal mining activities. Meanwhile, Artificial Intelligence (AI) has improved the accuracy of processing environmental monitoring data into actionable information that supports law enforcement efforts. Electronic reporting systems have broadened public participation in environmental monitoring, while electronic evidence and digital forensic techniques have strengthened the evidentiary process in criminal proceedings.

The legal status of electronic evidence has been formally recognized under Law Number 11 of 2008 concerning Electronic Information and Transactions, as amended by Law Number 1 of 2024, thereby extending the categories of admissible evidence under the Indonesian Criminal Procedure Code (KUHAP). Nevertheless, the implementation of information technology in environmental criminal law enforcement continues to face several challenges, including inadequate digital infrastructure, limited technological competence among law enforcement personnel, weak inter-agency coordination, and the absence of comprehensive technical regulations governing the use of digital technologies in environmental law enforcement.

RECOMMENDATIONS

The Government should strengthen the technical regulatory framework by establishing clear standards and procedures governing the use of satellite imagery, unmanned aerial vehicles (drones), Artificial Intelligence, and electronic evidence in environmental criminal law enforcement. Such regulations are essential to ensure legal certainty and the admissibility of digital evidence in judicial proceedings.

The capacity of law enforcement officers, particularly environmental investigators, should be enhanced through continuous training in digital forensics, information technology, and the application of emerging technologies in environmental crime investigations.

An integrated environmental information system should be developed to facilitate data sharing and interoperability among relevant institutions. Such integration would enable

environmental monitoring data to be accessed, exchanged, and utilized more effectively by all environmental law enforcement agencies.

Regional governments should be encouraged to invest in digital infrastructure, particularly in areas that are highly vulnerable to environmental crimes. Strengthening digital infrastructure will support the broader implementation of information technology in environmental monitoring and contribute to more effective environmental criminal law enforcement throughout Indonesia.

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THE EFFECT OF SULFUR APPLICATION ON THE GROWTH, YIELD, AND ANTIOXIDANT ACTIVITY OF SHALLOT (*Allium ascalonicum* L.) ON FLOATING CULTURE

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Abstract

Shallot (Allium ascalonicum L.) is one of the horticultural crops classified as a spice vegetable that is widely consumed and highly demanded by the community. Floating cultivation is an innovative agricultural system developed to address farming constraints in areas characterized by aquatic geographical conditions. This study aimed to determine the effect of sulfur application on the growth, yield, and antioxidant compounds of the Bima Brebes shallot variety under a floating cultivation system. The study was conducted in Indralaya District, Ogan Ilir Regency, South Sumatra Province, Indonesia, at an altitude of approximately 10 meters above sea level. The study employed a Completely Randomized Design (CRD) with sulfur application treatments consisting of: A1 (0 kg ha^{-1}), A2 (30 kg ha^{-1}), A3 (60 kg ha^{-1}), A4 (120 kg ha^{-1}), A5 (240 kg ha^{-1}). The results of this study showed that the optimum leaf length was 37.17 cm, achieved with an optimum fertilizer application rate of 116.67 kg ha^{-1}. The optimum number of leaves was 26.9 strands obtained at a fertilizer application rate of 121.20 kg ha^{-1}. The optimum plant growth rate was 1.08 kg ha^{-1} day^{-1} achieved with a fertilizer application rate of 97.23 kg ha^{-1}. The optimum fresh weight per plant was 54.7 g obtained at a fertilizer application rate of 97.11 kg ha^{-1}. The optimum total chlorophyll content was 9.58 mg L^{-1} achieved with a fertilizer application rate of 114.00 kg ha^{-1}, while the optimum antioxidant activity was 7215.9 obtained at a fertilizer application rate of 127.03 kg ha^{-1}.

Keywords: Floating culture; Shallot; Sulfur

INTRODUCTION

Shallot (*Allium ascalonicum* L.) is one of the horticultural crops classified as a spice vegetable that is widely consumed and highly demanded by the community. Shallots are commonly used as a flavor enhancer and seasoning in various food products, as well as a herbal medicine with pharmacological effects that contribute to human health. (Octaviani *et al.,* 2019). According to Aryanta., (2019) kandungan gizi dan senyawa yang terkandung bawang merah memiliki fungsi preventif jika digunakan sebagai bahan makanan dan memiliki fungsi kuratif jika digunakan sebagai obat herbal. Salah satu senyawa yang terkandung pada bawang merah adalah antioksidan. Antioksidan merupakan adalah senyawa yang dapat mencegah atau memperlambat kerusakan akibat radikal bebas terhadap zat lain di dalam tubuh (Gulcin, 2020). They function as electron donors, thereby inhibiting oxidation reactions through the neutralization and binding of free radicals (Figueiredo-González et al., 2017).

Shallot production in South Sumatra continues to experience fluctuations, one of the contributing factors being the region's geographical characteristics, as a significant portion of its area consists of wetlands, including approximately 285,941 ha of lebak swamp land and 273,919 ha of tidal swamp land (Badan Pusat Statistik Provinsi Sumatera Selatan, 2025). Therefore, several researchers have developed community-based innovations that can be implemented in inundated areas, one of which is floating agriculture, a cultivation system designed for waterlogged environments (Habiba *et al*., 2022; Isfat & Raihan, 2022).

Floating cultivation is an innovative agricultural system developed to address farming challenges in regions characterized by aquatic geographical conditions. This cultivation method ensures a stable water supply, thereby eliminating the need for additional irrigation, unlike conventional farming systems in which crops require regular watering (Idly *et al*., 2023). The technique has been reported to enhance local economic development while facilitating plant growth and productivity (Pavel *et al*., 2014). According to Susilawati *et al*., (2022) floating cultivation not only promotes plant growth but also serves as a preventive measure against flooding in agricultural production areas. However, successful shallot cultivation depends not only on the cultivation technique employed but also on the adequate supply of essential nutrients, particularly sulfur.

Sulfur is an essential nutrient that plays a vital role in the synthesis of the amino acids cystine, cysteine, and methionine into proteins required for shallot growth (Mustikawati *et al.*, 2020). Sulfur application has been reported to improve both the quantity and quality of crop yields (Mawardiana *et al*., 2021). In addition sulfur fertilization can reduce CO_2 emissions by up to 57.4% during various growth stages of shallot plants (Suwandi *et al*., 2016). According to Idly *et al*., (2024) the application of 60 kg ha^{-1} sulfur can enhance the growth and yield of shallots. Based on the aforementioned information, it is necessary to conduct a study to evaluate the effect of sulfur application on the growth, yield, and antioxidant compounds of the Bima Brebes shallot variety cultivated under a floating cultivation system.

METHOD

The research was conducted in Indralaya District, Ogan Ilir Regency, South Sumatra Province, at an altitude of 10 meters above sea level, with the following coordinates 3°13'11.1"S 104°38'52.2"E.

Toolst and Materials

Tools : 1) Stationery supplies; 2) Pond/water reservoir; 3) Polybags measuring 30 × 25 cm; 4) Bottle-based floating rafts; 4) Measuring tape, 5) Ruler; 6) Digital caliper; 7) camera; 8) Analytical balance; 9) Hoel; 10) Machete; 11) Oven; 12) Spectrofotometer UV-Vis; 13) Glass ware; 14) Filter Paper.

Bahan : 1) Chicken manure; 2) Shallot (Allium ascalonicum L.) bulbs of the Bima Brebes variety; 3) Soil; 4) ZA; SP-36, KCL dan NPK (16:16:16); 5) Fungicida; 6) Shallot extract; 7) Ethanol.

Cara Kerja

The raft was made from 100 1.5L mineral water bottles per raft. The raft was constructed by calculating the raft's buoyancy against the weight of the polybag using Archimedes' law, which is the formula: **Bottle Volume x Water Density x Gravity > Mass x Gravity** (Idly *et al*., 2024.).

Prior to planting, the shallot bulbs were trimmed by removing approximately one-third of the upper portion. This practice was carried out to accelerate shoot emergence and stimulate the development of lateral bulbs (Nazirah & Maulana, 2020). Subsequently, the bulbs were soaked in a Dithane fungicide solution containing 80% Mancozeb as the active ingredient at a concentration of 3 g L^{-1} of water for 5 minutes. Planting was performed by inserting the shallot bulbs into the planting holes using a screw-like twisting motion, ensuring that the tip of the seed bulb remained level with the soil surface (Tandi *et al*., 2021).

Research Methods

The experiment was arranged using a Completely Randomized Design (CRD) consisting of five treatments and three replications. The sulfur application rates evaluated were: A1 (0 kg ha^{-1}), A2 (30 kg ha^{-1}), A3 (60 kg ha^{-1}), A4 (120 kg ha^{-1}), and A5 (240 kg ha^{-1}). The data obtained from the study were analyzed using orthogonal polynomial regression with the aid of RStudio software.

The variables observed in this study included leaf length (cm), number of leaves per plant (leaves $plant^{-1}$), Air-dry weight (g). plant growth rate (kg ha^{-1} day^{-1}), total chlorophyll content (mg L^{-1}), and antioxidant activity (ppm)

The plant growth rate (PGR) was calculated using the following equation:

$$\mathbf{CGR} = \frac{W2 - W1}{(T2 - T1)}$$

Keterangan :
W1 : Initial dry weight
W2 : Final dry weight
T1 : Time of the first observation
T2 : Time of the final observation
(Yuniar *et al.,* 2021)

Chlorophyll content was analyzed using the *Winterman de Mots* method, which involved weighing 0.25 g of red onion leaves and grinding them using a mortar. The sample was extracted by adding 25 ml of 96% alcohol until all the chlorophyll was dissolved. The extract is filtered with filter paper. The filtered extract is placed into a cuvette and measured using a spectrophotometer at wavelengths of 649 nm and 665 nm (Putri *et al*., 2022; Wintermans & De Mots, 1965). The results of the absorbance measurement were then converted into mg/L using the formula below :

$$\textbf{Total chloroghyill (mg/L)} = (20 \times OD_{646} + 76{,}1 \times OD_{663})$$

The phytochemical analysis conducted was an antioxidant activity test using the DPPH method with a UV-Vis spectrophotometer at a wavelength of 517 nm and determining the IC_{50} value. To calculate the IC_{50} value, a linear regression method can be used by creating a curve consisting of sample concentration and % antioxidant inhibition. From this curve, an equation of the form y = ax + b is obtained. To obtain the % antioxidant capacity value, it can be calculated using the formula in the equation.

$$\textbf{Inhibisi (\%)} = 1 - \frac{absorbansi\ sampel}{absorbansi\ kontrol} x\ 100\ \% \qquad (1)$$

From the equation y = ax + b, the IC_{50} value (x) can be calculated using the formula in the linear regression equation.

$$\mathbf{IC_{50}} = \frac{50 - b}{a} \qquad (2)$$

(Pramitha & Sundari, 2020).

FINDINGS AND DISCUSSION

Leaf Length (cm)

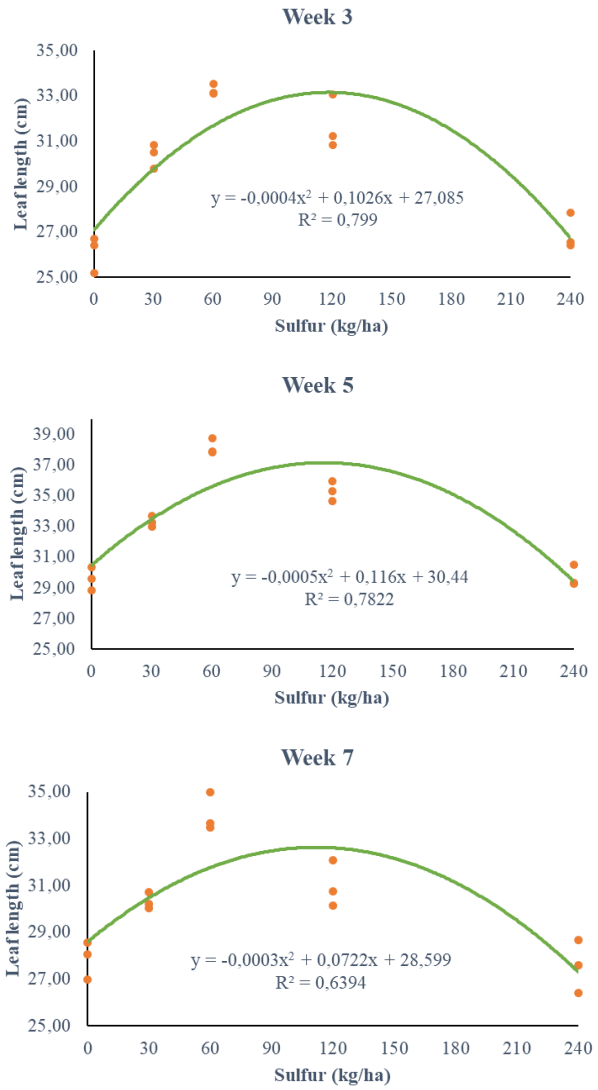


Figure 1 : Results of the orthogonal polynomial regression test for leaf length in the 3rd week, 5th week, and 7th week.

Based on the results of the regression test (Figure 1), the leaf length in the 3rd week obtained a coefficient of determination (R^2) of 0.799, which falls into the strong category where the leaf length is influenced by 79% by the application of sulfur. The results of the follow-up test in the 5th week obtained a coefficient of determination (R^2) of 0.7822, which falls into the strong category where the leaf length is influenced by 78% by the application of sulfur. The results of the follow-up test in the 7th week obtained a coefficient of determination (R^2) of 0.639, which falls into the moderate category where the leaf length is influenced by 64% by the application of sulfur. The optimum sulfur value is 116.67 kg ha^{-1} with an optimum leaf length of 37.17 cm. The growth and development of plants are greatly influenced by sulfur, which is a component of very important compounds such as glutathione, coenzymes, vitamins, and phytohormones that can affect the strength and growth of plants (Mustikawati *et al*., 2020). According to (Hasanah *et al*., 2021) sulfur can enhance the vegetative growth of plants because S is an important part of ferredoxin, a complex compound contained in chloroplasts that is used in carbohydrate catabolism. The application of sulfur can affect the quantity and quality of the soil, so the proper application of sulfur can enhance the metabolic processes in plants (Al-Amri & Al-Abdaly, 2021).

Number of Leaves (strands)

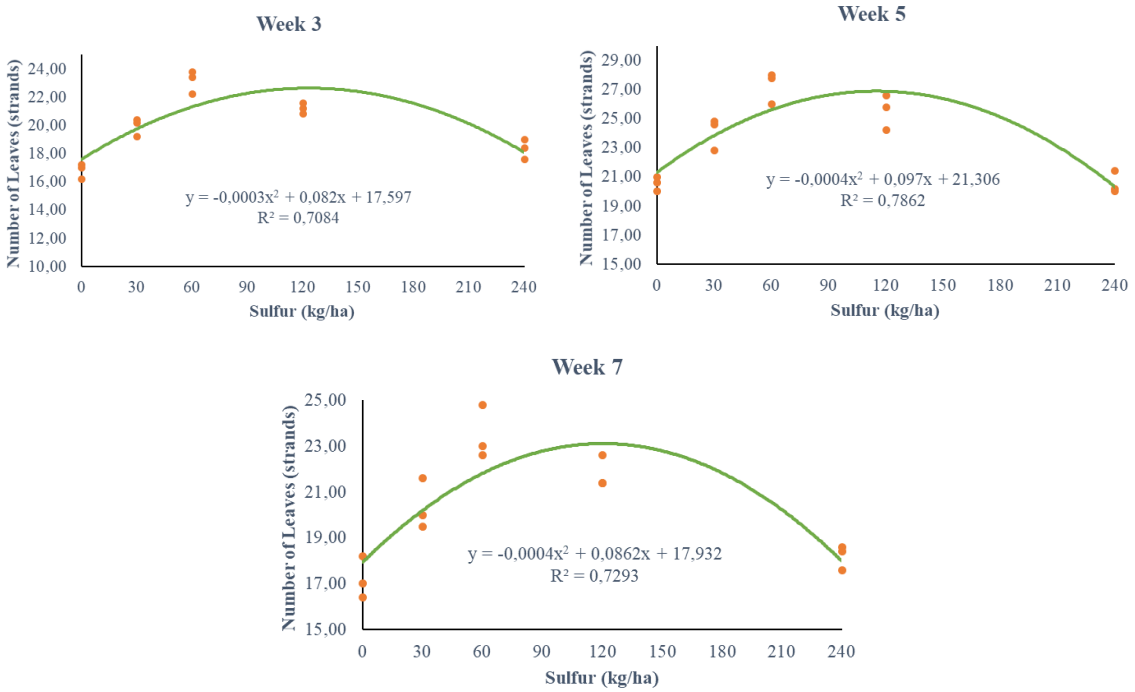


Figure 2 : Results of the orthogonal polynomial regression test on the number of leaves in the 3rd week, 5th week, and 7th week.

Based on the regression test results (Figure 2), the number of leaves in the third week had a coefficient of determination (R^2) of 0.7084, which falls into the moderate category where the number of leaves is influenced by 71% by the application of sulfur. The results of the follow-up test in the fifth week showed a coefficient of determination (R^2) of 0.7862, which falls into the strong category where the number of leaves is influenced by 79% by the application of sulfur. The results of the follow-up test in the seventh week showed a coefficient of determination (R^2) of 0.7293, which falls into the moderate category where the length of the leaves is influenced by 73% by the application of sulfur. The optimum sulfur value is 131.67 kg ha^{-1} with an optimum leaf length of 35.7 cm. According to Mustikawati *et al.*, (2020) the application of sulfur has the best effect on the number of leaves. According to (Agustin *et al*., 2020) plants require balanced fertilization during the vegetative phase. The growth characteristics of plants are controlled by many factors, one of which is influenced by nutrient absorption and availability (Abduh et al., 2021).

Plant Growth Rate (kg $ha^{-1}day^{-1}$)

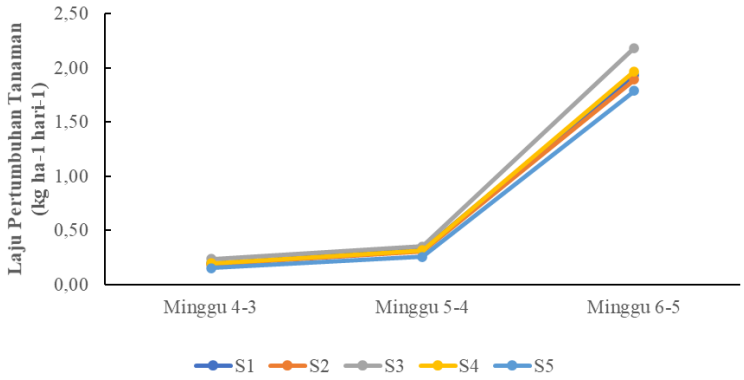


Figure 3 : Graph of Plant Growth Rate Increase from Week 3 to Week 6

Based on the graph (Figure 3), the increase in the growth rate of the plants from week 3 to week 6 experienced an increase every week. The increase in the growth rate of the plants from week 3 to week 5 was not very significant, but in week 6, the growth rate of the plants increased because, by that week, the plants were already at the tuber formation stage.

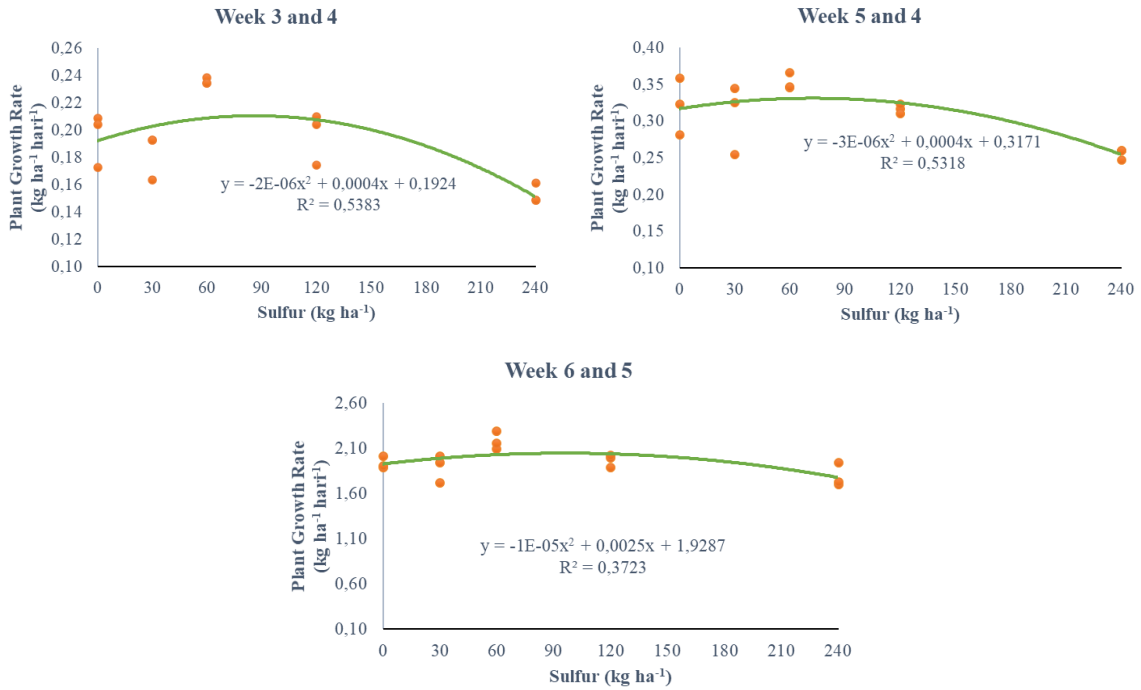


Figure 4 : Results of the orthogonal polynomial regression test for Plant Growth Rate (kg ha-1day-1) weeks 4-3, weeks 5-4, and weeks 6-5.

Based on the results of the regression test (Figure 4), the plant growth rate in week 4-3 obtained a coefficient of determination (R^2) of 0.5383, which falls into the moderate category where the plant growth rate is influenced by 54% due to sulfur application. The results of the follow-up test in week 5-4 obtained a coefficient of determination (R^2) of 0.5318, which also falls into the moderate category where the plant growth rate is influenced by 53% due to sulfur application. The results of the follow-up test in week 6-5 obtained a coefficient of determination (R^2) of 0.3723, which falls into the moderate category where the leaf length is influenced by 40% due to sulfur application. The optimum sulfur value is 97.23 kg ha^{-1} with an optimum growth rate of 1.08 kg ha^{-1} day^{-1}. Sulfur is an important element in the provision of other nutrients, especially in the fixation of nitrogen in plants Sulfur plays a role in photosynthesis and the electron transport system, as well as in coenzymes and prosthetic groups such as ferredoxin, which are important for nitrogen assimilation (Abadie & Tcherkez, 2019). The influence of sulfur application on cell division, enlargement, and elongation results in overall improvements in plant organs associated with faster and more uniform vegetative and generative growth of the plants (Patel *et al*., 2020).

Air-Dry Weight (g)

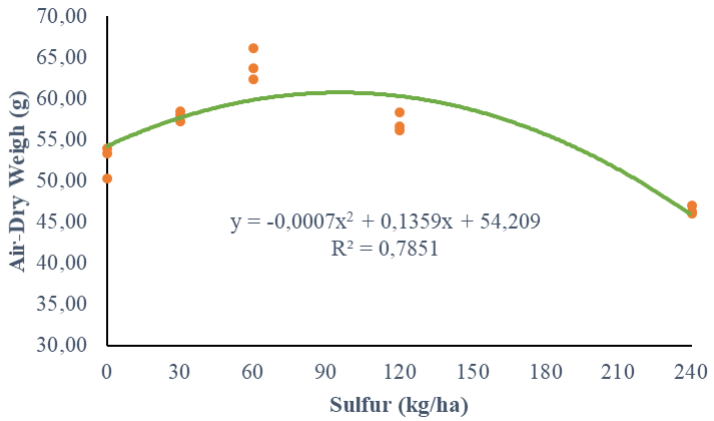


Figure 5 : Results of the orthogonal polynomial regression test for Air-dry weight (g)

Based on the results of the regression test (Figure 5), the coefficient of determination (R^2) for the weight of the skip is 0.7851, which falls into the strong category where the weight of the skip is influenced by 79% by the application of sulfur. The optimum sulfur value is 97.11 kg ha^{-1} with an optimum skip weight of 54.7 g. Sulfur is an element that plays a role in the composition of cell protoplasm and is highly needed in the photosynthesis process (Abadie & Tcherkez, 2019). The increase in photosynthesis during the generative phase is aimed at the formation and filling of bulb (Mustikawati *et al*., 2020). The increase in red onion bulbs due to the application of sulfur can be linked to its supply in the synthesis of coenzyme A and amino acids for protein production and the formation of specific disulfide bonds associated with the structural characteristics of plant protoplasm, thereby promoting an increase in bulb diameter and weight (Lacerda et al., 2022).

Total Chlorophyill (mg L^{-1})

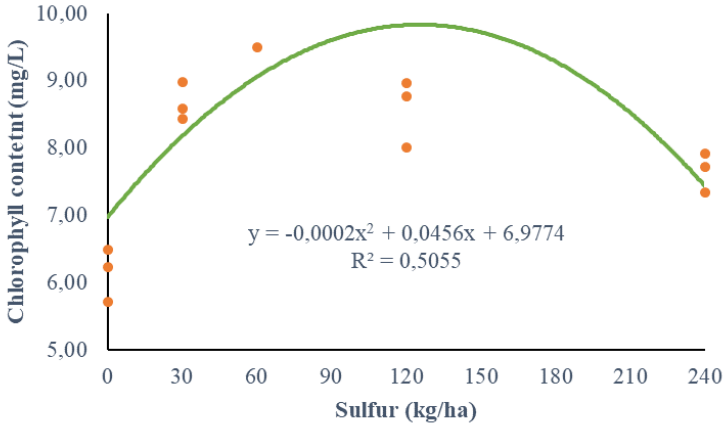


Figure 6 : Results of the orthogonal polynomial regression test for total chlorophyll (mg L^{-1})

Based on the results of the regression test (Figure 6), the chlorophyll content obtained a coefficient of determination (R^2) of 0.5055, which falls into the moderate category where the chlorophyll content is influenced by 51% by the application of sulfur. The optimum sulfur value is 114 kg ha^{-1} with an optimum chlorophyll content of 9.58 mg L^{-1}. Sulfur is an essential nutrient needed by plants that is related to the availability of chlorophyll in plants (Tukan *et al*., 2019). According to Gilani *et al.,* (2021) the use of sulfur causes an increase in photosynthetic pigments in plants. (Wahyana et al., 2017) stated that the deficiency or excess of one nutrient will affect all other nutrients.

Aktivitas Antioksidan (ppm)

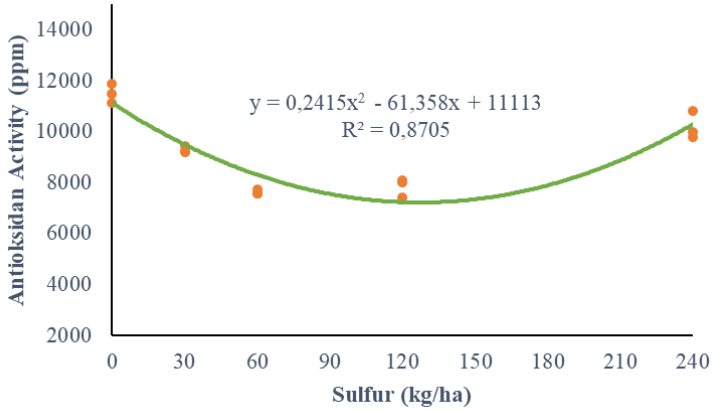


Figure 7 : Results of the orthogonal polynomial regression test on antioxidant activity (ppm)

Based on the results of the regression test (Figure 7), the antioxidant activity obtained a coefficient of determination (R^2) of 0.8705, which falls into the strong category where the antioxidant activity is influenced by 87% by the application of sulfur. The optimum sulfur value is 127.03 kg ha^{-1} with an optimum antioxidant activity of 7215.9 ppm. According to (Sukweenadhi et al., 2020) an IC_{50} value >200 indicates very weak antioxidant activity. The weak antioxidant activity is caused by many factors such as the high water content in red onions and the extraction process, which is not yet very pure and still rough, so compounds like flavonoids, allicin, etc., are still bound to glycoside groups (Hikmah & Anggarani, 2021). Meanwhile, according to (Septiani *et al.*, 2020) the decrease in antioxidant activity can occur during the processing stage, contact with air and light, causing compounds that include antioxidants like allicin and phenolic to oxidize.

CONCLUSION

The results of the conducted research can be concluded that the application of sulfur has a very strong effect on growth, yield, and antioxidant activity in floating cultivation. For the leaf length variable, sulfur had a very strong effect in the 3rd week (R^2: 0.799), the 5th week (R^2: 0.782), and a moderate effect in the 7th week (R2: 0.639). The number of leaves can be influenced by sulfur moderately in the 3rd week (R^2: 0.7084), the 7th week (R^2: 0.7293), and very strongly in the 5th week (R^2: 0.7862). The plant growth rate can be influenced by sulfur moderately in the 4th-3rd week (R2: 0.5383), the 5th-4th week (R^2: 0.5318), and very weakly in the 6th-5th week (R^2: 0.3723). The dry weight is very strongly influenced by sulfur (R^2: 0.7851). The chlorophyll content can be influenced by sulfur moderately (R^2: 0.5055), and the antioxidant activity can be very strongly influenced by sulfur (R^2: 0.8705).

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OPTIMIZATION OF CHICKEN MANURE AND ZA FERTILIZER DOSAGE ON THE YIELD AND PRODUCTIVITY OF RED ONION PLANTS IN A FLOATING CULTIVATION SYSTEM

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Abstract

The floating cultivation system is an alternative technology for the development of shallots in flooded land. This study aims to determine the optimal combination of chicken manure and ZA fertilizer doses on the yield and productivity of shallots in a floating cultivation system. The research used a factorial Randomized Block Design with doses of chicken manure (0, 1, 2, and 3 kg per plant) and ZA fertilizer (0, 2, 5, and 7 g per plant). The research results show that the interaction of both fertilizers significantly affects tuber volume, tuber number, fresh tuber weight, air-dry tuber weight, and productivity. The combination of 2 kg of manure per plant and 5 g of ZA fertilizer per plant resulted in the highest yield and productivity. The increase in yield is supported by the increased availability of nutrients, especially nitrogen and sulfur, which play a role in tuber formation and biomass accumulation. Thus, the combination is recommended to increase red onion production in floating cultivation systems.

Keywords: shallots, productivity, chicken manure, ZA fertilizer, floating cultivation sistem.

INTRODUCTION

Shallots (Allium ascalonicum L.) are one of the leading horticultural commodities with high economic value and play an important role in meeting the food needs of the Indonesian people. Shallots are widely used as cooking spices as well as raw materials in the food and pharmaceutical industries. The increase in demand for shallots from year to year has not been fully matched by an increase in production, so innovative cultivation technologies capable of sustainably increasing productivity are needed.

South Sumatra Province has vast potential for swamp land development in the agricultural sector. However, swampy land generally has various obstacles such as prolonged flooding, low soil aeration, and limited nutrient availability. These conditions can hinder root development and reduce the plant's ability to absorb nutrients, resulting in low productivity of red onions. Therefore, cultivation technology that can support plant growth in flooded conditions is needed.
One of the technologies that can be applied is the floating cultivation system. Floating cultivation is a planting technique using rafts or planting media that float on the water's surface, allowing plants to grow in submerged conditions. This system can maintain media moisture stability while also improving aeration at the root zone. Floating cultivation has been widely developed in swampy areas and flood-prone regions because it can optimize the use of marginal land (Lakitan et al. 2018).

The success of shallot cultivation in the floating system is greatly influenced by nutrient management. One of the widely used sources of nutrients is chicken manure. Chicken manure contains nitrogen (N), phosphorus (P), and potassium (K) elements that are utilized by plants for growth and development. In addition, the organic matter contained in it can improve the physical, chemical, and biological properties of the growing medium, thereby supporting root growth and nutrient absorption (Susilawati et al., 2018).

In addition to the main macro elements, sulfur (S) also plays an important role in the growth and formation of shallot bulbs. Sulfur functions in protein synthesis, chlorophyll formation, and the activity of various plant enzymes. One of the commonly used sources of sulfur is ZA fertilizer (Ammonium sulfate). The application of ZA fertilizer can increase nitrogen utilization efficiency while supporting the development of shallot bulbs (Hasanah et al., 2021).

Research on the combination of chicken manure and ZA fertilizer in floating cultivation systems of shallots is still limited, especially in the swampy land conditions of South Sumatra. Therefore, this study was conducted to determine the effect of applying chicken manure and ZA fertilizer on the yield and productivity of shallot plants in floating cultivation systems.

METHOD

Place and Time of Research

The research was conducted from July to September 2024 in the Kertapati district, Palembang City, South Sumatra.

Materials and Tools

The materials used in this research include Bauji variety red onion seed tubers, chicken manure, ZA fertilizer, and soil. The tools used include writing instruments, thread, bamboo, jerrycan, measuring tape, nylon rope, analytical balance, ruler, and polybags.

Research Design

The research uses a factorial Randomized Block Design (RBD) consisting of two factors with three replications.
The first factor is the dose of chicken manure, consisting of:
A_0 = 0 kg plant $^{-1}$
A_1 = 1 kg plant $^{-1}$
A_2 = 2 kg plant $^{-1}$

A_3 = 3 kg plant $^{-1}$

The second factor is the ZA dose, consisting of:
Z_0 = 0 g plant $^{-1}$
Z_1 = 2 g plant $^{-1}$
Z_2 = 5 g plant $^{-1}$
Z_3 = 7 g plant $^{-1}$

Research Implementation
The floating cultivation system was created using floating rafts placed on the surface of stagnant water. The planting media is placed into polybags and arranged on the floating raft. Chicken manure is applied before planting according to the treatment dosage, while ZA fertilizer is given during the plant growth phase according to the treatment. Shallots are planted and maintained thru activities such as watering, fertilizing, and pest and disease control according to cultivation standards.

Observation Parameters
The observed parameters include: Fresh weight of the tuber (g), Diameter of the tuber (cm), Fresh weight of the tuber (g), Air-dry weight of the tuber (g), Number of tubers per plant, Volume of the tuber (cm3), Productivity per hectare (ton ha^{-1}).

Data Analysis
The research data were analyzed using orthogonal polynomial variance analysis with R Studio and Excel software. Post hoc tests were conducted using orthogonal polynomial regression and Tukey's LSD (*Least Significant Difference*).

RESULTS AND DISCUSSION

The Influence of Chicken Manure and ZA Fertilizer on the Fresh Weight of Shallots

The research results show that the application of chicken manure and ZA fertilizer has a significant effect on the fresh weight of shallots in a floating cultivation system. The treatment of 2 kg of chicken manure per plant combined with 5 g of ZA fertilizer per plant resulted in the highest fresh weight compared to other treatments. These results indicate that the combination of organic fertilizer and sulfur fertilizer can enhance the vegetative growth of red onion plants. (Figure 1).

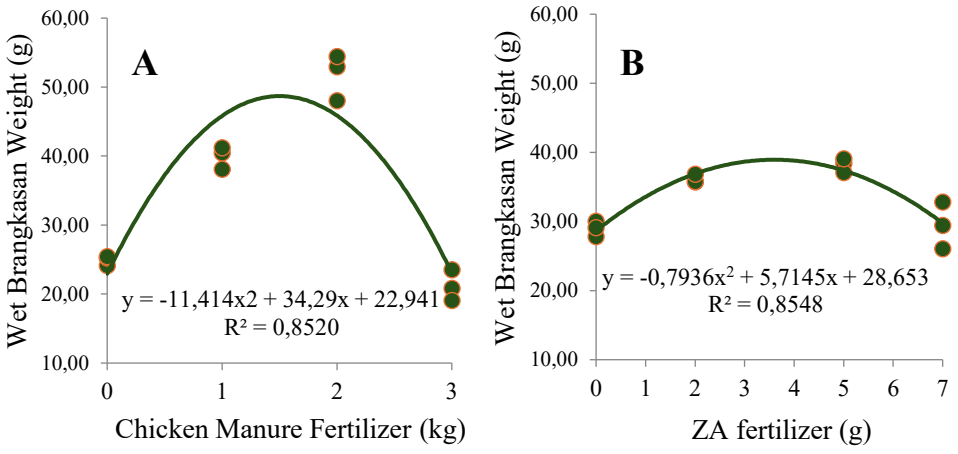


Figure 1. Results of the orthogonal polynomial regression test on the wet weight of the brangkasan influenced by the application of chicken manure fertilizer (A) and ZA fertilizer (B).

The increase in wet biomass indicates that the combination of chicken manure and ZA can support the vegetative growth of shallots in a floating cultivation system. In conditions where the media is always moist, the availability of organic matter from chicken manure helps maintain the structure of the growing media and enhances the activity of microorganisms involved in the mineralization of nutrients. This condition allows the roots to absorb water and nutrients more efficiently, thereby optimizing biomass formation.

The role of ZA fertilizer is not only as a source of nitrogen but also sulfur, which is important in the synthesis of plant amino acids and proteins. Hasanah et al. (2021) explain that sulfur plays a role in chlorophyll formation and enzyme activity, thereby supporting the rate of plant photosynthesis. With the increased capacity of photosynthesis, the accumulation of vegetative biomass becomes higher. On the contrary, applying fertilizers at excessively high doses tends to reduce the weight of the wet biomass due to nutrient imbalance and decreased efficiency in nutrient utilization by the plants. These findings are in line with Nadiah et al. (2024), who state that organic and inorganic fertilization should be applied at optimal doses to avoid antagonistic effects between nutrient elements.

The Influence of Chicken Manure and ZA Fertilizer on Bulb Diameter

Bulb diameter is one of the important parameters in determining the quality and productivity of shallots. The research results show that the application of chicken manure and ZA fertilizer has a significant effect on tuber diameter in the floating cultivation system. The best treatment was obtained with a combination of 2 kg of chicken manure per plant and 5 g of ZA fertilizer per plant. (Figure 2)

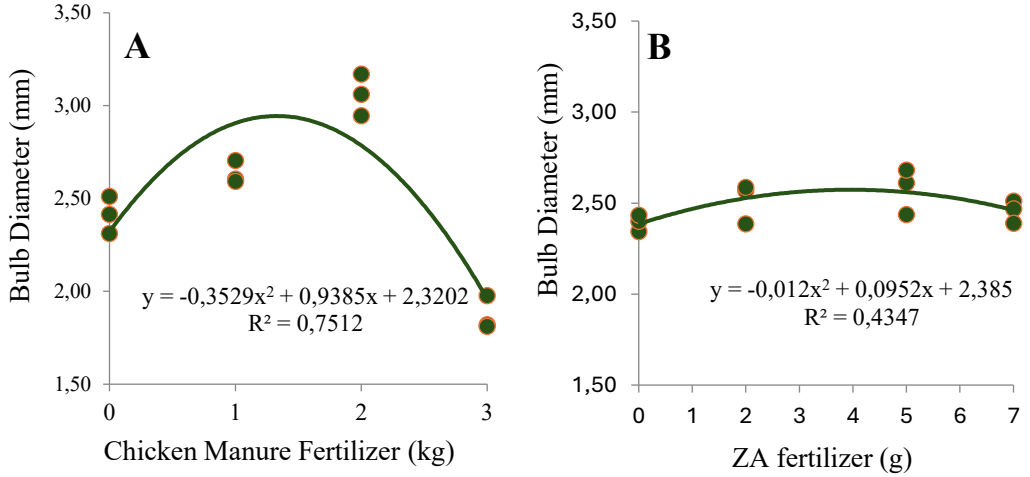


Figure 2. Results of the orthogonal polynomial regression test on tuber diameter influenced by the application of chicken manure fertilizer (A) and ZA fertilizer (B).

The increase in tuber diameter indicates that the availability of nutrients during the tuber formation process is in optimal condition. Nitrogen derived from chicken manure enhances leaf growth as the main source of photosynthates. The photosynthates produced are then translocated to the tuber as a storage organ.

Phosphorus and potassium contained in chicken manure also play a role in tuber formation. Phosphorus supports root development and energy transfer, while potassium functions in the translocation of photosynthesis products to the tuber (Mustikawati et al., 2020). Sulfur from ZA fertilizer increases nitrogen use efficiency and supports protein synthesis involved in tuber development (Sakhidin et al., 2022).

Stable humidity conditions in the floating cultivation system allow for the continuous absorption of nutrients, thereby supporting the growth of tubers.

The Influence of Chicken Manure and ZA Fertilizer on Fresh Bulb Weight

The application of chicken manure and ZA fertilizer significantly affects the fresh bulb weight of red onions. The highest fresh bulb weight was obtained from the combination of 2 kg of chicken manure per plant and 5 g of ZA fertilizer per plant. (Figure 3).

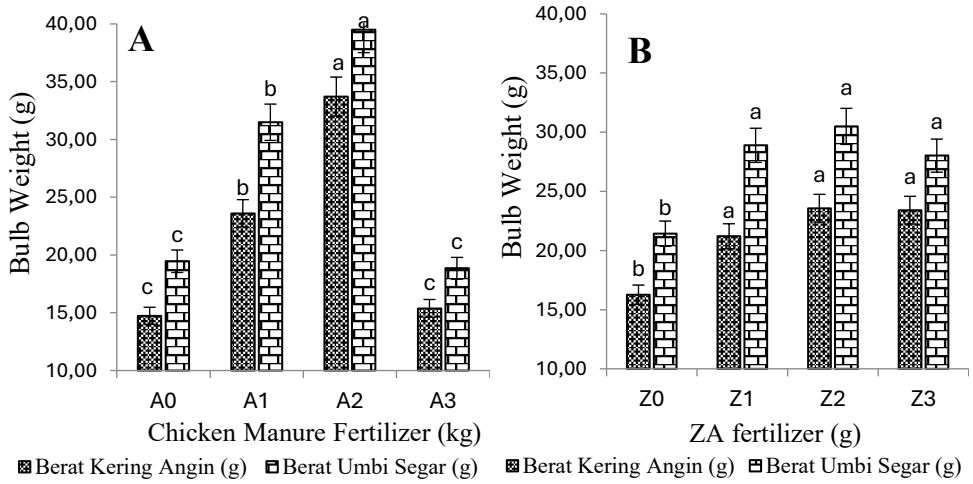


Figure 3. Average fresh tuber weight and air-dry tuber weight with various doses of chicken manure (A) and ZA fertilizer (B). (BNT 5% fresh tuber weight = 4.14 and air-dry weight = 1.80).

The weight of fresh tubers reflects the accumulation of biomass and water content in the tuber tissue. The floating cultivation system provides relatively stable moisture conditions, so the plants experience lower water stress compared to conventional cultivation on dry land. This condition allows the nutrient absorption process to occur more continuously (Baka et al., 2020).

Chicken manure fertilizer increases the availability of macro nutrients and improves the physical properties of the growing medium, while sulfur from ZA fertilizer supports chlorophyll formation and plant metabolism. Mustikawati et al. (2020) stated that sulfur plays an important role in the formation of chlorophyll and the photosynthesis process of red onions. Therefore, the increase in fresh bulb weight at the optimum dose indicates that the combination of the two fertilizers is capable of effectively supporting bulb formation under floating cultivation conditions.

The Influence of Chicken Manure and ZA Fertilizer on the Weight of Air-Dry Tubers.

The weight of the dry air bulb is a parameter that describes the accumulation of biomass from photosynthesis stored in the bulb after the moisture content decreases. The research results show that the application of chicken manure and ZA fertilizer has a significant effect on the air-dry bulb weight of red onions in the floating cultivation system. The combination of 2 kg

of chicken manure per plant and 5 g of ZA fertilizer per plant resulted in the highest dry bulb weight compared to other treatments. These results indicate that the combination of the two fertilizers can enhance the efficiency of tuber formation and filling. These conditions are in line with research findings that show an increase in the weight of fresh tubers and the weight of air-dried tubers with the combination of optimal doses of chicken manure and ZA fertilizer. (Figure 3).

The weight of the air-dried tuber reflects the accumulation of dry matter resulting from photosynthesis stored in the tuber after the moisture content decreases. The increase in this parameter indicates that the fertilizer treatment not only enhances the water content of the tuber but also increases the accumulation of carbohydrates and tissue-forming compounds.

Hardiansyah and Guritno (2022) state that the availability of sufficient nitrogen and sulfur can increase carbohydrate accumulation in plant storage organs. Sulfur plays a role in the formation of amino acids such as cysteine and methionine, which support enzyme activity and plant metabolism. Thus, the increase in the dry weight of the tubers reflects the physiological efficiency of the plant in converting photosynthesis products into food reserves stored in the tubers.

The Influence of Chicken Manure and ZA Fertilizer on the Number of Tubers.
The number of tubers is one of the main yield components that determine the productivity of shallots. The research results show that the application of chicken manure and ZA fertilizer has a significant effect on the number of bulbs per plant. The combination of 2 kg of chicken manure per plant and 5 g of ZA fertilizer per plant resulted in the highest number of tubers, approximately 5.53 tubers per clump. This result shows that the availability of nutrients at that dosage is capable of supporting the formation of shoots that then develop into tubers. (Figure 4).

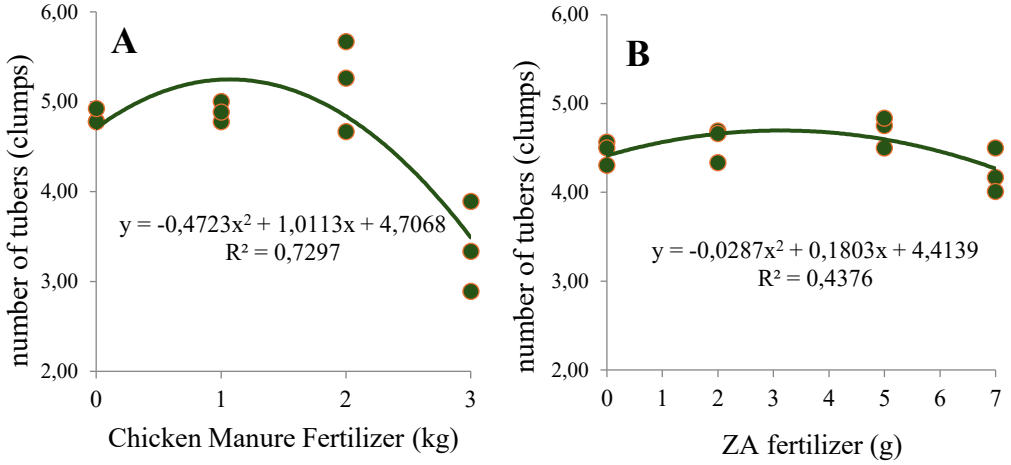


Figure 4. Results of the orthogonal polynomial regression test on the number of tubers influenced by the application of chicken manure fertilizer (A) and ZA fertilizer (B).

The number of tubers is greatly influenced by the number of tillers formed during the vegetative phase. Chicken manure fertilizer increases nutrient availability and soil microorganism activity, thereby stimulating the formation of lateral shoots. These shoots then develop into tillers and eventually form new bulbs.

According to Nanda et al. (2022), the number of shallot bulbs is closely correlated with the

number of tillers formed during the vegetative phase. Sulfur from ZA fertilizer also supports the process of cell division and differentiation necessary for the formation of new shoots. Therefore, the combination of chicken manure fertilizer and ZA at the optimum dosage results in a higher number of tubers compared to other treatments. On the other hand, excessive fertilization can cause physiological stress, leading to suboptimal formation of shoots and tubers.

The Influence of Chicken Manure and ZA Fertilizer on Bulb Volume.
Bulb volume is an important indicator that describes the size and level of development of red onion bulbs. The research results show that the application of chicken manure and ZA fertilizer has a significant effect on tuber volume in the floating cultivation system. The highest tuber volume was obtained with the combination of 2 kg of chicken manure per plant and 5 g of ZA fertilizer per plant, indicating a synergy between these two nutrient sources in supporting tuber enlargement. In this study, the highest tuber volume reached 17.89 cm^3 with a specific treatment combination that was not significantly different from other optimal dose combinations. (Figure 5).

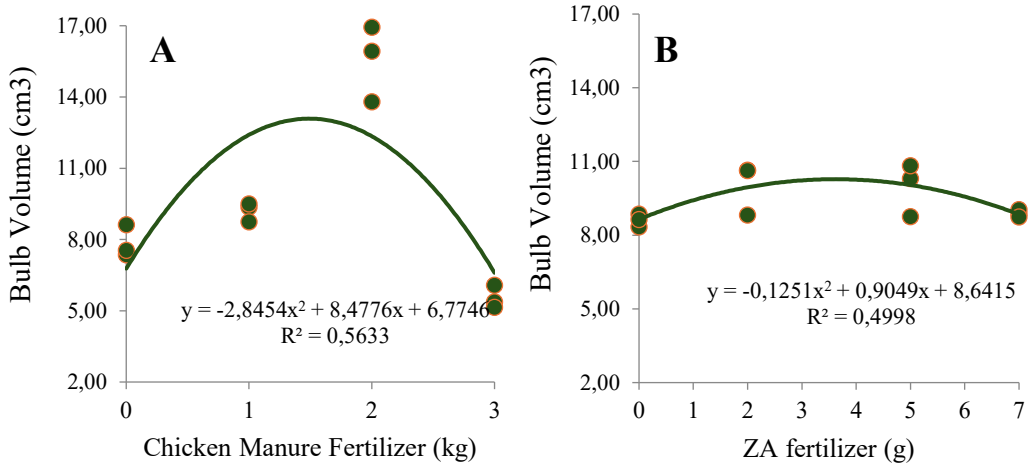


Figure 5. Results of the orthogonal polynomial regression test on tuber volume influenced by the application of chicken manure fertilizer (A) and ZA fertilizer (B).

The volume of the tuber describes the overall development level of the tuber tissue. The increase in tuber volume under optimal treatment indicates that cell division and enlargement occur more intensively. In addition to providing macro nutrients, chicken manure fertilizer also improves the structure of the growing medium, allowing the roots to develop better. Ramadhani et al. (2022) state that tuber volume is directly proportional to photosynthetic activity and the plant's ability to translocate photosynthates to storage organs. Sulfur from ZA fertilizer increases chlorophyll formation and photosynthetic enzyme activity, thereby supporting the tuber filling process. Thus, the increase in tuber volume is the result of the synergy between the improvement of the growing medium by organic fertilizers and the enhancement of plant metabolism efficiency by ZA fertilizer.

The Influence of Chicken Manure and ZA Fertilizer on Productivity per Hectare.
Productivity per hectare is the main indicator of cultivation success. The research results show that chicken manure and ZA fertilizer can significantly increase the productivity of shallots in a floating cultivation system. The highest productivity was obtained with the treatment of 2 kg of chicken manure per plant combined with 5 g of ZA fertilizer per plant. (Figure 6).

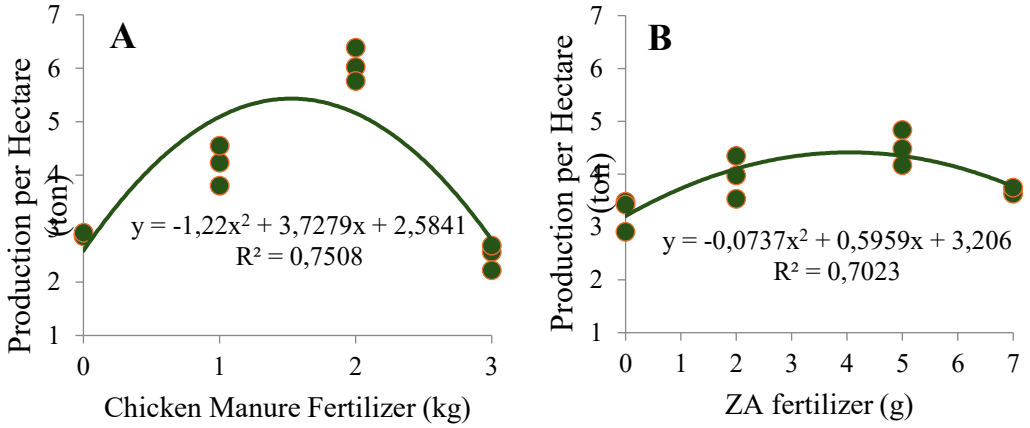


Figure 6. Results of the orthogonal polynomial regression test on hectare production influenced by the application of chicken manure (A) and ZA fertilizer (B).

Productivity is the accumulation of all yield components, including the number of tubers, tuber diameter, tuber volume, and tuber weight. The combination of 2 kg of chicken manure fertilizer per plant and 5 g of ZA fertilizer per plant produces the highest productivity because it can create a balance between vegetative growth and tuber formation.

Chicken manure fertilizer improves the physical, chemical, and biological properties of the growing medium, while ZA fertilizer provides the nitrogen and sulfur needed for protein synthesis and chlorophyll formation. Susikawati et al. (2018) reported that chicken manure fertilizer can increase cation exchange capacity and nutrient availability, while Hasanah et al. (2021) emphasized the importance of sulfur in supporting photosynthesis and plant stress resistance. The results of this study indicate that the floating cultivation system has great potential to be developed in swampy areas and flood-prone regions, especially when supported by proper nutrient management thru a combination of organic fertilizers and ZA fertilizer.

CONCLUSION

The application of chicken manure and ZA fertilizer significantly affects the yield and productivity of red onion plants in the floating cultivation system. The combination of chicken manure treatment at a dose of 2 kg per plant and ZA fertilizer at 5 g per plant resulted in the highest wet shoot weight, bulb diameter, fresh bulb weight, air-dry bulb weight, number of bulbs, bulb volume, and productivity per hectare. The combination of organic fertilizer and sulfur fertilizer is capable of enhancing vegetative growth, bulb formation, and productivity of shallots under floating cultivation conditions.

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