J-ENSITEC

Journal Of Engineering and Sustainable Technology

Vol. 12 No. 02 June 2026

Computer Science
Industrial Engineering
Mechanical Engineering
Civil Engineering

9 772407 600008

DAFTAR ISI

J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02, June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10452-10460

Analysis Of The Effectiveness Of The Use Of Local Government Information Systems (SIPD) In The Budget Preparation Process (APBD) At The National Unity And Political Agency Of South Sumatra Province

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ARTICLE INFO

Article history:
Received 27 December 2025
Revised 10 February 2026
Accepted 11 Marect 2026
Available online 25 June 2026

Keywords:
APBD;
Effectiveness;
E-Government;
Public Sector Information;
SIPD;
Systems;

IEEE style in citing this article:
D. Prayogi and N. Huda, "Analysis of the effectiveness of the use of local government information systems (SIPD) in the budget preparation process (APBD) at the National Unity and Political Agency of South Sumatra Province," *J-ENSITEC (Journal of Engineering and Sustainable Technology)*, vol. 12, no. 2, pp. 10452-10460, 2026,

DOI:
https://doi.org/10.31949/j-ensitec.v12i02.17559

ABSTRACT

The implementation of the Regional Government Information System (SIPD) represents a fundamental paradigm shift in the digital transformation of Indonesian local governance, specifically designed to enhance effectiveness, efficiency, and transparency in the management of the Regional Revenue and Expenditure Budget (APBD). This study aims to conduct a comprehensive analysis of the effectiveness of SIPD implementation in the APBD preparation process at the National Unity and Politics Agency (Badan Kesbangpol) of South Sumatra Province. Utilizing the DeLone and McLean Information Systems Success Model as the theoretical framework, this research evaluates six core dimensions: System Quality, Information Quality, System Use, User Satisfaction, Individual Impact, and Organizational Impact. A quantitative approach was employed using a survey method with 40 respondents comprising budget drafting staff, budget analysts, treasurers, and IT support teams. The data were analyzed using descriptive statistics to determine the level of effectiveness and identify inhibiting factors. The results indicate that the overall effectiveness of SIPD is categorized as "Effective Enough" with an average score of 3.22 on a Likert scale of 1-5. The System Use dimension achieved the highest score (3.48), reflecting a high level of user adoption due to mandatory regulations, while the System Quality dimension received the lowest score (2.93), highlighting significant challenges in IT infrastructure, system response time, and feature customization. The study concludes that while SIPD has been successfully integrated into the agency's workflow and positively impacts organizational accountability, urgent improvements are required in technical infrastructure, user training, and feature customization to optimize its potential.

1. INTRODUCTION

Digital transformation in the government sector, known as e-government, has become a national priority agenda in Indonesia in the past decade [1]. The paradigm shift from paper-based government management to electronic-based management is not just a technological trend, but an urgent need to respond to public demands for transparency, accountability, and speed of service. One of the most strategic and monumental initiatives within the framework of regional bureaucratic reform is the implementation of the Local Government Information System (SIPD). This system was designed by the Ministry of Home Affairs as an integrated platform that connects various local government functions, from development planning, regional financial management, to performance reporting, in one integrated and real-time database[2].

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The urgency of implementing SIPD is rooted in the pathological complexity in the management of the Regional Revenue and Expenditure Budget (APBD) which has been constrained by data fragmentation for many years. Prior to the unification of SIPD, local governments in Indonesia tended to use partial and stand-alone financial management applications (siloed applications). This condition resulted in data duplication, inconsistencies between planning documents (RPJMD/RKPD) and budgeting documents (KUA-PPAS/APBD), and difficulties in conducting fiscal consolidation nationally. The Ministry of Home Affairs of the Republic of Indonesia then mandated the use of SIPD through the Minister of Home Affairs Regulation Number 70 of 2019 concerning Regional Government Information Systems, which required all local governments to switch to this system to realize the vision of "One Data Indonesia".

In South Sumatra Province, the National and Political Unity Agency (Kesbangpol) plays a very vital and strategic role in maintaining political stability, security, and national resilience at the regional level. As a Regional Apparatus Organization (OPD), the Kesbangpol Agency has a constitutional and administrative obligation to compile and manage the APBD to support the operation of its strategic programs. These programs include the development of Pancasila ideology, handling social conflicts, monitoring foreigners, and facilitating financial assistance for political parties. Given the sensitivity and urgency of the main tasks and functions (Tupoksi), the process of preparing the APBD at the Kesbangpol Agency requires a high level of accuracy and speed. Delays or errors in budget preparation can have implications for hampered early detection of conflicts or failures in maintaining regional political conduciveness.

The process of preparing the APBD at the Kesbangpol Agency is a very crucial activity and involves a diverse ecosystem of users, ranging from budgeting staff who input technical data, budget analysts who verify the suitability of programs, to treasurers who manage the structure of expenditure accounts. The effectiveness of the use of SIPD in this process is the main determinant for the quality of budget planning and accountability for the use of public funds within the Kesbangpol Agency. If this system runs effectively, then the budget preparation workflow will be efficient, transparent, and accountable. On the other hand, if this system experiences obstacles, the risk of inefficiency and maladministration will increase[3].

However, the transition to a comprehensive digital system such as SIPD cannot be separated from various fundamental challenges. Empirical phenomena in the field show that although the adoption of the system has been carried out mandatorily, the level of effectiveness of its use still varies and often encounters obstacles. Several previous studies indicate that there are technical and non-technical obstacles in the implementation of SIPD in various regions[4]. In his research, it was found that the main obstacles to the implementation of SIPD are often related to the lack of effective socialization, the limitation of information technology infrastructure in the regions, and the resistance to change of users who are accustomed to the old system. On the other hand[5]. highlights system quality issues, such as slow access speeds during peak loads and the completeness of features that do not fully accommodate the specifications of regional needs.

Similar problems are also indicated to occur in the South Sumatra Provincial Kesbangpol Agency. Although the SIPD has been implemented, there has been no comprehensive and measurable evaluation that measures the extent to which this system is effective in supporting the APBD preparation process. The fundamental question that arises is: Does this system really speed up the bureaucratic work process or does it actually add a new administrative burden? Is the information generated by the SIPD accurate, timely, and relevant for managerial decision-making? And to what extent does this system have a positive impact on the performance of individual employees and the performance of the organization as a whole?

The main purpose of this study is to analyze and evaluate the effectiveness of the use of SIPD in the process of preparing the APBD at the South Sumatra Provincial Kesbangpol Agency in depth. This study uses a quantitative approach by adopting the theoretical framework of the DeLone and McLean Information System Success Model. This model was chosen because of its proven comprehensiveness in measuring the success of information systems through six dimensions that are causally interrelated: System Quality, Information Quality, Use, User Satisfaction, Individual Impact, and Organizational Impact[6].

This research has a high urgency, not only as an academic evaluation, but also as a basis for practical policy-making. For the Kesbangpol Agency, the results of this study can map weak points in the implementation of the system, both in terms of infrastructure and human resources. For the South

Sumatra Provincial Government, this finding can be a barometer of the success of digital transformation at the OPD level and serve as a reference for improving SIPD implementation strategies in the future. In addition, this research also contributes to the literature on e-government in developing countries, especially in the context of the transition of a centralistic regional financial management system.
In the reporting systematics, this study will describe in detail the methodology used, the profile of the research object to provide organizational context, the analysis of statistical data from user responses, as well as an in-depth discussion that relates the data findings to theory and practice in the field. The final part of the report will present concrete conclusions and recommendations that can be implemented to improve the effectiveness of SIPD[7].

2. METHOD

This research is carried out through a series of systematic stages to ensure that the data collected is valid, reliable, and can be processed effectively. The research stages are designed to follow a logical flow from preparation, data collection, data processing, to analysis of results. The following are the stages of research carried out:
Stage 1: Research Preparation At this stage, researchers conduct:

a. Identify Research Problems
   Conducting initial observations at the South Sumatra Provincial Health Agency to understand the context of the use of SIPD in the APBD preparation process. Problem identification was carried out through informal discussions with SIPD users and direct observation of the budget preparation work process.
b. Studi Literature
   Review the literature related to the DeLone and McLean Model, local government information systems (SIPD), information system effectiveness, and previous studies relevant to the research topic.
c. Determination of the Theoretical Framework
   Chose the DeLone and McLean Models as the primary theoretical framework for measuring the effectiveness of SIPD. This model was chosen because it is comprehensive in evaluating the success of information systems through six dimensions: System Quality, Information Quality, System Utilization, User Satisfaction, Individual Impact, and Organizational Impact.
d. Preparation of Questionnaire Instruments
   Designed a questionnaire based on the six dimensions of the DeLone and McLean Models. The questionnaire consisted of 27 question items on a Likert scale of 1-5. Each dimension had 4-5 question items designed to dig deep into user perception.
e. Validasi Instrumen
   Conducting a test of the validity and reliability of the questionnaire instrument through a pilot test to 5 respondents to ensure that each question item can be understood well and measure the construct in question

Stage 2: Data Collection, After the instrument is declared valid and reliable, the data collection stage is carried out with the following steps:

a. Determination of Research Sample Using the purposive sampling method, 40 respondents were selected who met the following criteria:
   - Actively use SIPD in daily work
   - Have been using SIPD for at least 6 months
   - Distributed in four position groups: APBD Compiler Staff (15 people), APBD Analysis (12 people), Treasurer (8 people), and IT Support Team (5 people)
b. Questionnaire Distribution
   The questionnaire was distributed directly (offline) to respondents at the South Sumatra Provincial Kesbanpol Agency office. The offline method was chosen to ensure a high return rate and provide an opportunity for the researcher to explain the purpose of the question if there is ambiguity.

c. Participatory Observation
In addition to the questionnaire, the researcher also made direct observations on:
- User interaction with the SIPD interface
- The condition of the network infrastructure and hardware
- Technical issues that arise in real-time during operational working hours

d. Documentation Studies
Review supporting documents such as:
- Final Internship Report
- Organizational structure of the Kesbanpol Agency
- SIPD usage guide
- SIPD usage historical data

Stage 3: Data Processing and Analysis. The data that has been collected is then processed and analyzed through the following stages:

a. Data Validation and Verification
Check the completeness of the answers on each questionnaire. Questionnaires that are incomplete or do not meet the criteria will be excluded from the analysis.

b. Data Tabulation
Enter respondent answer scores into a data matrix (row=respondent, column=question item) using Microsoft Excel. Each respondent is uniquely coded (R1, R2, ..., R40) and each question item is coded (Q1, Q2, ..., Q27).

c. Descriptive Statistical Calculation
Calculate the mean and standard deviation for:
- Each question item (Q1 - Q27)
- Each dimension (System Quality, Information Quality, System Usage, User Satisfaction, Individual Impact, Organizational Impact)
- Overall effectiveness score

d. Categorization of Results
Convert the average value into an effectiveness category based on the class interval:
- 1.00 - 1.80: Very Ineffective
- 1.81 - 2.60: Ineffective
- 2.61 - 3.40: Quite Effective
- 3.41 - 4.20: Effective
- 4.21 - 5.00: Highly Effective

e. Data Interpretation
Conduct an in-depth analysis of statistical figures by linking them to:
- Context of the main duties and functions of the Kesbanpol Agency
- Information systems theory (DeLone and McLean Model)
- Previous studies
- Findings from observations and documentation studies

Stage 4: Preparation of Reports and Recommendations, The final stage of research includes:

a. Preparation of Research Reports
Compile a systematic research report with the following structure: Introduction, Literature Review, Object Profile, Results and Discussion, and Conclusions and Suggestions.

b. Formulation of Recommendations
Based on the findings of the study, formulating concrete recommendations that can be implemented to improve the effectiveness of the use of SIPD, including the following aspects:

- Improvement of IT infrastructure
- Strengthening human resource capacity
- System feature and performance optimization
- Improved technical support

c. Validation of Findings

Discuss the results of the research with the supervisor and the Kesbanpol Agency to ensure that the findings and recommendations are relevant and can be implemented.

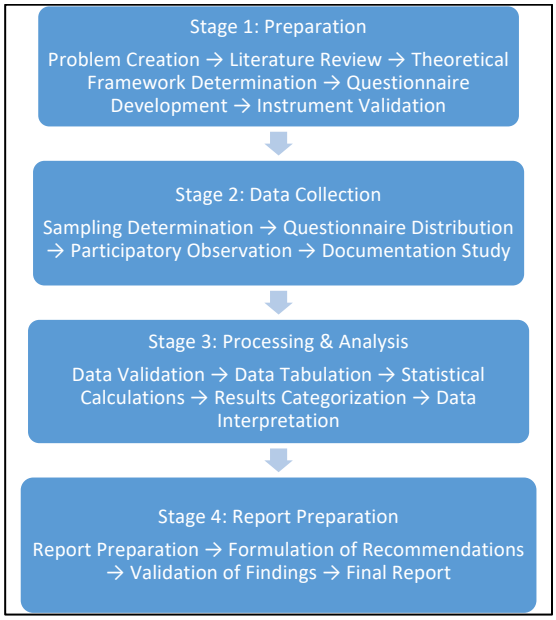

Figure 1. Stage Flow Diagram

All stages of this research were carried out in a period of 4 months (August - November 2024) involving 40 respondents from various work units at the South Sumatra Provincial Health and Social Welfare Agency.

3. RESULTS AND DISCUSSION

3.1 Respondent Demographic Profile

The analysis of the respondents' profiles provides important insights into the background of SIPD users at the Kesbangpol Agency. Based on the data collected, the majority of respondents (75%) are in the productive age range between 25 and 45 years old. This age group is generally categorized as digital immigrants who are quite adaptive or even digital natives, who have an adequate level of technological literacy. The educational background of the respondents is dominated by Bachelor (S1) and Diploma (D3) graduates from the disciplines of administration, economics/accounting, and informatics engineering. This composition shows that in terms of basic competencies, employees of the Kesbangpol Agency have sufficient modalities to operate complex management information systems[9].

In terms of experience of use, the average respondent has been using SIPD for 3-4 years. This indicates that they have passed the initial adaptation phase (learning curve) and are now in the stage of regular use. However, this considerable experience also means that their assessment of the system is based on valid long-term interactions, not just first impressions.

3.2 Descriptive Statistical Analysis of the Effectiveness of SIPD

Table 1. Summary of Descriptive Statistics per Question Item

Item	Dimensions	Quick Questions	Mean	Std Dev	Min	Max	Category
Q1	System Quality	Ease of navigation	2.75	0.82	1	4	Quite Effective
Q2	System Quality	Access speed	2.85	0.88	1	5	Quite Effective
Q3	System Quality	System reliability	2.80	0.75	2	4	Quite Effective
Q4	System Quality	Feature integration	3.30	0.92	1	5	Quite Effective
Q5	Quality of Information	Data completeness	3.50	0.76	2	5	Effective
Q6	Quality of Information	Data accuracy	3.20	0.65	2	4	Quite Effective
Q7	Quality of Information	Punctuality	2.95	0.85	2	4	Quite Effective
Q8	Quality of Information	Report format	3.10	0.78	2	4	Quite Effective
...	...	...	...	...	...	...	...
Q27	Organizational Impact	Planning fit	3.60	0.67	2	5	Effective

The table above shows descriptive statistics for each question item, providing a more detailed picture of respondents' perceptions. Some key findings:

a. Items with the highest score: Q27 (Planning-budgeting suitability, score 3.60) and Q5 (Data completeness, score 3.50)
b. Items with the lowest score: Q1 (Ease of navigation, score 2.75) and Q3 (System reliability, score 2.80)
c. Highest standard deviation: Q4 (Feature integration, SD 0.92), showing the most diverse perceptions between respondents
d. Lowest standard deviation: Q6 (Data accuracy, SD 0.65), indicating a relatively high consensus among respondents

These findings confirm that technical issues (ease of navigation, system reliability, speed of access) are areas that need the most immediate improvement. The evaluation of the effectiveness of SIPD was carried out by analyzing the average scores of 40 respondents' answers to 27 question items. The results of the descriptive statistical calculation for each dimension are presented concisely in Table 2 below.

Table 2. Recapitulation of Questionnaire Analysis Results by Dimension

Variable Dimensions	Average score (*Mean*)	Standard Deviation	Effectiveness Category
System Quality	2.93	0.74	Quite Effective
Quality of Information	3.19	0.68	Quite Effective
System Usage	3.48	0.56	Effective
User Satisfaction	3.22	0.73	Quite Effective
Individual Impact	3.15	0.69	Quite Effective
Organizational Impact	3.32	0.66	Quite Effective
Overall Average	3.22		Quite Effective

In aggregate, the average effectiveness value of SIPD is 3.22, which places it in the "Quite Effective" category. This indicates that the implementation of SIPD in the Kesbangpol Agency has been running and provides basic benefits, but has not yet reached the optimal performance expected from a mature e-government system. There is significant variation between dimensions, where the "System Usage"

dimension achieves the highest score (Effective category), while the "System Quality" dimension is at the lowest score.

3.3 In-Depth Discussion Per Dimension

3.3.1 System Quality - The Main Weak Point

The System Quality Dimension recorded the lowest score of 2.93, making it a major bottleneck in the overall effectiveness of SIPD. An analysis of Q1 to Q4 question items reveals several critical issues:

a. Access Speed (Response Time): Respondents, especially from the APBD Drafting Staff group, consistently gave low scores on items related to system loading speed. This problem becomes particularly acute during the peak season, where all OPDs in Indonesia access the central servers of the Ministry of Home Affairs at the same time. The limited internet network infrastructure in the Kesbangpol Agency office also exacerbates this condition, causing high latency that hinders productivity.
b. System Reliability: There are still frequent technical errors, such as data storage failures (save errors) or sessions that end abruptly (session timeout). For users who are entering lengthy shopping details, this incident is very frustrating because it requires re-input
c. Flexibility of Features: Features in SIPD are considered rigid and less adaptive to the dynamics of specific regional needs. For example, the mechanism of budget shifts that have a very long procedure in the system is often not in line with the needs of handling urgent situations, such as social conflicts that require a quick budget response from the Kesbangpol Agency.
d. These findings are in line with the research of Samosir et al. (2023) which states that the centralization of government information systems often sacrifices flexibility and speed of access for the sake of data uniformity. In the context of Kesbangpol, the quality of this "mediocre" system is a real technical obstacle.

3.3.2 Information Quality - Quite Good but Needs to be Reformatted

With a score of 3.19, the quality of the information produced by SIPD is considered quite good.

a. Accuracy: The accuracy aspect of data is highly valued. The multi-level validation mechanism in the SIPD (starting from staff input, verification of the Head of Subdivision, to the validation of the Head of Agency) is effective in minimizing budget arithmetic errors.
b. Timeliness & Format: A major issue in this dimension is the format of the report. APBD analysts often complain that the default reports produced by SIPD are often incompatible with the internal managerial report format requested by regional leaders. As a result, analysts have to do a double job: download data from SIPD, and then manually reformat it in a spreadsheet. This reduces efficiency and increases the risk of human error at the secondary reporting stage.

3.3.3 System Use - Pseudo-Effectiveness?

The System Usage Dimension obtained the highest score of 3.48 and is the only dimension that is categorized as "Effective". However, this high number must be interpreted critically. In the context of a mandatory system, the high frequency of use does not necessarily reflect the user's voluntariness or love for the system. Employees of the Kesbangpol Agency use SIPD intensively (Q9-Q12) because this system is the only legal channel for submitting and disbursing budgets. There is no other alternative. If they do not use SIPD, the budget will not be disbursed and the work program cannot run. Therefore, this high usage score reflects compliance and lack of choice, rather than the success of the system in attracting user interest. However, the positive side is that SIPD has succeeded in becoming the backbone of operations and eliminating the use of unintegrated shadow systems.

3.3.4 User Satisfaction - Mirror of System Quality

A user satisfaction score of 3.22 indicates that users are "moderately satisfied", but not enthusiastic. There is a strong correlation between low system quality (slow speeds, errors) and this moderate level of satisfaction. Analysis of individual respondent data shows an interesting anomaly. IT Support teams (R36-R40) tend to give slightly higher satisfaction scores than Drafting Staff (R1-R15). This may be due to different self-efficacy; IT teams have the technical ability to troubleshoot independently, so their frustration is lower than administrative staff who feel helpless when the system is down. This underscores the importance of responsive technical support to maintain user satisfaction [13].

3.3.5 Individual Impact - The Productivity Paradox

A score of 3.15 on the individual impact dimension indicates the existence of a phenomenon of the "productivity paradox". On the one hand, SIPD makes it easy to search for historical data and supports the concept of paperless offices. However, on the other hand, complex input procedures and slow system performance make task completion time longer than the previous system. Some respondents (e.g. R9 and R14) gave a low score on productivity items (Q19), which implies the perception that this system actually adds to the administrative workload. For field employees at the Kesbangpol Agency who are used to working dynamically, having to sit for hours waiting for the system to load is considered counterproductive[10].

3.3.6 Organizational Impact - Increased Accountability

Although individual users face challenges, they recognize that SIPD has a significant positive impact on organizations with a score of 3.32. Transparency & Accountability: SIPD creates a complete digital audit trail. Any changes in budget figures are recorded by the system, minimizing the chance of "stealth budgeting" or unauthorized data manipulation. This is crucial for the Kesbangpol Agency which manages sensitive grant funds such as political party assistance[11]. Planning-Budgeting Integration: The SIPD forces consistency between the planning document (Renja) and the budget document (RKA). Activity programs that are not in the planning cannot suddenly appear in the budget. This improves planning discipline in the Kesbangpol Agency.

3.4 Analysis of Perception Variations Between Positions

The respondents' data showed an interesting variation in perception between groups of positions. The Treasurer group gave a relatively higher average score (3.29) than the APBD Analyst (3.15). This is likely due to the fact that the financial administration feature in the SIPD is more structured and helps the treasurer's duties in bookkeeping, while the analysis feature for budget analysts is still limited. The Compiling Staff has the most diverse perceptions, greatly influenced by the quality of the internet connection when they work. This variation shows that the improvement intervention strategy cannot be hit evenly, but must be adjusted to the specific needs of each user role[12].

4. CONCLUSION

Based on a comprehensive analysis of the effectiveness of the use of the Local Government Information System (SIPD) in the process of preparing the APBD at the South Sumatra Provincial Kesbangpol Agency, several strategic conclusions can be drawn:

a. Effectiveness Level: The implementation of SIPD is generally at the level of "Moderately Effective" (Score 3.22). This system has served as the main instrument of regional financial administration, but it still has significant room for improvement to achieve optimal effectiveness.
b. Infrastructure Gap: The System Quality Dimension (2.93) is the weakest point. The limitations of network infrastructure, central server response speed, and rigidity of system features are the main obstacles that erode productivity and user satisfaction.
c. Compliance vs Satisfaction: The high System Usage score (3.48) is driven more by regulatory mandates (obligations) than the quality of the user experience (User Experience). Users comply with the system despite facing technical constraints.
d. Positive Institutional Impact: Despite technical constraints at the individual level, SIPD has proven to be effective in improving the accountability, transparency, and discipline of budget planning at the organizational level of the Kesbangpol Agency. This system successfully mitigates the risk of budget irregularities.
e. Human Factors: The success of the current implementation depends heavily on the durability and adaptability of human resources who are willing to go the extra mile to overcome the system's shortcomings.

Suggestions and Recommendations:

To improve the effectiveness of SIPD in the future, the following steps are recommended:Bagi Manajemen Badan Kesbangpol:

a. IT Infrastructure Upgrades: Make priority investments in dedicated internet bandwidth upgrades and rejuvenation of operators' computer devices to address local latency issues.

b. Strengthening Internal Helpdesk: Establish a more responsive and proactive internal technical support team to assist non-technical employees when facing system constraints.

For Provincial/Central Governments (System Developers):

a. Server & Feature Optimization: It is necessary to optimize the capacity of the central server to handle peak loads. In addition, the development of more flexible custom report features is needed so that regions can produce managerial reports without manual work.
b. Continuous Training: Changing the training method from mass socialization to more in-depth and specific role-based technical training.

For future researchers:
It is recommended to conduct further qualitative research to delve deeper into the coping mechanisms of user adaptation strategies in dealing with SIPD technical constraints, as well as expand the scope of research to other OPDs to obtain a comparative picture.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02, June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10461-10468

Implementation Of Long Short-Term Memory (LSTM) For Routing Optimization In Ad Hoc Networks (FANETS)

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ARTICLE INFO

Article history:
Received 07 April 2026
Revised 17 April 2026
Accepted 25 April 2026
Available online 25 June 2026

Keywords:
End-To-End Delay
FANET
LSTM
Packet Delivery Ratio
Routing Adaptif

IEEE style in citing this article:
Mastang and M. A. Pahmi, "Implementation of long short-term memory (LSTM) for routing optimization in ad hoc networks (FANETS)," *J-ENSITEC (Journal of Engineering and Sustainable Technology)*, vol. 12, no. 2, pp. 10461-10468, 2026,

DOI:
https://doi.org/10.31949/j-ensitec.v12i02.17890

ABSTRACT

Flying Ad Hoc Network (FANET) is a mobile wireless network formed by multiple Unmanned Aerial Vehicles (UAVs) with highly dynamic topology. This rapid topology change makes routing more complex than in conventional Mobile Ad Hoc Networks, since UAV movement can continuously affect link quality, disconnection probability, and packet delivery delay. This study applies Long Short-Term Memory (LSTM) to optimize FANET routing using time-series network metrics, including signal-to-noise ratio, delay, throughput, energy, packet loss rate, jitter, and bandwidth utilization. The LSTM model learns temporal relationships among network conditions, enabling next-hop selection to consider not only current link status but also its evolution over time. The proposed method is evaluated against AODV, OLSR, and the Stochastic Probability Algorithm (SPA) using Packet Delivery Ratio (PDR) and end-to-end delay under different numbers of UAVs and UAV speeds. Results show that LSTM consistently achieves the highest PDR across all scenarios. For UAV number variation, LSTM improves PDR from 0.166 to 0.380, outperforming AODV, OLSR, and SPA. For UAV speed variation, LSTM maintains PDR between 0.89 and 0.73, remaining superior to the comparison methods. In addition, LSTM produces the lowest delay, ranging from 0.60 to 0.70 s for UAV number variation and 0.35 to 0.61 s for UAV speed variation. These results demonstrate that LSTM effectively captures the temporal dynamics of FANET and is suitable for adaptive routing support.

1. INTRODUCTION

Flying Ad Hoc Network (FANET) is an ad hoc network formed by several UAVs that communicate with each other without full dependence on fixed infrastructure[1]. UAVs are implemented in military operations, agriculture, disaster monitoring, traffic, logistics, aerial photography, mapping[2], and communication networks such as FANET because they can move quickly, flexibly, and reach areas that are difficult to access. In this network, each UAV can function as a source node, destination node, as well as a relay node that forwards packets to other UAVs[3]. Its working mechanism begins when a node observes the neighbors around it, measures link quality and then selects the multi-hop path considered most feasible for sending packets to the destination. Different from static networks, FANET operates in three-dimensional space so that changes in position, speed, and flight direction will directly affect network topology[4]. As a result, the routing process must be carried out adaptively, quickly, and be able to respond to channel condition changes in near real time. If the route decision is delayed, packets can be sent through a link that has already weakened or even disconnected, thereby reducing Packet Delivery Ratio (PDR) and increasing delay.

Figure 1 shows the packet delivery process in FANET from the source to the destination through several alternative paths. The source cannot always send directly to the destination because of radio range limitations, so the packet must pass through intermediate UAVs[5]. In the illustration, several candidate paths are available, such as Path 1, Path 2, and Path 3, with different numbers of hops and different link

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conditions. In practice, path selection is not sufficient if it is based only on the smallest number of hops, because a short path is not necessarily stable[6]. A path with more hops but stronger and more stable links can produce better PDR and lower retransmission. Therefore, FANET routing is essentially a dynamic decision-making problem[7] that must consider link stability, channel quality, node mobility, and the possibility of topology changes in the next time slot.

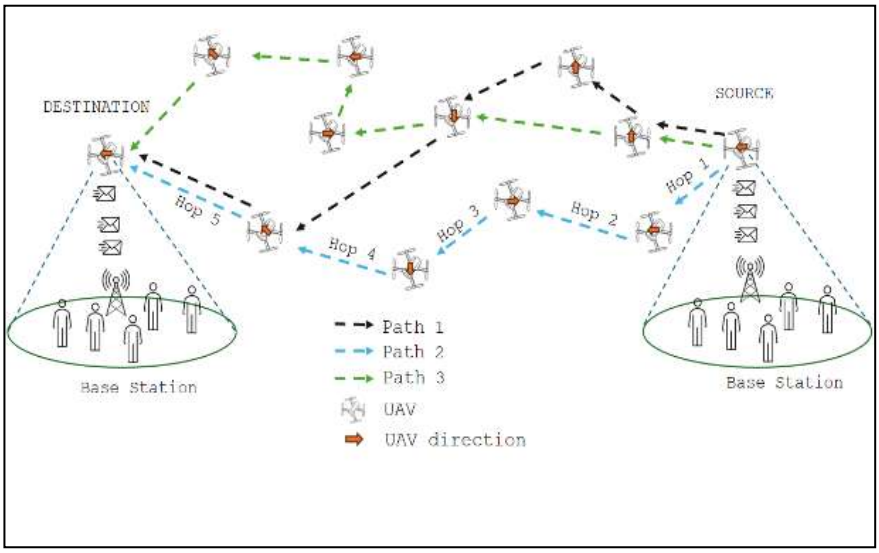

Figure 1. Packet delivery process in FANET

The main constraints of FANET lie in very high mobility[8], frequent link disconnection, and channel quality variation that is difficult to predict. When UAV speed increases, the distance between nodes changes more rapidly, so the routing table built by conventional protocols can quickly become outdated[9]. AODV is indeed flexible because it is reactive[10], but it still often experiences route discovery overhead when a link breaks. OLSR can maintain topology information through periodic updates[11], but the control burden can increase under high-mobility conditions. SPA uses probabilistic principles to select routes[12], but its accuracy is strongly determined by the quality of link success probability estimation. Other challenges are the limited energy of UAVs, changing packet queues, inter-channel interference, as well as the need to balance throughput, delay, and delivery reliability simultaneously.

In addition, the data traffic characteristics in FANET are also highly fluctuating. Telemetry packets, images, videos, and control data can arrive in unpredictable patterns that cause queue conditions at UAVs to change rapidly from one interval to the next. Therefore, a good routing decision must observe the sequence of metric changes, not merely a single value. A temporal learning-based approach becomes relevant because it can connect past conditions, current conditions, and future condition tendencies. This is the reason LSTM is selected in this study, because its memory structure allows the model to retain information that is important for route prediction, while discarding old information that is no longer relevant to current network dynamics.

The novelty of this study lies in the use of LSTM[13] as a route-quality prediction mechanism based on time series for FANET routing. Rather than only evaluating an instantaneous snapshot of current network conditions, LSTM processes a sequence of observations from several time intervals so that it can recognize patterns of link quality change before a routing decision is taken. With this approach, the system not only responds to instantaneous conditions, but also utilizes short-term and long-term memory to avoid paths that tend to deteriorate. The proposed implementation arranges the network metrics of each link into a sequential input vector, processes it inside the LSTM, and then produces a route-quality score used to select the best next hop. The contribution of this study is the availability of a concrete input-process-output scheme for integrating deep learning into FANET routing, together with a direct comparison with AODV, OLSR, and SPA in two main mobility scenarios.

2. METHOD

The implementation of LSTM in this study is designed as a route-quality prediction module that operates on top of the FANET routing process. Each UAV periodically collects link-condition data to its nearest neighbors, and then the data are formed into a time sequence before being sent to the LSTM model. The main system inputs are the network metrics that are most relevant to packet delivery success, namely signal-to-noise ratio (SNR), local delay, throughput, residual node energy, packet loss rate (PLR), jitter, and bandwidth utilization. These parameters are common measures for assessing how a network performs[14]. Thus, at each time t, a feature vector is obtained that represents the quality of a candidate next hop. A set of vectors from several previous times forms an observation window that is used to predict route feasibility at the next time. The model output is not merely a good-or-bad label, but a route-quality score that can be used to rank all candidate paths adaptively.

Concretely, the implementation flow consists of three stages. The input stage begins when the source UAV or relay reads network conditions from active neighbors and arranges them into a standardized numerical vector. The process stage is carried out by feeding the vector sequence into the LSTM unit so that temporal relationships among metrics can be learned. The output stage produces a prediction value that is interpreted as path quality or next-hop priority. This mechanism is important because changes in delay, energy, and channel quality are not purely random, where there are often patterns of degradation or improvement that can be captured from the history of several time slots. In other words, LSTM allows routing decisions to be made based on the tendency of network dynamics, not merely based on a single instantaneous measurement.

Figure 2 shows the basic working mechanism of LSTM. Information from the previous time is stored in the cell state and hidden state. The forget gate selects the part of the old memory that needs to be retained, the input gate determines the new information that deserves to be written into memory, while the candidate state carries the representation of candidate new information resulting from nonlinear transformation. After that, the output gate determines which part of the latest cell state is forwarded as the hidden state. In the FANET context, the cell state can be understood as memory regarding the tendency of link stability, for example whether a neighbor over several intervals tends to experience decreasing SNR, increasing delay, or rapid energy depletion. The hidden state then becomes a compact representation that is ready to be used to predict routing quality at the next step.

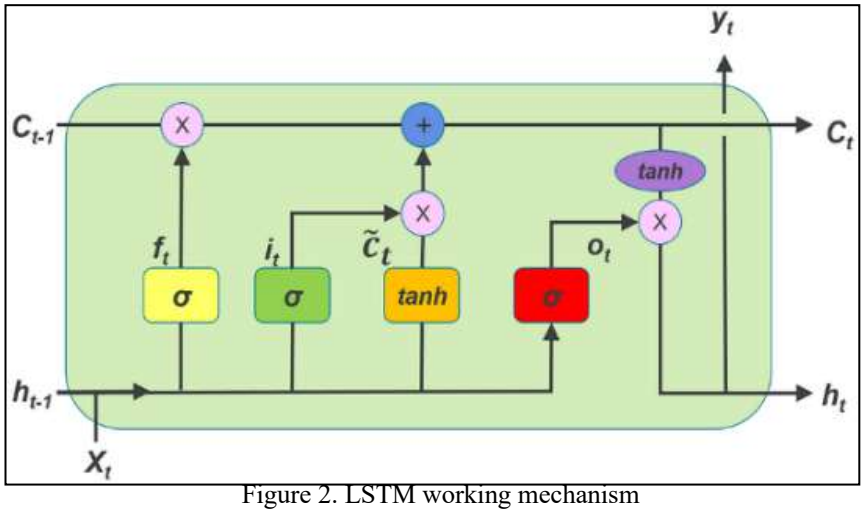

Figure 2. LSTM working mechanism

Table 1 summarizes the LSTM-based FANET routing flow in three stages: input, process, and output. UAVs collect network metrics, convert them into feature vectors, and arrange them as time sequences. The LSTM processes these sequences to predict route quality, then the sender ranks candidate next hops and selects the best path adaptively.

Table 1. Input-process-output flow of LSTM implementation in FANET routing

Stage	Implementation	Output
Input	Each UAV reads SNR, delay, throughput, residual energy, PLR, jitter, and bandwidth utilization from candidate neighbors at each time slot.	Feature vector x_t for each candidate link.
Process	Feature vectors are arranged into a time sequence, normalized, and then processed by LSTM to capture temporal patterns of link-quality change.	Hidden-state representation h_t and route-quality prediction score.
Output	The sender node ranks all candidate next hops based on the prediction score and selects the path with the best value that still satisfies connectivity requirements.	Adaptive routing decision and best next-hop selection.

The following are the core equations used to implement LSTM in FANET.

$$x_t = [SNR_t, D_t, PLR_t, J_t, BU_t]^T \quad (1)$$

$$f_t = \sigma(W_f[h_{t-1}, x_t] + b_f) \quad (2)$$

$$i_t = \sigma(W_i[h_{t-1}, x_t] + b_i) \quad (3)$$

$$\tilde{c}_t = \tanh(W_c[h_{t-1}, x_t] + b_c) \quad (4)$$

$$c_t = f_t * c_{t-1} + i_t * \tilde{c}_t \quad (5)$$

$$o_t = \sigma(W_o[h_{t-1}, x_t] + b_o) \quad (6)$$

$$h_t = o_t * \tanh(c_t) \quad (7)$$

$$\hat{y}_t = W_y h_t + b_y \quad (8)$$

In these equations, W and b are the weights and biases learned during training, σ is the sigmoid function, $\tanh$ is the hyperbolic function, and $*$ denotes element-wise multiplication. The value $\hat{y}_t$ is used as a route-quality prediction score to evaluate each candidate next hop.

For these equations to become truly operational in FANET routing, each candidate neighbor is treated as an evaluation object having its own condition sequence. Suppose UAV i has several neighbors j, then each link $i \rightarrow j$ is formed into its own input sequence. After the model produces score $\hat{y}_t$ for each candidate, the sender node selects the next hop with the highest score as long as it still satisfies the basic connectivity requirements. This strategy provides two advantages. First, the decision becomes more anticipatory because the model has observed historical patterns. Second, route changes do not need to wait for total link failure, because path quality that begins to decline can be detected earlier from the sequence pattern.

To test the effectiveness of the proposed method, LSTM performance is compared with three other approaches, namely AODV, OLSR, and Stochastic Probability Algorithm (SPA). AODV represents a reactive protocol, OLSR represents a proactive approach, while SPA represents probability-based route selection. Evaluation is carried out in two main scenarios: variation in the number of UAVs of 10, 20, 30, 40, and 50 nodes, and variation in UAV speed of 20, 25, 30, 35, and 40 m/s. The two evaluation metrics analyzed are Packet Delivery Ratio (PDR) and end-to-end delay. PDR is used to observe the packet delivery success rate, while delay shows how quickly data reach the destination. With this test design, the advantages of LSTM can be observed both under increasing node-density conditions and under increasingly aggressive mobility conditions.

Table 2 presents the comparison methods used to evaluate the proposed routing model. LSTM is positioned as the proposed method because it applies a predictive time-series approach with temporal memory, allowing routing decisions to consider historical network behavior. AODV is included as a reactive baseline since it builds routes only when needed, making it useful for observing route-discovery response to link changes. OLSR represents a proactive baseline because it maintains topology information

through periodic updates, which helps examine control overhead under high mobility. SPA is used as a probabilistic baseline, where route selection depends on link success probability, enabling comparison of prediction accuracy.

Table 2. Comparison methods in the evaluation

Method	Main characteristic	Role in evaluation
LSTM	Predictive time-series-based approach with temporal memory.	Proposed method for routing optimization.
AODV	Reactive routing protocol that establishes routes when needed.	Baseline to observe route-discovery response to link dynamics.
OLSR	Proactive routing protocol with periodic topology updates.	Baseline to observe the impact of control overhead under high mobility.
SPA	Route selection based on link success probability.	Probabilistic baseline to compare route prediction accuracy.

3. RESULTS AND DISCUSSION

Figure 3 shows the comparison of PDR with respect to the number of UAVs. In general, all methods show an increasing trend when the number of UAVs increases from 10 to 50 nodes. This increase is logical because more UAVs mean more alternative relay paths are available, so the probability that the source finds a route to the destination also increases. However, LSTM still provides the highest PDR values at all test points, namely 0.166, 0.282, 0.334, 0.363, and 0.380. These values consistently remain above AODV, which reaches 0.137 to 0.357, OLSR at 0.102 to 0.340, and SPA at 0.050 to 0.316. These results indicate that the use of network-condition history makes LSTM better in selecting paths that are truly feasible for packet delivery.

From an operational point of view, the superiority of LSTM in Figure 3 indicates that an increase in network density does not necessarily automatically produce optimal routing decisions if the algorithm is not able to filter candidate paths correctly. When the number of UAVs increases, the number of possible next hops also increases and the complexity of decision-making increases. LSTM is able to transform this complexity into an advantage because the model can distinguish links that tend to be stable from links that only appear good momentarily. Compared with conventional methods that depend more on route updates or static probability estimation, LSTM utilizes temporal relationships among observations so that packets are more often sent through paths with a higher probability of success. Thus, Figure 3 confirms that sequence learning is suitable for routing in FANET topology that is rich in path alternatives.

Figure 4 shows the comparison of PDR with respect to UAV speed. All methods experience a performance decline when speed increases from 20 m/s to 40 m/s, because higher mobility accelerates topology changes and increases the possibility of link breakage during the delivery process. Even so, LSTM still maintains the best performance with PDR values of 0.89, 0.83, 0.80, 0.75, and 0.73. As a comparison, AODV produces 0.85 to 0.65, OLSR 0.79 to 0.63, and SPA 0.75 to 0.58. This difference shows that LSTM is more resistant to network-quality degradation caused by speed, especially under the heaviest condition when UAVs move at 40 m/s.

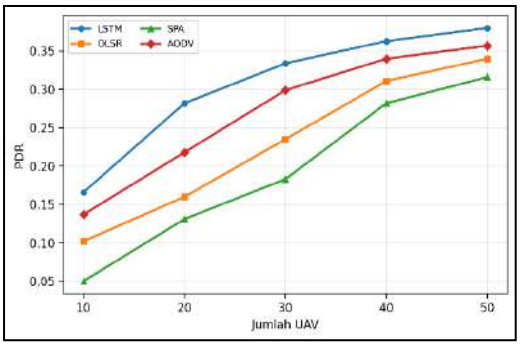

Figure 3. PDR comparison based on number of UAVs

This superiority can be explained by the ability of LSTM to capture patterns of link-quality change before the link truly fails. At high speed, the distance between nodes and communication orientation change very rapidly, so protocols that only react after the route is broken will always lag behind by one step. LSTM works more predictively, where if in the last several intervals a neighbor shows a pattern of decreasing SNR, increasing delay, or increasing PLR, the model can reduce the route score earlier and direct packets to another, safer path. It is this predictive character that makes LSTM PDR remain the highest at all speed levels. In other words, Figure 4 confirms that temporal memory is an important component for maintaining routing reliability in highly dynamic FANET.

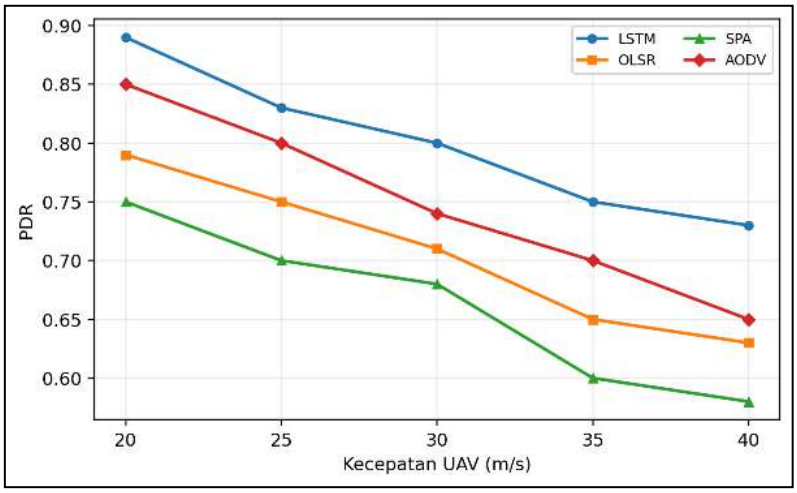

Figure 4. PDR comparison based on UAV speed

Figure 5 shows end-to-end delay with respect to the number of UAVs. Different from PDR, which is expected to increase, delay instead increases in all methods as the number of UAVs grows, because the increase in nodes enlarges traffic, queues, and the possibility of longer multi-hop forwarding processes. However, LSTM again shows the best results with delays of 0.60, 0.63, 0.66, 0.67, and 0.70 s. These values are lower than AODV at 0.61 to 0.73 s, OLSR at 0.65 to 0.80 s, and SPA at 0.68 to 0.90 s. Thus, although the network becomes increasingly dense, LSTM is still able to keep packet travel time lower than the other methods.

Analytically, lower delay indicates that LSTM not only succeeds in delivering more packets but also directs packets through more efficient paths. When route selection is performed on more stable links, the need for retransmission, route repair, and delays due to route switching can be reduced. This effect is very important in FANET because unstable topology often causes packets to wait for new route establishment. LSTM reduces this phenomenon by selecting next hops that have better stability prospects based on observation history. The results in Figure 5 show that predictive intelligence not only affects reliability, but also directly contributes to system latency, which is highly crucial for UAV-based monitoring, search, and tactical communication applications.

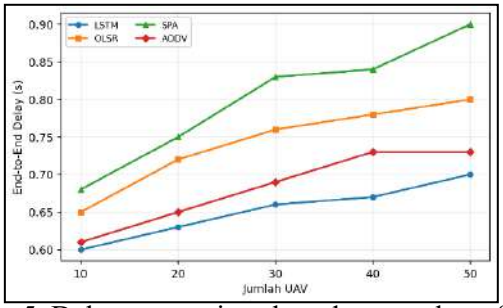

Figure 5. Delay comparison based on number of UAVs

DOI: https://doi.org/10.31949/j-ensitec.v12i02.17890

Figure 6 shows delay with respect to UAV speed, and the results show a stronger impact of mobility. All methods experience increasing delay as speed rises from 20 m/s to 40 m/s. LSTM still records the lowest delays, namely 0.35, 0.44, 0.49, 0.56, and 0.61 s. In contrast, OLSR is at 0.49 to 0.71 s, AODV is at 0.56 to 0.78 s, and SPA is at 0.60 to 0.80 s. From these data, it can be seen that the gap between LSTM and the comparison methods becomes even more pronounced when speed increases, which means that the adaptation capability of LSTM becomes increasingly valuable in more dynamic environments.

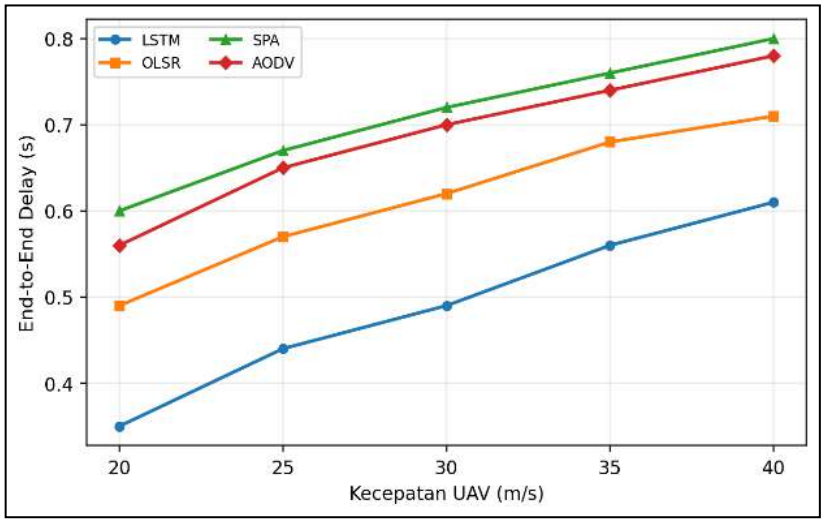

Figure 6. Delay comparison based on UAV speed

The interpretation of Figure 6 is that high mobility not only affects delivery success, but also increases waiting time due to frequent route switching, packet buffering, and link-break recovery. LSTM is able to suppress this effect because routing decisions are made based on temporal patterns that have been learned, not merely based on current link status. When a candidate path shows a deteriorating trend, the model can lower the priority of that path before failure occurs, so that the forwarding process continues on a more stable trajectory. Therefore, the combination of results in Figures 3 to 6 provides a consistent conclusion: LSTM excels both in reliability metrics and in delay metrics, and this superiority becomes increasingly important when FANET complexity increases because of additional nodes or higher UAV speed.

Table 3 shows a summary of UAV performance using the LSTM method compared with other methods. The PDR value of LSTM is 11% higher than AODV, 25% higher than OLSR, and 37% higher than SPA. Meanwhile, the delay in LSTM is 4% lower than AODV, 12% lower than OLSR, and 18% lower than SPA.

Table 3. Summary of method comparison

Method	Average PDR	Average Delay
LSTM	0.305	0.652
OLSR	0.229	0.742
AODV	0.270	0.682
SPA	0.192	0.800

4. CONCLUSION

The implementation of LSTM is proven to improve the quality of routing decisions in FANET because it is able to utilize the history of network metrics as the basis for route-quality prediction.

Compared with AODV, OLSR, and SPA, this method produces the highest average Packet Delivery Ratio of 0.305 in scenarios of both variation in the number of UAVs and variation in UAV speed, while at the same time maintaining the lowest average end-to-end delay of 0.652. In the node-variation scenario, LSTM shows that network density can be transformed into an advantage when next-hop selection is carried out predictively. In the speed-variation scenario, LSTM remains stable even though topology changes rapidly, so links with the potential to fail can be avoided earlier. Overall, this study confirms that LSTM is feasible to be used as the core of adaptive routing optimization in FANET. Future development can be directed toward adding energy metrics, throughput, or time-weighting mechanisms so that the model becomes more responsive to extreme network dynamics in the future.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02, June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10469-10476

Design Of A Coconut Shell Charcoal Briquette Mixer Machine With A Capacity Of 50kg

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ARTICLE INFO

Article history:
Received 17 April 2026
Revised 28 April 2026
Accepted 03 Mei 2026
Available online 25 June 2026

Keywords:
Coconut shell charcoal
Briquettes
Mixer machine
Simulation
Twisting moment shaft

IEEE style in citing this article:
A. Rachmat and G. D. Saputra, "Design of a coconut shell charcoal briquette mixer machine with a capacity of 50 kg," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10469-10476, 2026.

DOI:
https://doi.org/10.31949/j-ensitec.v12i02.17946

ABSTRACT

Coconut shell waste has not been optimally utilized, despite its potential to be processed into charcoal briquettes with higher economic value. One of the critical stages in briquette production is the mixing process, which requires an efficient and reliable mixing system to ensure homogeneity. This study aims to design a coconut shell charcoal briquette mixer machine with a capacity of 50 kg. The design methodology includes determining the mixer drum capacity, frame dimensions, and shaft specifications, followed by mechanical analysis to evaluate the torsional load acting on the shaft. Simulation analysis was conducted to assess the structural performance of the machine. The results indicate that the maximum stress due to torsional loading is 1.714×10^5 Pa, while the resulting deformation is 3.306×10^{-5} m. These results demonstrate that the designed mixer machine meets the required safety criteria and is capable of operating effectively in the briquette mixing process. The proposed design is expected to improve efficiency and consistency in coconut shell charcoal briquette production.

1. INTRODUCTION

Coconut shells are a common waste product found in traditional markets. They are often discarded, but they can also be quite valuable. One way to process coconut shell waste is to make coconut shell charcoal briquettes. This coconut shell waste can be utilized by communities to build small-scale businesses, as coconut shells are a readily available raw material. Coconut shell waste can also be used as a substitute for fuels such as cooking gas.

The frame is one of the components that must be considered in designing a product or tool, because the frame will accommodate or hold all the loads of each component so it must be considered, according to Angga Restu Pahlawan et al (2021), the existing load on the frame system will affect the deflection that occurs in the frame structure, so that it can cause cracks and even breaks. So when designing a frame, careful and precise calculations must be made to reduce the possibility of damage to the frame. In processing coconut shell charcoal, there are several stages, one of which is the process of mixing briquette materials, adding a transmission system with a shaft as a power transmitter so that the mixing process

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occurs, and producing a mixer machine that is capable of mixing briquette components that are easy to operate, a mixer machine design process is needed to determine various aspects, such as design, type of material used, diameter of the shaft used and others [1].

Mixing relatively large quantities requires a long mixing time, so a mixer is needed to speed up the mixing process.Uneven mixing and feed mixing occur due to manual mixing of large quantities [2]. Large-scale mixing operations require a long time, so a mixer is necessary. This mixer is specifically designed to facilitate faster and more efficient mixing, thus streamlining the mixing process [3].

Stirring is an action that triggers movement within the material being mixed. The goal of stirring is to achieve a good mix. Mixing here serves to overcome differences in conditions, temperature, or other characteristics present in a material.The mixing process is inextricably linked to the use of a shaft as a component. Several shafts are used in the mixing process. One shaft drives the mixer blades, while the other drives the cylinder or container.During the mixing process, the shaft is subjected to a load, known as a torsional load. A torsional load is a force that causes a twisting moment, resulting in torsion. Torsion is the rotation of an object due to the resulting torque [4].

The shaft is a crucial component in the design of a rice husk grinding machine. Therefore, an analysis will be conducted to measure the stress levels that cause torsional moments in the material and its safety factor to prevent shaft fatigue, which can lead to plastic deformation. Based on the discussion mentioned, the author feels compelled to conduct research on a coconut shell charcoal mixer machine using a hollow blade with the title "Design of a Coconut Shell Briquette Mixer Machine with a Capacity of 50 Kg" [5].

2. METHOD

The research method used in the DESIGN OF A 50KG CAPACITY COCONUT SHELL CHARCOAL BRIQUETTE MIXER MACHINE follows the stages explained in the sub-discussions which will be explained as follows through the diagram:

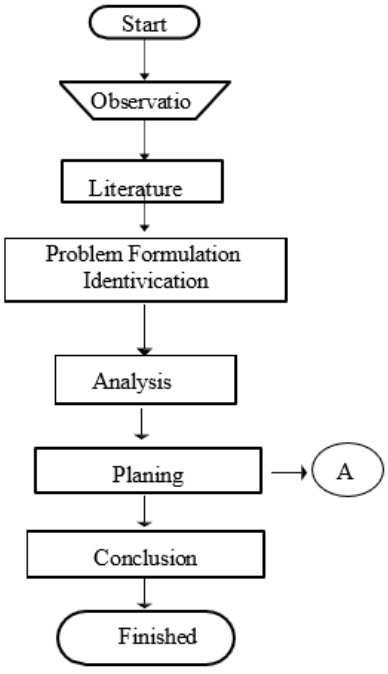

Figure 2.1 Research Flowchart

• Observation

Conducted observations on the mixer machine being used in the briquette mixing process at PT. Briket HD Tasikmalaya, West Java. During this activity, we observed the elements used in the mixer machine and asked the operator directly about how to operate the machine.

• Literature Review

The author conducted a literature review by searching for research journals related to coconut shell charcoal briquette mixing machines and conducting a review to support this research.

• Problem Identification and Formulation

The problem encountered during the production of coconut shell charcoal briquettes in the Faculty of Engineering workshop at Majalengka University was that the resulting briquettes were cracking, a result of the imperfect mixing process.

• Analysis

The analysis involved creating a model for a 50 kg capacity coconut shell charcoal briquette mixer machine. This model will be used in the design process, which will then be included in the modeling sketch and so on.

• Design Process

The design process for this 50 kg coconut shell charcoal briquette mixer machine involves several steps, including initial design, modeling, material selection, assembly, and analysis.

• Conclusion

The author will gather data from a series of design processes to arrive at a conclusion

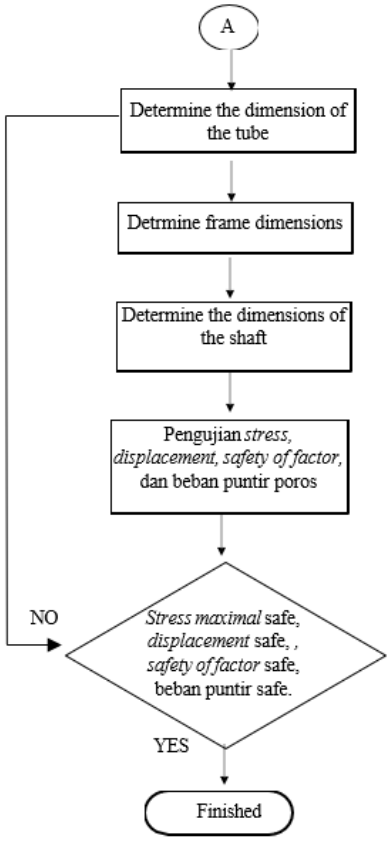

Figure 2.2 Research Flowchart process

• Determining the cylinder dimensions

The process of determining the cylinder dimensions is to determine the appropriate size for the desired volume capacity through calculations, followed by initial design sketches and 3D modeling.

• Determining the frame dimensions

The process of determining the frame dimensions is carried out to ensure the frame is capable of supporting all existing loads. To ensure the frame is capable of supporting all existing loads, a sketch is created and followed by 3D modeling.

• Determining the shaft diameter

Determining the shaft diameter is carried out to minimize shaft failure, as the shaft will later function as a rotating cylinder, under load. To prevent excessive deformation, the shaft diameter is determined.

• Testing

In designing this coconut shell charcoal briquette mixer machine, several tests are conducted, such as stress testing, displacement testing, safety factor testing, and torsional load testing on the mixer cylinder shaft. These tests are conducted to ensure safety during construction and use. If there are any design irregularities, redesign is carried out to achieve safe test results.

3. RESULTS AND DISCUSSION

In the process of creating technology, the first step is to design the machine elements to be created. Design is the first step in a series of technological development activities. The first stage in the design process is creating an initial design plan.

3.1. Design Process

3.1.1 Mixer Tube

This mixer tube is a place used as a place for the mixing process of all briquette components, made using stainless steel plate material, this material is superior in its anti-corrosion properties which will increase its service life longer.

• Calculating the Mixer Tank Capacity

Tube volume

$V = \pi r^2 . t$ (1)

$V = 3{,}14 \times 25^2 . 40$

$V = 3{,}14 \times 625 . 40$

$V = 78.500\ cm^3$

Volume of a truncated cone

$V = \frac{1}{3}\pi.t.((r_1^2) + r_1.r_2 + (r_2^2))$ (2)

$= 18{,}626\ cm^3$

Volume Total

$V_{total} = V_{Tabung} + V_{Kerucut\ Terpancung}$ (3)

$V_{total} = 78.500\ cm^3 + 18.626{,}125\ cm^3$

$V_{total} = 115.752{,}25\ cm^3$

Tube dimension

So the density of coconut shell charcoal briquettes is 0.777g/cm3. To find out the maximum capacity that the cylinder can accommodate,

$\rho = \frac{m}{v}$ (4)

$m = \rho . v$

$m = 0.777x115{,}752.25$

$m = 89{,}953.59\ g$

So, the maximum capacity that the cylinder can hold is 89,953.59 g, or 89.95 kg.

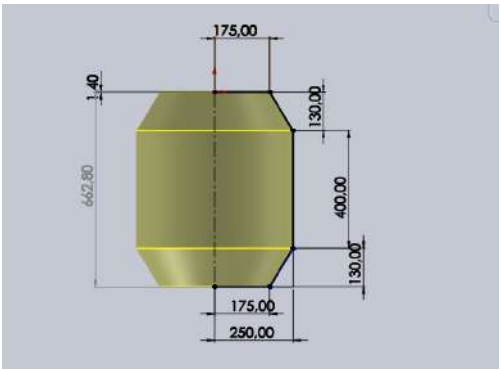

Figure 3.1 Mixer Tube

3.1.2 Drive Motor

The drive motor used in this mixer design is an electric motor with specifications of 1 hp, 1400 rpm, 0.75 kW, and 220V (single-phase).

Where the torque of this motor is not yet known, the following calculation is carried out:

$$T = \frac{5250.HP}{n} \quad (5)$$

$$T = \frac{5250.1}{1450}$$

$$= 3{,}75 \text{ Nm}$$

So the torque on the drive motor is 3.75 Nm.

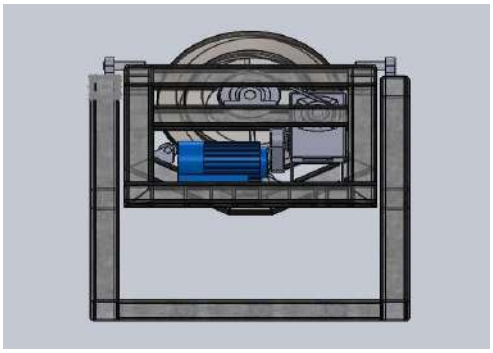

Figure 3.2 Position of the Drive Motor on the Mixer Machine

3.1.3 Gearbox

This gearbox is used to change the speed of the drive motor. The gearbox used in the design of this mixer machine has a ratio of 1:40.

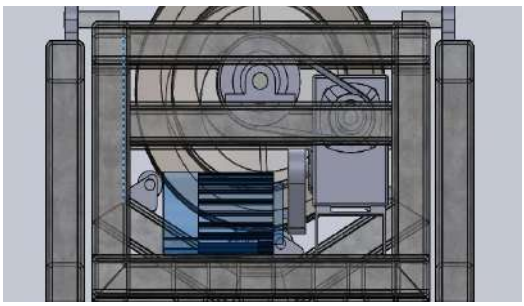

Figure 3.3 Gearbox Position on Mixer Machine

3.1.4 Transmission System

The transmission system used in this mixer machine design utilizes four pulleys, each with different dimensions: one pulley with a diameter of 3 inches, one pulley with a diameter of 6 inches, and two pulleys with a diameter of 2 inches. The following calculations were performed to design these pulleys:

Given:

n_1 = 1400 rpm (putaran motor)
d_1 = 2 inci = 50,8 mm (*pulley* motor)
d_2 = 2 inci = 50,8 mm (*pulley in gearbox*)
d_3 = 3 inci = 76,2 mm (*pulley out gearbox*)
d_4 = 6 inci = 152,4 mm (*pulley ass*)
n_3 = 35 rpm (putaran *out gearbox*)

Asked

n_2 = ?
n_4 = ?

answer

$$n_1.d_1=n_2.d_2 \quad (6)$$

$$n_1= n_2 \cdot \frac{d_2}{d_1}$$

= 17,5 rpm

• Pulley Contact Angle

Given:

$d1 = 2inci = 50.8\ mm$
$d2 = 2inci = 50.8\ mm$
Distance (c) = 112.01 mm
Asked: Belt length (L)

$$L = 2c + \frac{\pi}{2}(d_2 + d_1) + \frac{1}{4c}(d_2 - d_1)^2 \quad (7)$$

= 411,532 mm

θ = 179,5°

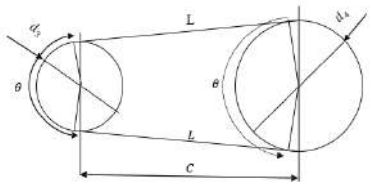

Figure 3.4 Pulley Contact Angle

3.1.5 Shaft

There are several things that must be considered and taken into account when designing the mixer tube drive shaft, including the following:

Power to be transmitted	*fc*
Average power required	1,2-2,0
Maximum power required	0,8-1,2
Normal power	1,0-1,5

$$d_s = [\ \frac{5,1}{\tau_a} \text{ x } K_t \text{ x } C_b \text{x T }] \quad (8)$$

= 22,11 mm

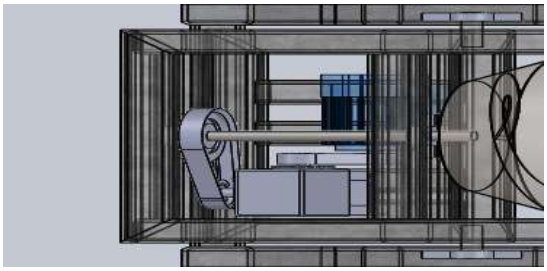

Figure 3.5 Position of the Mixer Tube Drive Shaft

3.1.6 Frame

Simulation

This simulation was conducted to determine the stress, displacement, and safety factor values that occur in the frame and axle when rotating.

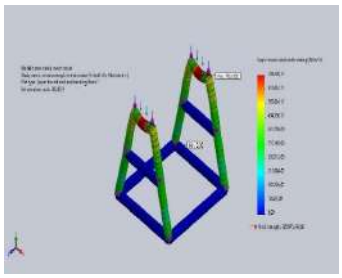

Figure 3.6 Frame Stress

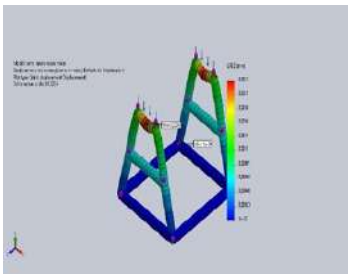

Figure 3.7 Frame Displacement

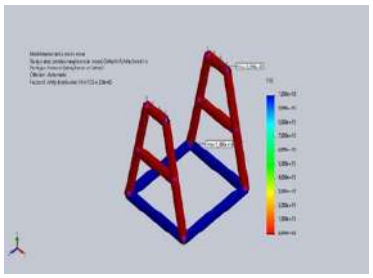

Figure 3.8 SF (safety factor)

The simulation of the torsional moment occurs in the mixer tube as follows,

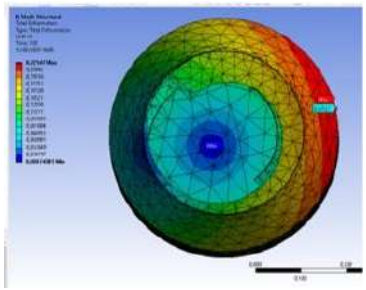

Figure 3.9 Total Deformation

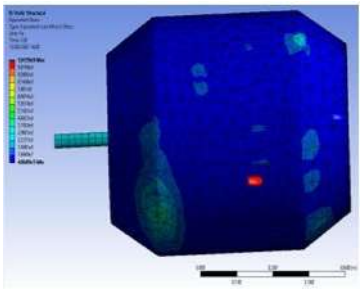

Figure 3.10 Equivalent Stress

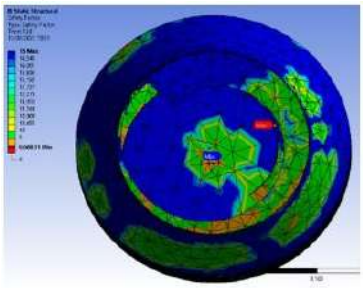

Figure 3.11 SF (safety factor)

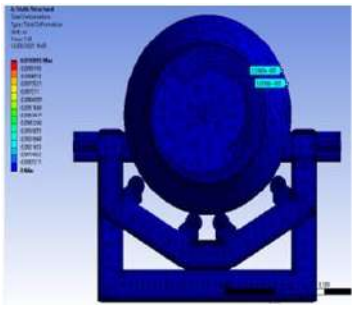

Figure 3.12 Def. Using Support

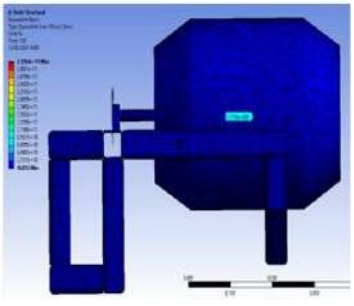

Figure 3.13 Stress Using Supports

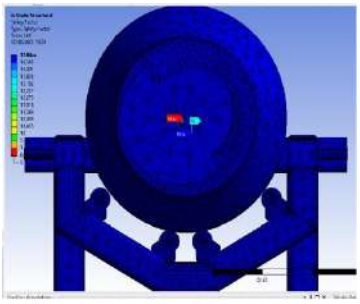

Figure 3.14 SF Using Supports

4. CONCLUSION

The conclusions of the research conducted, entitled "Design of a 50 kg Capacity Coconut Shell Charcoal Briquette Mixer Machine," are:

1. The design process for this 50 kg capacity coconut shell charcoal briquette mixer machine resulted in a mixer tube with a height of 662.80 mm, an inlet diameter of 350 mm, and a tube diameter of 500 mm. The frame uses hollow galvanized steel with frame dimensions of 700 mm in length, 750 mm in width, and 800 mm in height.
2. By using a 30 mm diameter shaft, it is capable of withstanding torsional loads with an equivalent stress value of 1.714 x 10 Pa and a deformation of 3.306 x 10 m, as well as a safety factor value of 15.

ACKNOWLEDGEMENTS

All praise and gratitude to the presence of Allah SWT, who has bestowed His grace and guidance, so that the author can complete the final research report entitled "Design of a Coconut Shell Charcoal Briquette Mixer Machine with a Capacity of 50kg". The author would like to express his deepest gratitude to:
1. My beloved parents, who have provided endless encouragement and prayers for the author. Thank you for your unwavering love and support.
2. Mr. Dony Susandi, S.T., M.T., Dean of the Faculty of Engineering, Majalengka University.
3. Mr. Engkos Koswara, S.T., M.T., Advisor and Chair of the Mechanical Engineering Study Program, Faculty of Engineering, Majalengka University.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10477-10488

The Effect Of Smk3 Implementation, Safety Culture And Project Leadership On Ohs Performance In Construction Projects In Dili City, Timor Leste

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ARTICLE INFO

Article history:
Received 19 April 2026
Revised 29 April 20256
Accepted 03 Mei 2026
Available online 25 June 2026

Keywords:
Construction projects
OHSMS
OHS performance
Safety culture
Project leadership

IEEE style in citing this article:
P. M. L. Pacheco, A. Soekiman, and C. A. Siregar, "The effect of SMK3 implementation, safety culture, and project leadership on OHS performance in construction projects in Dili City, Timor Leste," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10477-10488, 2026.

DOI:
https://doi.org/10.31949/j-ensitec.v12i02.17972

ABSTRACT

The construction industry is widely recognized as one of the sectors with the highest levels of occupational risk, particularly in developing countries such as Timor Leste. The implementation of the Occupational Health and Safety Management System (OHSMS/SMK3) in construction projects is often limited to administrative compliance and is not fully supported by a strong safety culture and effective project leadership, resulting in suboptimal Occupational Health and Safety (OHS) performance. Therefore, understanding the interaction among these factors is essential to improving safety outcomes in construction environments. This study aims to analyze the influence of OHSMS implementation, safety culture, and project leadership on OHS performance in construction projects located in Dili City, Timor Leste. The research also examines both direct and indirect relationships among variables, including the mediating role of safety culture and OHSMS implementation. A quantitative research approach was employed using a survey method, in which structured questionnaires were distributed to construction project personnel directly involved in OHS activities. The collected data were analyzed using the Partial Least Square–Structural Equation Modeling (PLS-SEM) technique to evaluate the measurement and structural models. The findings reveal that OHSMS implementation and safety culture have significant positive effects on OHS performance. Project leadership demonstrates a crucial role in strengthening safety culture and enhancing the implementation of OHSMS, while also exerting an indirect influence on OHS performance through these mediating variables. Overall, the results emphasize the importance of integrating systematic, cultural, and leadership approaches to achieve sustainable improvements in occupational health and safety performance within construction projects in Timor Leste.

1. INTRODUCTION

The construction industry is one of the sectors that accounts for the largest number of work accidents, especially in developing countries. The complexity of the field, the rapid change in project conditions, and the involvement of many parties make the implementation of SMK3 a major challenge. Although SMK3 is required by regulations such as Government Regulation No. 50 of 2012, its implementation is often only administrative and has not shown real effectiveness in reducing incidents in the field [1]. Implementation that is only formal without the support of a strong work culture causes safety performance results to not be optimal.

The aspect of safety culture is very important because it affects the internalization of K3 values at every level of the project organization. Safety culture encompasses workers' perceptions, attitudes, and

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active participation in maintaining safety, not just procedural compliance. Studies in Makassar show that the effectiveness of SMK3 is greatly influenced by worker participation and a supportive work environment for safety practices [2]. These findings confirm that the formal SMK3 system will not be effective if it is not supported by a strong work culture [2].

The project leadership factor also plays a crucial role in creating a real safety culture. Transformational, communicative, and visionary leadership in terms of safety has been proven to be able to increase workers' compliance with K3 standards and strengthen the implementation of SMK3. Research on construction company PT Sinai Indonesia found that leadership does not have a significant influence on safety culture partially, but organizational culture has a strong contribution [3]. This shows the need for further research on the interaction between leadership, organizational culture, and the implementation of K3.

Project leadership factors also play an important role in creating a real safety culture. Transformational, communicative, and visionary leadership in terms of safety has been proven to be able to increase workers' compliance with K3 standards and strengthen the implementation of SMK3. Research on construction company PT Sinai Indonesia found that leadership does not have a significant influence on safety culture partially, but organizational culture has a strong contribution [3]. This shows the need for further research on the interaction between leadership, organizational culture, and K3 implementation.

In the context of the city of Dili, Timor Leste, the growth of post-reconstruction infrastructure development raises the urgency for occupational safety in construction projects. Preliminary observations show that the use of PPE is low and the accident reporting system has not been consistently running, while national K3 regulations have not been fully aligned with international standards. The lack of academic literature on the implementation of SMK3 and its supporting factors in Timor Leste reinforces the urgency of this research.

Most research related to SMK3, safety culture, and leadership is focused on countries such as Indonesia and Malaysia, with different contexts and cultures. There is a research gap related to how these three variables interact with each other in the local context of Timor Leste. Thus, this study aims to explore the relationship between the implementation of SMK3, safety culture, and project leadership on the performance of K3 in Dili City through multivariate quantitative analysis.

This research offers novelty in building a conceptual model that combines system variables (SMK3), cultural (safety culture), and managerial (leadership) variables in one analytical framework. Not only delving into structural aspects, this study also examines the social and behavioral dimensions that affect the effectiveness of work safety systems in construction projects.

With this approach, the results are expected to make a comprehensive empirical contribution to the development of more effective and contextual K3 policies in Timor Leste, as well as serve as a reference for contractors, project managers, and policymakers.

2. METHOD

Stages of research

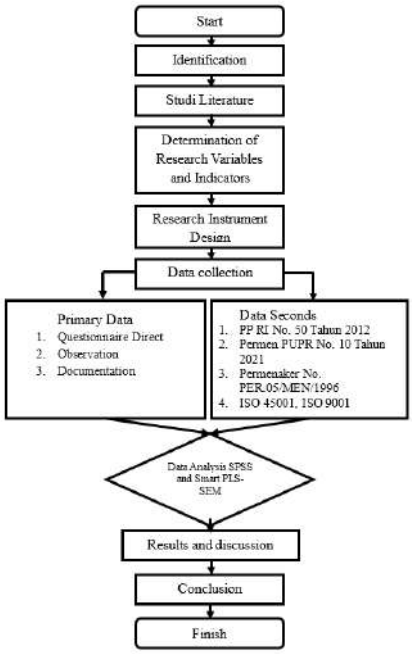

Figure 1. Stages of research

Research Variables

In this study, research variables are determined based on the results of the study Each variable is operationalized into several relevant and measurable indicators to facilitate the process of data collection and research analysis. The determination of indicators is carried out by referring to various national and international standards as well as scientific literature related to occupational safety and health (K3), safety culture, project leadership, and K3 performance. The independent variables in this study include SMK3 Management System (X1), Safety Culture (X2), and Project Leadership (X3), while the dependent variables are K3 Performance (Y). Each variable is described in indicators adopted from credible theoretical and regulatory sources, such as the ILO-OSH 2001 standard, ISO 45001:2018, Government Regulation of the Republic of Indonesia Number 50 of 2012, as well as various expert opinions in the field of occupational safety and organizational management. The details of the variables, indicators, and theoretical sources used in this study are presented in the following table.

Table 1. Research Variables

Research Variables	Indicator	Source
SMK3 Management System (X_1)	K3 Policies and Commitments	ILO-OSH 2001 Permenaker No. 05 Tahun 1996, Ramli, 2010; Sutalaksana, 2018
	Risk Identification and Evaluation	ISO 45001:2018, Ramli (2010)
	Planning and Implementation of K3 Programs	Permenaker No. 05 Tahun 1996, Ramli (2013)
	K3 Training and Competencies	Government Regulation Number 50 of 2012, Goetsch (2011), Suma'mur, 2019
	K3 System Audit and Evaluation	PP RI No. 50, 2012) Goetsch (2011), (Suma'mur, 2019).
Safety Culture (X_2)	Management's Commitment to Safety	PP RI No. 50, 2012) (ILO-OSH 2001), ISO 45001:2018

		Ramli (2010) Goetsch (2011),
	Effective Safety Communication	PP RI No. 50, 2012) ISO 45001:2018 Ramli (2010),
	Occupational Safety & Health Training and Education (K3)	PP RI No. 50, 2012) (ILO-OSH 2001), ISO 45001:2018 Ramli (2010) Goetsch (2011),
	Participation of K3 Workers	PP RI No. 50, 2012) Ramli (2010), Geller (2001) Cooper (2000).
	Attitudes Towards Reporting and Lessons from Incidents	ILO-OSH 2001 Reason (1997) ISO 45001:2018 PP No. 50 Tahun 2012 Ramli (2013),
Project Leadership (X_3)	Transformational Leadership (Vision, Motivation, and Example)	Burns, 1978 Bernard M Bass, 1985
	Transactional leadership (oversight, incentives)	Burns, 1978 Bernard M Bass, 1985
	Decision-making in emergency situations	Klein, 1998 Flin et al., 2008 Reason, 1997
	Direct involvement in K3 programs	ILO, 2001, Goetsch, 2015, Cooper, 2000
	Ability to build team trust	Mayer et al., 1995 Yukl, 2013 Robbins & Judge, 2017
K3 Performance (Y)	Accident Frequency (FR)	Indrayana et al Hanifah dkk
	K3 Procedure Compliance	Susilawati et al. 2022), Firdaus & Hasin (2022)
	Training & Safety Talk	Susilawati et al. 2022), Firdaus & Hasin (2022)
	Routine Audits & Inspections	Susilawati et al. 2022), Firdaus & Hasin (2022)
	Participation and Incident Reporting/Near Incident	Susilawati et al. 2022), Firdaus & Hasin (2022)

3. RESULTS AND DISCUSSION

With the validity test, it is hoped that only the question items that meet the requirements are maintained for the main data collection stage, so that the research instrument can really measure the variables in question precisely and accurately. The following table is the data of the validity test results of the pilot study with SPSS V25 and refers to the R table value of 0.576:

Table 2. SPSS V25 validity test results

		X01	X02	X03	X04	X…..	Total	
X01	Pearson Correlation	1	0,345	.707*	.690*	….....	0,598	Valid
	Sig. (2-tailed)		0,329	0,022	0,027	….....	0,068	
	N	10	10	10	10	….....	10	
X02	Pearson Correlation	0,345	1	0,000	0,524	….....	0,585	Valid
	Sig. (2-tailed)	0,329		1,000	0,120	….....	0,075	
	N	10	10	10	10	….....	10	
X03	Pearson Correlation	.707*	0,000	1	0,488	….....	0,609	Valid

	Sig. (2-tailed)	0,022	1,000		0,153	….....	0,062	
	N	10	10	10	10	….....	10	
X04	Pearson Correlation	.690*	0,524	0,488	1	….....	.716*	Valid
	Sig. (2-tailed)	0,027	0,120	0,153		….....	0,020	
	N	10	10	10	10	….....	10	
X05	Pearson Correlation	.791**	0,218	0,559	.764*	….....	0,591	Valid
	Sig. (2-tailed)	0,006	0,545	0,093	0,010	….....	0,072	
	N	10	10	10	10	….....	10	
X06	Pearson Correlation	0,345	0,524	0,488	0,524	….....	.701*	Valid
	Sig. (2-tailed)	0,329	0,120	0,153	0,120	….....	0,024	
	N	10	10	10	10	….....	10	
X07	Pearson Correlation	.881**	0,284	.830**	.689*	….....	.676*	Valid
	Sig. (2-tailed)	0,001	0,427	0,003	0,028	….....	0,032	
	N	10	10	10	10	….....	10	
X08	Pearson Correlation	0,527	.873**	0,373	0,509	….....	.660*	Valid
	Sig. (2-tailed)	0,117	0,001	0,289	0,133	….....	0,038	
	N	10	10	10	10	….....	10	
X09	Pearson Correlation	.791**	0,218	0,559	.764*	….....	0,591	Valid
	Sig. (2-tailed)	0,006	0,545	0,093	0,010	….....	0,072	
	N	10	10	10	10	….....	10	
X10	Pearson Correlation	.791**	0,218	0,559	.764*	….....	0,591	Valid
	Sig. (2-tailed)	0,006	0,545	0,093	0,010	….....	0,072	
	N	10	10	10	10	….....	10	
X11	Pearson Correlation	0,294	.689*	0,000	0,284	….....	.676*	Valid
	Sig. (2-tailed)	0,410	0,028	1,000	0,427	….....	0,032	
	N	10	10	10	10	….....	10	
X12	Pearson Correlation	0,294	.689*	0,000	0,284	….....	.676*	Valid
	Sig. (2-tailed)	0,410	0,028	1,000	0,427	….....	0,032	
	N	10	10	10	10	….....	10	
X13	Pearson Correlation	0,264	0,509	0,373	0,509	….....	.848**	Valid
	Sig. (2-tailed)	0,462	0,133	0,289	0,133	….....	0,002	
	N	10	10	10	10	….....	10	
X14	Pearson Correlation	0,000	.690*	0,000	0,345	….....	.661*	Valid
	Sig. (2-tailed)	1,000	0,027	1,000	0,329	….....	0,037	
	N	10	10	10	10	….....	10	
X15	Pearson Correlation	0,211	0,408	0,000	0,408	….....	0,582	Valid
	Sig. (2-tailed)	0,558	0,242	1,000	0,242	….....	0,077	
	N	10	10	10	10	….....	10	
X16	Pearson Correlation	0,408	0,563	0,289	0,563	….....	.737*	Valid
	Sig. (2-tailed)	0,242	0,090	0,419	0,090	….....	0,015	
	N	10	10	10	10	….....	10	
X17	Pearson Correlation	0,000	0,582	0,000	0,218	….....	0,580	Valid
	Sig. (2-tailed)	1,000	0,078	1,000	0,545	….....	0,079	
	N	10	10	10	10	….....	10	
X18	Pearson Correlation	0,452	0,530	0,319	0,530	….....	.757*	Valid
	Sig. (2-tailed)	0,190	0,115	0,368	0,115	….....	0,011	
	N	10	10	10	10	….....	10	
X19	Pearson Correlation	0,452	0,530	0,319	0,530	….....	.804**	Valid
	Sig. (2-tailed)	0,190	0,115	0,368	0,115	….....	0,005	
	N	10	10	10	10	….....	10	
X20	Pearson Correlation	0,226	.842**	0,000	0,530	….....	.729*	Valid
	Sig. (2-tailed)	0,530	0,002	1,000	0,115	….....	0,017	
	N	10	10	10	10	….....	10	
X21	Pearson Correlation	0,294	0,527	0,415	0,527	….....	.755*	Valid
	Sig. (2-tailed)	0,410	0,118	0,233	0,118	….....	0,012	
	N	10	10	10	10	….....	10	
X22	Pearson Correlation	0,395	0,327	0,559	0,327	….....	.787**	Valid
	Sig. (2-tailed)	0,258	0,356	0,093	0,356	….....	0,007	
	N	10	10	10	10	….....	10	
X23	Pearson Correlation	0,264	0,145	0,373	0,145	….....	0,604	Valid
	Sig. (2-tailed)	0,462	0,688	0,289	0,688	….....	0,064	
	N	10	10	10	10	….....	10	
X24	Pearson Correlation	0,000	0,218	0,000	0,218	….....	0,624	Valid

	Sig. (2-tailed)	1,000	0,545	1,000	0,545	….....	0,054	
	N	10	10	10	10	….....	10	
X25	Pearson Correlation	0,395	0,327	0,559	0,327	….....	.787**	Valid
	Sig. (2-tailed)	0,258	0,356	0,093	0,356	….....	0,007	
	N	10	10	10	10	….....	10	
X26	Pearson Correlation	0,000	0,218	0,000	0,218	….....	0,624	Valid
	Sig. (2-tailed)	1,000	0,545	1,000	0,545	….....	0,054	
	N	10	10	10	10	….....	10	
X27	Pearson Correlation	0,452	0,530	.639*	0,530	….....	.719*	Valid
	Sig. (2-tailed)	0,190	0,115	0,047	0,115	….....	0,019	
	N	10	10	10	10	….....	10	
X28	Pearson Correlation	0,226	0,530	0,319	0,218	….....	0,624	Valid
	Sig. (2-tailed)	0,530	0,115	0,368	0,545	….....	0,054	
	N	10	10	10	10	….....	10	
X29	Pearson Correlation	0,204	0,282	0,577	0,282	….....	.703*	Valid
	Sig. (2-tailed)	0,572	0,430	0,081	0,430	….....	0,023	
	N	10	10	10	10	….....	10	
X30	Pearson Correlation	0,000	0,488	0,000	0,488	….....	0,624	Valid
	Sig. (2-tailed)	1,000	0,153	1,000	0,153	….....	0,054	
	N	10	10	10	10	….....	10	
Y1	Pearson Correlation	0,494	-0,034	.698*	.648*	….....	.670*	Valid
	Sig. (2-tailed)	0,147	0,926	0,025	0,043	….....	0,034	
	N	10	10	10	10	….....	10	
Y2	Pearson Correlation	0,494	-0,034	.698*	.648*	….....	.670*	Valid
	Sig. (2-tailed)	0,147	0,926	0,025	0,043	….....	0,034	
	N	10	10	10	10	….....	10	
Y3	Pearson Correlation	0,494	-0,034	.698*	0,307	….....	0,597	Valid
	Sig. (2-tailed)	0,147	0,926	0,025	0,389	….....	0,068	
	N	10	10	10	10	….....	10	
Y4	Pearson Correlation	0,316	0,218	0,447	.655*	….....	0,611	Valid
	Sig. (2-tailed)	0,373	0,545	0,195	0,040	….....	0,061	
	N	10	10	10	10	….....	10	
Y5	Pearson Correlation	0,395	0,327	0,559	0,327	….....	.787**	Valid
	Sig. (2-tailed)	0,258	0,356	0,093	0,356	….....	0,007	
	N	10	10	10	10	….....	10	
Y6	Pearson Correlation	.678*	0,094	.639*	.717*	….....	.666*	Valid
	Sig. (2-tailed)	0,031	0,797	0,047	0,020	….....	0,036	
	N	10	10	10	10	….....	10	
Y7	Pearson Correlation	0,395	0,327	0,559	0,327	….....	.787**	Valid
	Sig. (2-tailed)	0,258	0,356	0,093	0,356	….....	0,007	
	N	10	10	10	10	….....	10	
Y8	Pearson Correlation	0,527	-0,145	.745*	0,582	….....	0,624	Valid
	Sig. (2-tailed)	0,117	0,688	0,013	0,078	….....	0,054	
	N	10	10	10	10	….....	10	
Y9	Pearson Correlation	0,527	0,509	.745*	0,509	….....	.748*	Valid
	Sig. (2-tailed)	0,117	0,133	0,013	0,133	….....	0,013	
	N	10	10	10	10	….....	10	
Y10	Pearson Correlation	0,294	0,527	0,415	0,527	….....	.755*	Valid
	Sig. (2-tailed)	0,410	0,118	0,233	0,118	….....	0,012	
	N	10	10	10	10	….....	10	
Total	Pearson Correlation	0,598	0,585	0,609	.716*	….....	1	
	Sig. (2-tailed)	0,068	0,075	0,062	0,020	….....		
	N	10	10	10	10	….....	10	

Based on the results of the Validity Test pilot study with 10 respondents and tested using SPS V25, it was found that 40 test items were declared valid by referring to the R calculation > of the R table (0.576), then a reliability test will be carried out.

Reliability Test

Reliability test is a statistical procedure used to measure the extent to which a research instrument can provide consistent results if tested again under similar conditions. Reliability is important because a reliable instrument will guarantee that the data obtained truly reflects the real situation, not just a coincidence. One

of the most commonly used methods is Cronbach's Alpha, provided that a reliability coefficient value of ≥ 0.70 is considered sufficient to declare an instrument reliable, although in exploratory research a value of ≥ 0.60 is still acceptable [4]. Thus, research instruments that meet the reliability requirements will increase the credibility of the data analysis results.

Tabel 3. Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
X01	156,2000	239,733	0,571	0,967
X02	155,9000	243,211	0,565	0,967
X03	156,2000	243,067	0,590	0,967
X04	155,9000	241,211	0,701	0,966
X05	156,0000	244,222	0,573	0,967
X06	155,9000	241,433	0,685	0,966
X07	156,1000	240,100	0,656	0,966
X08	156,0000	239,111	0,636	0,966
X09	156,0000	244,222	0,573	0,967
X10	156,0000	244,222	0,573	0,967
X11	156,1000	240,100	0,656	0,966
X12	156,1000	240,100	0,656	0,966
X13	156,0000	235,333	0,836	0,965
X14	156,2000	238,400	0,637	0,966
X15	156,0000	238,000	0,548	0,967
X16	156,2000	233,511	0,712	0,966
X17	156,4000	240,711	0,553	0,967
X18	156,1000	234,767	0,736	0,966
X19	156,1000	233,656	0,787	0,966
X20	156,1000	235,433	0,706	0,966
X21	156,3000	238,678	0,739	0,966
X22	156,4000	241,600	0,776	0,966
X23	156,0000	240,222	0,578	0,967
X24	156,3000	245,789	0,612	0,967
X25	156,4000	241,600	0,776	0,966
X26	156,3000	245,789	0,612	0,967
X27	156,1000	235,656	0,695	0,966
X28	156,1000	237,878	0,595	0,967
X29	156,2000	234,400	0,676	0,966
Y30	156,2000	242,844	0,605	0,967
Y31	156,5000	238,056	0,646	0,966
Y32	156,5000	238,056	0,646	0,966
Y33	156,5000	239,611	0,569	0,967
Y34	156,7000	242,011	0,589	0,967
Y35	156,4000	241,600	0,776	0,966
Y36	156,3000	236,900	0,639	0,966
Y37	156,4000	241,600	0,776	0,966
Y38	156,4000	239,822	0,599	0,967
Y39	156,0000	237,333	0,730	0,966
Y40	156,3000	238,678	0,739	0,966

From the results of the reliability test using SPSS V25, Cronbach's Alpha 0.967 was obtained greater than 0.70 so that the questionnaire could be declared quite reliable.

Evaluation of the PLS-SEM Model

Figure 2 below shows the research structural models (inner and outer models) used in the analysis using Partial Least Squares Structural Equation Modeling (PLS-SEM). The model describes the relationship between latent variables consisting of the Implementation of the K3 Management System (X1), Safety Culture (X2), Project Leadership (X3), and K3 Performance (Y). Each variable is measured by a number of indicators represented by yellow checkers, while the relationships between latent variables are depicted through a one-way arrow indicating the direction of influence. In general, this model aims to examine the

extent to which project leadership and safety culture affect the implementation of SMK3, as well as how these three variables together affect the performance of K3 in construction projects.

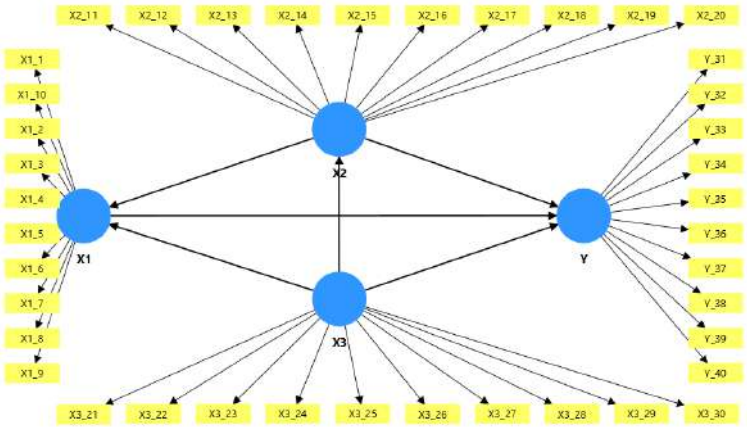

Figure 2. PLS-SEM Model

Reviews Outer Model

Convergent Validity

Convergent validity in the measurement model with the indicator reflective model is assessed based on the correlation between the item score/component score and the construct score calculated using PLS. The reflective size is considered high if it has a correlation of more than 0.70 with the measured construct. However, in the early stages of research or in the development of measurement scales, a loading value between 0.5 to 0.6 is still considered adequate [5]. This value describes how much of a correlation there is between each measurement item (indicator) and its construct. Thus, all outer loading is in the range of 0.5 to 0.6.

Tabel 3. Convergent Validity Outer Loadings (Loading Factor)

	X1	X2	X3	Y
X1_1	0.733			
X1_10	0.830			
X1_2	0.892			
X1_3	0.813			
X1_4	0.829			
X1_5	0.807			
X1_6	0.764			
X1_7	0.683			
X1_8	0.823			
X1_9	0.900			
X2_11		0.848		
X2_12		0.819		
X2_13		0.883		
X2_14		0.747		
X2_15		0.917		
X2_16		0.801		
X2_17		0.801		
X2_18		0.690		
X2_19		0.891		
X2_20		0.909		
X3_21			0.813	
X3_22			0.696	
X3_23			0.835	
X3_24			0.771	
X3_25			0.821	
X3_26			0.889	
X3_27			0.829	

X3_28			0.843	
X3_29			0.635	
X3_30			0.918	
Y_31				0.785
Y_32				0.806
Y_33				0.929
Y_34				0.769
Y_35				0.801
Y_36				0.900
Y_37				0.817
Y_38				0.734
Y_39				0.780
Y_40				0.831

Discriminant Validity

The discriminant validity test is performed to ensure that each latent construct has a clear difference from the others. Based on the test results shown in the correlation matrix between constructs, all correlation values between latent variables are below the value of 0.85. This shows that there is no problem of multicollinearity or overlapping concepts between constructs[6]. Thus, each latent construct can be declared to have good discriminant validity because it is able to represent concepts that are different from each other [7].

Tabel 4. Discriminant Validity

	X1	**X2**	**X3**	**Y**
X1				
X2	0.387			
X3	0.365	0.210		
Y	0.437	0.314	0.470	

Crros Loading

The following table 4 shows the results of the convergent and discriminant validity test through cross-loading analysis between indicators on each latent variable in the research model. This test aims to ensure that each indicator has a higher level of linkage (loading factor) to the construct it is measuring compared to other constructs. Based on the table, each indicator of the K3 Management System (X1), Safety Culture (X2), Project Leadership (X3), and K3 Performance (Y) variables showed the highest loading value on the corresponding construct, indicating that each indicator was able to reflect its latent variables well. This shows that the model has sufficient convergent and discriminant validity, so that the instruments used can be declared reliable and feasible for further structural analysis in the study.

Tabel 5. Crros Loading

	X1	**X2**	**X3**	**Y**
X1_1	0.733	0.324	0.284	0.222
X1_10	0.830	0.310	0.345	0.431
X1_2	0.892	0.375	0.331	0.388
X1_3	0.813	0.337	0.352	0.286
X1_4	0.829	0.244	0.220	0.318
X1_5	0.807	0.256	0.303	0.305
X1_6	0.764	0.304	0.258	0.370
X1_7	0.683	0.195	0.227	0.285
X1_8	0.823	0.366	0.257	0.377
X1_9	0.900	0.337	0.256	0.376
X2_11	0.320	0.848	0.209	0.220
X2_12	0.230	0.819	0.168	0.208
X2_13	0.296	0.883	0.165	0.211
X2_14	0.255	0.747	0.112	0.257
X2_15	0.327	0.917	0.178	0.345
X2_16	0.349	0.801	0.221	0.290
X2_17	0.395	0.801	0.084	0.318

X2_18	0.132	0.690	0.212	0.103
X2_19	0.368	0.891	0.109	0.268
X2_20	0.384	0.909	0.196	0.331
X3_21	0.245	0.200	0.813	0.356
X3_22	0.332	0.122	0.696	0.424
X3_23	0.301	0.085	0.835	0.326
X3_24	0.209	0.133	0.771	0.303
X3_25	0.295	0.262	0.821	0.402
X3_26	0.275	0.131	0.889	0.420
X3_27	0.374	0.168	0.829	0.382
X3_28	0.232	0.124	0.843	0.358
X3_29	0.173	0.163	0.635	0.202
X3_30	0.343	0.174	0.918	0.475
Y_31	0.346	0.312	0.349	0.785
Y_32	0.468	0.335	0.389	0.806
Y_33	0.416	0.253	0.420	0.929
Y_34	0.307	0.380	0.386	0.769
Y_35	0.299	0.130	0.284	0.801
Y_36	0.281	0.285	0.391	0.900
Y_37	0.318	0.224	0.514	0.817
Y_38	0.359	0.098	0.243	0.734
Y_39	0.317	0.311	0.377	0.780
Y_40	0.290	0.185	0.350	0.831

Output Line Coefficient (Outer Model)

After the measurement model (outer model) is declared to meet the criteria of validity and reliability, the next stage is to test the structural model (inner model). Structural model analysis aims to determine the causal relationship between latent constructs, namely how much influence each independent variable has on the dependent variables in the research model.

Figure 3 below shows the results of the PLS (Partial Least Squares) structural model estimation which illustrates the relationship between constructs, path coefficient values, and R-square values (R^2) in each endogenous variable. The R-square value indicates how much the independent variable is able to explain the variability of the dependent variable, while the path coefficient describes the direction and strength of the relationship between constructs.

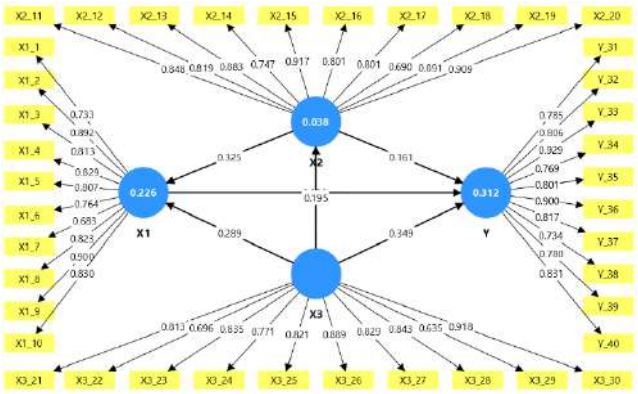

Figure 3 Path Coefficient (Outer Model)

Thus, the image describes the direction of the relationship between variables as follows:

1. Project Leadership (X3) affects Safety Culture (X2), SMK3 Implementation (X1), and K3 Performance (Y).
2. Safety Culture (X2) affects the Implementation of SMK3 (X1) and K3 (Y) Performance.
3. The implementation of SMK3 (X1) also has an influence on K3 (Y) Performance.

The R-square value of each construct is:

1. X1 is 0.226,
2. X2 is 0.038,
3. Y is 0.312.

These values show that exogenous variables have a fairly strong influence on endogenous constructs, especially on the Performance variable K3 (Y) which can be explained by 31.2% by the construct that affects it.

4. CONCLUSION

Based on the results of data analysis and discussion that has been carried out in the previous chapter, it can be concluded that several important things can be concluded as follows:

1. Project Leadership (X3) has a positive and significant effect on the implementation of the Occupational Safety and Health Management System (SMK3) (X1). This shows that the better the quality of leadership applied in a project, the more effective the implementation of the K3 management system in the work environment. Project leaders who are able to provide example, motivation, and good supervision are proven to increase workers' compliance and awareness of safety procedures.
2. Safety Culture (X2) has a positive effect on the implementation of SMK3 (X1), although the level of influence is moderate. This means that a strong safety culture among workers and management can strengthen the implementation of SMK3 in the field. However, this effect is not very dominant, indicating that other factors such as management policies or resources still play an important role in the successful implementation of the K3 system.
3. Project Leadership (X3) also has a positive and significant influence on Safety Culture (X2). This means that a leadership style that is participatory, communicative, and concerned about safety contributes to the formation of a good safety culture in the project work environment.
4. The implementation of SMK3 (X1) has been proven to have a positive and significant effect on K3 (Y) Performance. This indicates that the better the implementation of the K3 management system in the project, the higher the level of K3 performance achieved, such as a reduction in the number of work accidents, increased compliance with safety standards, and increased work efficiency.
5. Safety Culture (X2) has a positive but insignificant effect on K3 (Y) Performance. These results suggest that while safety culture is important in creating safe behaviors, its direct effect on K3 performance has not been particularly strong. This factor is likely to take longer to make a significant impact through sustained behavioral change.
6. Project Leadership (X3) has a positive and significant influence on K3 (Y) Performance, both directly and indirectly through the mediation variable of SMK3 implementation. This shows that project leaders play a strategic role in improving occupational safety performance through supervision, communication, as well as the implementation of effective management systems.
7. Based on the results of the R-square test, it is known that the research model is able to explain 31.2% variation in the K3 (Y) Performance variable, which means that this model has moderate explanatory power. Meanwhile, the results of the Predictive Relevance (Q^2) test showed that the model had good predictive relevance, especially for the variables of SMK3 Implementation and K3 Performance.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10489-10496

Bibliometric Analysis of Rice Husk Biomass Potential as an Environmentally Friendly Alternative Fuel

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ARTICLE INFO

Article history:
Received 25 April 2026
Revised 30 April 2026
Accepted 07 Mei 2026
Available online 25 June 2026

Keywords:
Biomass
Rice Husk
Renewable Energy
Bioenergy

IEEE style in citing this article:
S. N. Naylah, D. Ramadhani, M. A. Ramadhan, R. Romatona, M. A. As-Silmy, and E. A. Zharif, "Bibliometric analysis of rice husk biomass potential as an environmentally friendly alternative fuel," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10489-10496, 2026.

Doi:
https://doi.org/10.31949/j-ensitec.v12i02.18019

ABSTRACT

The increasing global energy demand and environmental concerns have intensified the search for sustainable alternative fuels. Rice husk, an abundant agricultural by-product in rice-producing countries, has attracted growing attention as a promising biomass resource. However, previous studies have mainly focused on technical conversion processes, while limited research has systematically examined publication trends and thematic developments in this field. Therefore, this study aims to analyze global research trends on rice husk biomass as an environmentally friendly alternative fuel using a bibliometric approach. Data were collected from the Scopus database covering publications from 2020 to 2026 using relevant keywords related to rice husk biomass and renewable energy. The data were analyzed using VOSviewer and Microsoft Excel to identify publication growth, dominant journals, collaboration networks, and keyword trends. The results show a significant increase in publications, reaching a peak in 2024, with Renewable Energy as the leading publication source. Keyword co-occurrence analysis revealed major themes such as biofuels, pyrolysis, combustion, and emission control. Thematic mapping indicates that combustion efficiency and thermal performance remain core research topics, while pelletizing and environmental assessment are emerging themes. This study provides insights into research directions and highlights the importance of technological innovation, efficiency improvement, and sustainability assessment to enhance rice husk utilization as a renewable energy source.

1. INTRODUCTION

The global energy crisis, rising fossil fuel prices, and increasing environmental concerns have encouraged many countries to accelerate the transition toward renewable energy sources. Fossil fuel dependence not only threatens long-term energy security but also contributes significantly to greenhouse

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gas emissions and climate change(Harahap, Nasution, and ... 2020). Therefore, developing sustainable and environmentally friendly alternative energy sources has become a global priority(Mesin et al. 2021).

Among renewable energy resources, biomass has gained considerable attention due to its abundance, renewability, and relatively carbon-neutral characteristics(Hasrudy Siregar et al. 2022; Madhubashani et al. 2021). In agricultural countries such as Indonesia, agricultural residues represent an important biomass resource with significant energy potential. One of the most abundant agricultural wastes is rice husk, a by-product of rice milling that accounts for approximately 20–30% of total rice grain weight(Surahmanto et al. 2023).

Indonesia is one of the largest rice-producing countries in the world, generating millions of tons of rice husk annually. However, a large portion of this residue remains underutilized or is disposed of through open burning, causing environmental pollution and wasting potential energy resources. This condition creates opportunities to convert rice husk into value-added renewable fuel products(Budiyono et al. 2023).

Rice husk possesses favorable fuel characteristics, including lignocellulosic composition, wide availability, and calorific values ranging from 13–16 MJ/kg. It can be converted into useful energy through combustion, gasification, pyrolysis, briquetting, and pelletizing technologies(Siregar, Siregar, and Effendi 2021). However, several challenges remain, such as high ash content, low bulk density, conversion efficiency limitations, and emission concerns.

Previous studies have primarily focused on technical performance and conversion technologies. However, limited studies have comprehensively mapped global research trends, publication growth, collaboration networks, and emerging themes related to rice husk biomass utilization. This indicates a research gap in understanding the scientific development of this topic from a bibliometric perspective(Khamis et al. 2026).

Therefore, this study aims to conduct a bibliometric analysis of rice husk biomass research published in the Scopus database from 2020 to 2026. This study contributes by identifying publication trends, leading journals, collaboration patterns, and future research opportunities to support sustainable biomass energy development.

2. METHOD

The research method used in this study is a bibliometric method with a quantitative descriptive approach. This approach was chosen to systematically analyze the development of scientific publications related to the potential of rice husk biomass as an environmentally friendly alternative fuel. The bibliometric method allows for the identification of research patterns, scientific collaborations, and topic trends based on quantitative data from the scientific literature(Duque-Acevedo et al. 2022; Khamis et al. 2026). The primary data source was obtained from the Scopus database, an internationally reputable database with extensive coverage of scientific publications. The data used was limited to journal articles published between 2020 and 2026 to ensure the novelty and relevance of the research. The search process was conducted using a combination of keywords such as "biomass," "rice husk," "renewable energy," "bioenergy," and "agricultural waste" with the help of Boolean operators (AND, OR) to obtain specific and focused results.

The data collection technique involved several stages: identification, screening, and selection of articles. In the identification stage, all documents relevant to the keywords were collected from Scopus. Next, a screening process was conducted based on inclusion criteria, including document type (journal article), language (English), and topic relevance to the research focus. Duplicate or irrelevant articles were eliminated to maintain data validity. After the selection process, the data was exported in CSV or RIS format to facilitate further analysis. This study used VOSviewer software to visualize the bibliometric network and Microsoft Excel to process descriptive data, such as publication distribution, keyword frequency, and author and institutional contributions.

Data analysis was conducted using several key techniques: co-authorship analysis to identify collaboration patterns among researchers, keyword co-occurrence analysis to uncover dominant themes and interrelationships between topics, and citation analysis to assess the influence and contribution of publications in the field. Furthermore, research trend analysis was conducted to observe the development

of the number of publications and the evolution of topics over time. The overall research process included keyword selection, data collection from Scopus, article screening and selection, data extraction, analysis using VOSviewer and Excel, and network visualization and interpretation of results. This process ensures that the research results provide a comprehensive overview of the development of rice husk biomass research as an alternative energy source.

3. RESULTS AND DISCUSSION

1. Most Relevant Sources

To understand how scientific publication trends in rice husk biomass are evolving, it is important to first identify the most active and influential journal sources. This analysis provides an overview of the primary channels for research dissemination and identifies the dominant scientific centers in the field of biomass-based renewable energy(Geethakarthi 2021).

Figure 1. Most Relevant Sources

Based on this visualization, the Renewable Energy journal is the most dominant publication source with the highest number of documents(Sasongko et al. 2024). This indicates that the journal has a strong focus on renewable energy issues, including biomass. Furthermore, the presence of proceedings such as the AIP Conference Proceedings and the IOP Conference Series indicates that research developments are also frequently presented in scientific forums. Other journals, such as the Journal of Cleaner Production, indicate the link between biomass and environmental sustainability issues. This distribution demonstrates that biomass research is interdisciplinary and spread across various reputable scientific platforms(Cho et al. 2025).

To gain a more comprehensive understanding of the distribution of scientific publications in the field of rice husk biomass, it is necessary to identify the most active and significantly contributing journal sources(Stefanelli et al. 2023). This analysis is essential for identifying centers of knowledge dissemination and journals with a strong focus on biomass-based renewable energy development. The results of the data processing are then presented in the following table.

Table 1. Top Publication Sources on Rice Husk Biomass Research

NO	Journal Source	Number of Documents
1	Renewable Energy	10
2	AIP Conference Proceedings	6

3	IOP Conference Series: Earth and Environmental Science	5
4	Journal of Cleaner Production	4
5	Energy Sources, Part A: Recovery, Utilization and Environmental Effects	3
6	Biomass and Bioenergy	3
7	Sustainability (Switzerland)	2
8	Energy Reports	2
9	Renewable and Sustainable Energy Reviews	2
10	Materials Today: Proceedings	2

The following table shows that the Renewable Energy journal is the most dominant publication source with the highest number of documents. This indicates that the journal plays a strategic role in disseminating research related to renewable energy, particularly biomass(Jagnade and Panwar 2024). Furthermore, the presence of proceedings such as the AIP Conference Proceedings and the IOP Conference Series indicates that research development is also encouraged through international scientific forums. Journals such as the Journal of Cleaner Production and Biomass and Bioenergy reflect the integration of energy and environmental sustainability. Overall, this distribution demonstrates that rice husk biomass research is developing multidisciplinary and is spread across various reputable scientific platforms(Srivastava et al. 2023).

2. Documents by Year

In addition to publication sources, the dynamics of research development can also be observed through trends in the number of publications over time. This analysis is important to determine the extent to which the topic of rice husk biomass is gaining or losing attention in the global scientific community.

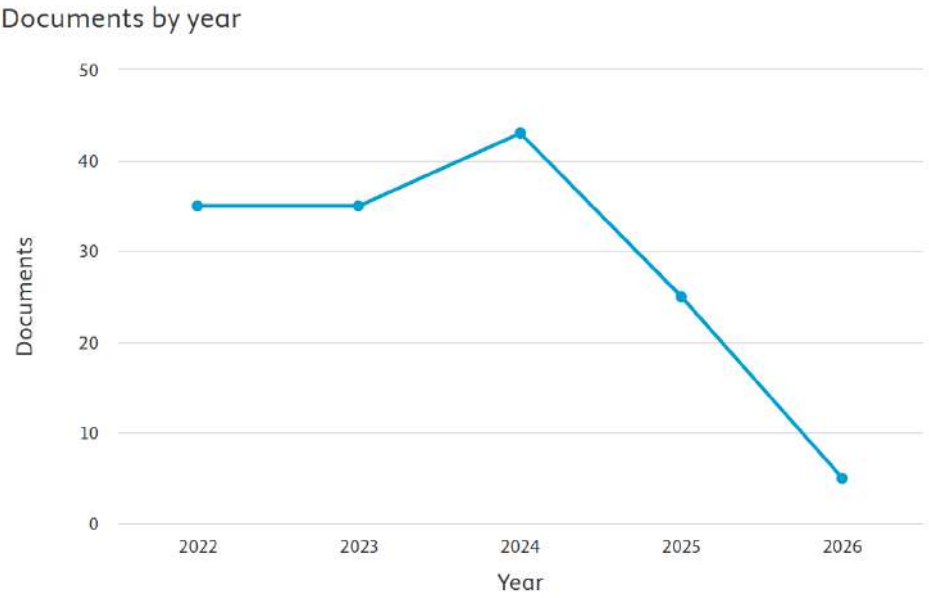

Figure 2. Annual Publication Trends (2022–2026)

The graph shows an increase in the number of publications from 2022 to a peak in 2024. This reflects growing interest in biomass energy as an alternative solution amid the global energy crisis. However, after this period, there is a decline in 2025 and 2026, likely influenced by limited recent data or a change in research focus(Wu et al. 2025). Overall, this trend confirms that biomass research is still in its developing phase and remains relevant for further study.

3. Network Visualization (Co-occurrence Keywords)

To gain a deeper understanding of the scientific structure of biomass research, an analysis of the relationships between the concepts used by researchers is necessary(Xu et al. 2026). These relationships can be identified through the appearance of associated. keywords in various scienti publications.

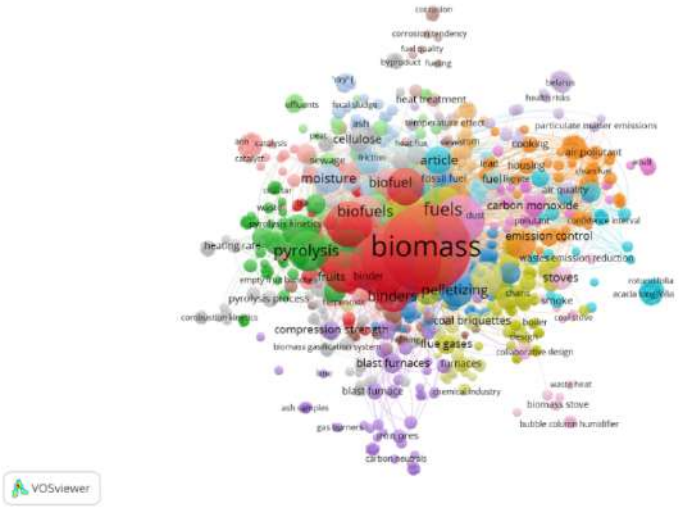

Figure 3. Keyword Co-occurrence Network

The visualization shows that "biomass" is the main hub in the research network, with strong links to keywords such as "biofuels," "pyrolysis," and "fuels." This indicates that the primary research focus lies on biomass energy conversion processes. Furthermore, links to keywords such as "emission control" and "air quality" indicate a concern for environmental impacts. The resulting clusters reflect the existence of several research subfields developing in parallel, such as conversion technology and environmental aspects(Przybyla and Nadaleti 2023; Siregar et al. 2024).

To understand the conceptual structure of rice husk biomass research, an analysis of the interrelationships between keywords used in scientific publications is necessary. This analysis aims to identify key themes and the relationships between emerging research topics. The results of the co-occurrence analysis are then summarized in the following table to provide a more structured overview.

Table 2. Most Frequent Keywords in Rice Husk Biomass Research

No	Keywords	Frequency (Occurrence)	Description
1	Biomass	High	Main research topic
2	Biofuels	High	Biomass energy conversion
3	Pyrolysis	High	Biomass processing technology
4	Fuels	Medium	Energy application
5	Pelletizing	Medium	Fuel quality improvement
6	Combustion	Medium	Combustion process
7	Emission Control	Medium	Environmental impact
8	Air Quality	Low–Medium	Environmental quality
9	Carbon Monoxide	Low	Gas emissions
10	Agricultural Waste	Medium	Biomass source

The table above shows that the keyword "biomass" is the primary focus of research, indicating that the focus of studies is still oriented towards the use of biomass as an energy source(Le et al. 2022). The strong association with keywords such as "biofuels" and "pyrolysis" indicates that much research is directed at energy conversion technologies. Furthermore, the emergence of keywords such as "emission control"

ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)

and "air quality" indicates a growing concern about the environmental impacts of biomass use. Therefore, it can be concluded that research in this field focuses not only on technical aspects but also encompasses broader sustainability and environmental dimensions(Przybyla and Nadaleti 2023).

4. Country Collaboration Map

Research development is inseparable from contributions and collaboration between countries. Therefore, analyzing geographic distribution is crucial for identifying countries that are actively participating and patterns of international cooperation in biomass research.

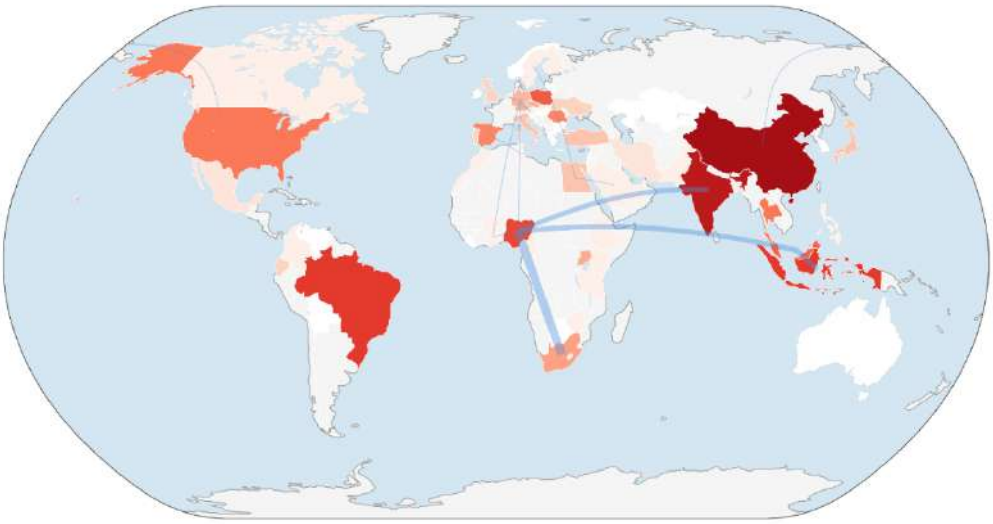

Figure 4. Country Collaboration Map

The map shows that countries such as China, India, and Indonesia have made significant contributions to biomass research. This is closely related to the availability of biomass resources in these countries. Furthermore, cross-regional collaboration is evident, particularly between Asia, Europe, and Africa. This collaboration reflects the fact that biomass research is a global issue that requires synergy between countries in technology development and implementation(Pueyo 2026).

5. Thematic Map

To understand the direction and position of the development of research topics, a thematic mapping is needed that is able to group the main issues based on their level of importance and maturity in the scientific literature.

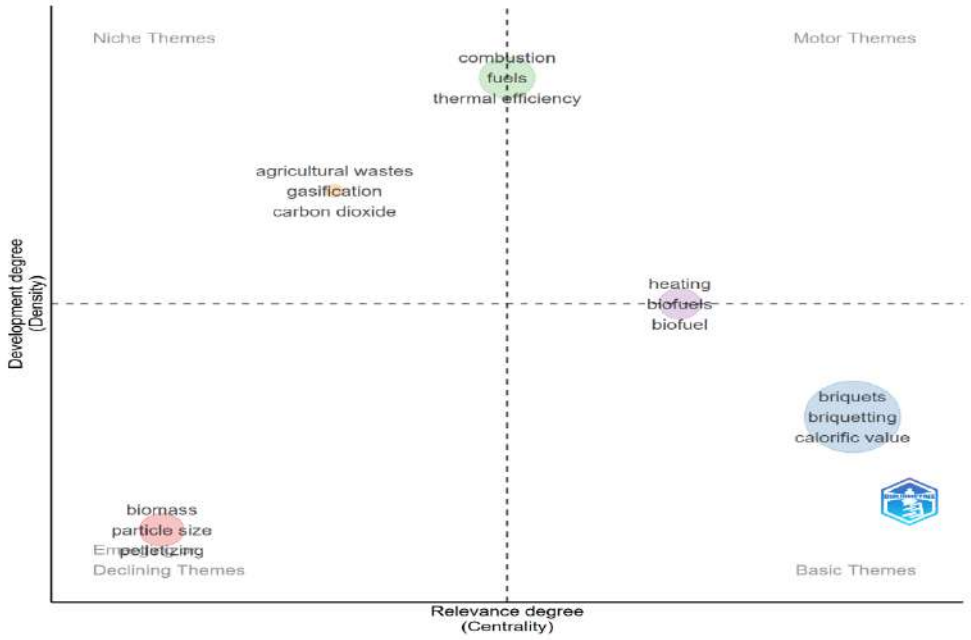

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Figure 5. Thematic Map of Research Topics

The thematic map shows that topics like "combustion" and "thermal efficiency" fall into the motor themes category, meaning they are highly developed and play a significant role in research. Meanwhile, "briquettes" and "calorific value" fall into the basic themes category, which serve as the foundation for research but still require further development. Themes like "gasification" fall into the niche themes category, which are specific but well-developed. Meanwhile, "biomass" and "pelletizing" fall into the emerging or declining themes category, indicating potential new trends or declining interest. This mapping provides a strategic overview of the future direction of biomass research(Kole et al. 2022).

4. CONCLUSION

This study analyzed the development of global research on rice husk biomass as an environmentally friendly alternative fuel using a bibliometric approach. The results indicate a significant increase in scientific publications, particularly during the 2022–2024 period, reflecting the growing international interest in renewable energy solutions based on agricultural biomass. Renewable Energy was identified as the most dominant publication source, showing that this topic has gained strong attention within the field of sustainable energy research.

Furthermore, keyword network analysis revealed that the major research focus is concentrated on biomass conversion technologies such as pyrolysis, combustion, and biofuels, along with increasing attention to environmental aspects such as emission control and air quality. Thematic mapping also showed that combustion efficiency and thermal performance remain central themes, while pelletizing, briquetting, and environmental assessment have emerged as promising future research areas. International collaboration among countries such as China, India, and Indonesia demonstrates that rice husk biomass research has broad global relevance, particularly in countries with strong agricultural sectors.

The scientific contribution of this study lies in providing a comprehensive overview of publication trends, research hotspots, collaboration patterns, and thematic evolution in rice husk biomass studies. These findings can serve as a strategic reference for researchers, policymakers, and industry stakeholders in developing sustainable biomass energy programs. Future studies are recommended to focus on techno-economic feasibility analysis, life cycle assessment, emission reduction technologies, supply chain optimization, and pilot-scale implementation to enhance the practical utilization of rice husk biomass as a competitive renewable energy source.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to Al-Azhar University Medan for providing academic support and research facilities. We also thank all parties who contributed to the completion of this study, especially those who assisted in data collection and analysis. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10497-10507

Design and Development of Ariesta Hotel Reservation Information System Based Website Using Waterfall Method

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ARTICLE INFO

Article history:
Received 25 April 2026
Revised 30 April 2026
Accepted 07 Mei 2026
Available online 25 June 2026

Keywords:
Bootstrap
Information Systems
Hotel Reservations
Website
Waterfall

IEEE style in citing this article:
E. M. Benolon, Y. P. K. Kelen, and S. S. Manek, "Design and development of Ariesta hotel reservation information system based website using waterfall method," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10497-10507, 2026.

Doi :
https://doi.org/10.31949/j-ensitec.v12i02.18002

ABSTRAK

The limitations of the manual reservation system at Hotel Ariesta Kefamenanu result in inefficient information delivery, a high risk of recording errors, and potential double bookings. This study aims to develop a web-based reservation information system to improve service efficiency and data accuracy. The Waterfall method is applied to ensure a structured and systematic development process in accordance with user requirements. The system is developed using the Bootstrap framework to provide a responsive interface accessible across multiple devices.

The results indicate that the proposed system reduces the reservation processing time and minimizes data recording errors compared to the previous manual system. In addition, the system improves the accuracy of reservation data management and enables real-time access to hotel information, including room types, facilities, and pricing. The implementation of this system also enhances promotional effectiveness and expands customer reach through continuous online accessibility.

Therefore, the developed system serves as an effective solution to support digital transformation and improve operational performance at Hotel Ariesta Kefamenanu.

1. INTRODUCTION

The rapid development of information technology has significantly transformed various sectors, including the hospitality industry. The utilization of internet-based technology enables faster, more accurate, and easily accessible information delivery to the public. In the hospitality industry, web-based information systems have become an important strategy to improve service quality and expand promotional reach to potential customers. Through such systems, customers can obtain real-time information without limitations of time and location [11], [18].

Hotel Ariesta Kefamenanu is one of the lodging service providers that offers various types of rooms and facilities for customers. However, the current reservation system is still conducted manually, either through telephone communication or by visiting the location directly. This process has several limitations, including restricted information dissemination, the risk of data recording errors, and the possibility of

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double bookings. In addition, data processing and report generation are still performed manually, resulting in lower efficiency and requiring relatively more time.

Several previous studies have shown that the implementation of web-based reservation systems can improve operational efficiency and service quality in the hospitality sector. Online reservation systems provide convenience for customers in making bookings and assist hotel management in handling data in a structured and integrated manner [3], [10], [20]. Furthermore, the application of structured software development methods, such as the Waterfall model, can support systematic system development and improve the quality of the resulting software [12], [2].

Based on these problems, this study proposes the development of a web-based reservation information system for Hotel Ariesta. The system is designed to provide comprehensive hotel information, support the reservation process, and improve efficiency in data management. The system development is carried out using the Waterfall method, which consists of sequential stages, including requirement analysis, system design, implementation, testing, and maintenance [12].

The novelty of this study lies in the development of a web-based reservation system that is specifically tailored to the operational needs of Hotel Ariesta Kefamenanu, integrating hotel information, reservation services, and data management into a single platform. In addition, this study emphasizes the use of the Bootstrap framework to produce a responsive and user-friendly interface that can be accessed across multiple devices. Unlike previous studies that generally focus on generic system development, this research highlights system customization based on actual user needs and local conditions. Therefore, the proposed system is expected to improve service quality, enhance data accuracy, and support digital transformation in the local hospitality sector.

2. METHOD

This study employs the Waterfall software development method, which is a structured and sequential approach consisting of several systematic stages. The Waterfall model is widely used in software development due to its clear workflow and well-defined phases, allowing each stage to be completed before proceeding to the next stage [12]. This method is considered suitable for this research because the system requirements are clearly identified from the beginning.

The research process begins with problem identification at Hotel Ariesta Kefamenanu, where the existing reservation system is still conducted manually, leading to inefficiencies in information delivery and data management. To support system development, data collection is carried out using several methods, namely observation, interviews, and literature study. Observation is conducted by directly examining the ongoing reservation process to identify system weaknesses and user needs. Interviews are conducted with hotel administrators to obtain detailed information regarding system requirements, business processes, and challenges faced in managing reservations. Meanwhile, the literature study is performed by reviewing relevant journals, books, and previous research related to web-based reservation systems and the Waterfall method to strengthen the theoretical foundation.

The system development process follows the stages of the Waterfall model as illustrated in Figure 1, which include requirements analysis, system design, implementation, testing, and maintenance. The detailed explanation of each stage is as follows:

1. **Requirements Analysis**
   At this stage, system requirements are identified based on the results of observation and data collection. The analysis focuses on user needs, system functionality, and constraints in the existing manual system.
2. **System Design**
   The system design stage involves creating system architecture, database design, and user interface design. This stage aims to provide a clear blueprint for system development.
3. **Implementation**
   In this stage, the system is developed based on the design that has been created. The web-based system is implemented using appropriate programming languages and supported by the Bootstrap framework to ensure a responsive interface.

4. **Testing**
   The testing stage is conducted to ensure that the system functions properly according to the specified requirements. Testing includes functional testing to identify errors and ensure system reliability.
5. **Maintenance**
   After implementation, the system enters the maintenance stage, which involves system updates, error corrections, and performance improvements to ensure long-term usability

The overall process of system development using the Waterfall method is illustrated in Figure 1 to provide a clearer understanding of the research workflow.

3. RESULTS AND DISCUSSION

3.1. System Analisis

The reservation system at Hotel Ariesta Kefamenanu is currently conducted manually, where customers must contact the hotel via telephone or visit directly to obtain information regarding room availability, room types, and facilities. Reservation data are recorded manually in a logbook, including guest name, check-in and check-out dates, room type, and length of stay.

This manual process has several limitations, including a high risk of data recording errors, data loss, and inefficiency in managing reservation information. In addition, room availability information is not integrated, requiring staff to check data manually before providing information to customers. This condition increases the risk of inaccurate information and double bookings.

Compared to web-based reservation systems, the manual system is significantly less efficient in terms of service speed, data accuracy, and accessibility. Previous studies have shown that web-based reservation systems can provide real-time information and improve operational efficiency in the hospitality sector [3], [10]. Therefore, the existing system at Hotel Ariesta requires improvement through digital transformation. Based on these problems, a web-based reservation information system is proposed to replace the manual process. The proposed system aims to improve efficiency, minimize errors, and provide real-time access to reservation information. The comparison between the existing system and the proposed system is presented in Figure 2 and Figure 3.

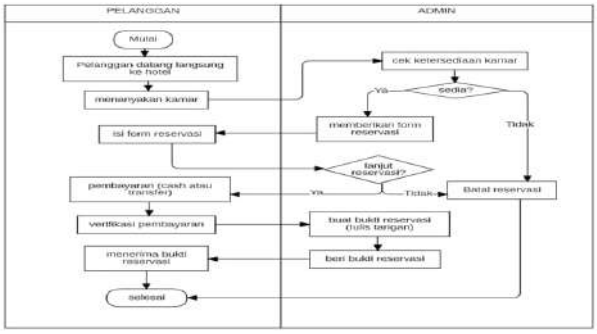

Figure 1 Flowchart of the system in action.

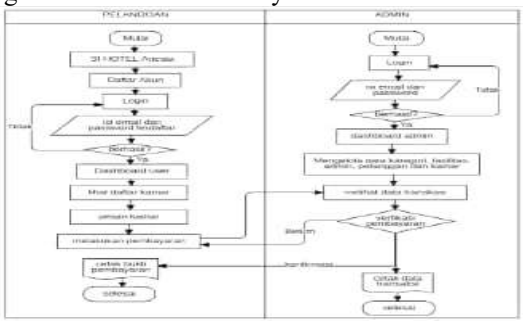

Figure 2. Proposed system flowchart

3.2. System Modeling

Use Case Diagram Flow

Use case diagrams are used to illustrate the interaction between actors and the system. In the Ariesta Hotel Information System, there are two main actors, namely Admin and User (Customer). The Admin manages system data such as rooms, facilities, and transactions, while the User performs activities such as registration, login, and room reservation.

This modeling approach is consistent with previous studies that emphasize the importance of clear system modeling to support effective system development [20]. The use case diagram of the system can be seen in Figure 4.

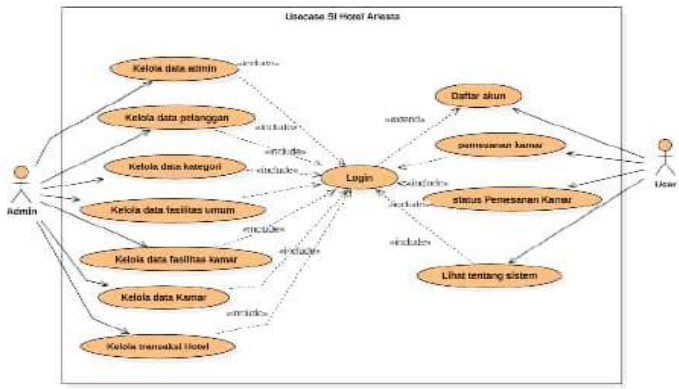

Figure 3. *Use Case Diagram*

3.3. Database Design

The database design is developed to support structured data storage and management. The system consists of several main tables, including user data, room data, booking data, and facility data.

A well-designed database enables efficient data processing and reduces redundancy. Compared to manual data recording, database-based systems provide better data integrity and accessibility. This is in line with previous research stating that database integration improves system performance and data accuracy [5], [19]. The database design is illustrated in Figure 5.

Figure 4. *Database*

3.4 System Implementation

The implementation of the web-based reservation system provides several advantages compared to the previous manual system. Users can access hotel information, check room availability, and make reservations online without time and location constraints. From the system interface, features such as registration, login, room selection, and reservation processing have been successfully implemented. Unlike the manual system, which relies on human interaction, the developed system automates the reservation process, reducing processing time and minimizing errors. In addition, the admin can manage data more

ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)

efficiently through the dashboard, including managing rooms, facilities, and transactions. This result supports previous studies which state that web-based systems improve service quality and operational efficiency in hotel management [3], [10].

The interface display results of the Ariesta Hotel reservation information system that has been successfully developed are as follows:

1. Main Page Display

The main page is the first page displayed when users access the Ariesta Hotel Information System. This page functions as the initial interface that provides an overview of the hotel and the available services. The main page typically displays several navigation menus such as the room data menu, login menu, account registration menu, and system information menu. In addition, the main page also presents brief information about the hotel, including the hotel description, available facilities, and several related images. The details of the main page can be seen in Figures 6, 7, and 8.

Figure 5. Main page

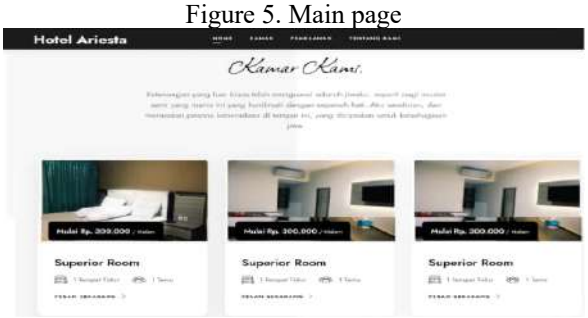

Figure 6. Main page (continued)

Figure 7. Main page (continued)

2. Account registration page display

The account registration page is used by users who do not yet have an account to register in the system. The account registration page can be seen in Figure 9.

DOI: https://doi.org/10.31949/j-ensitec.v12i02.18002

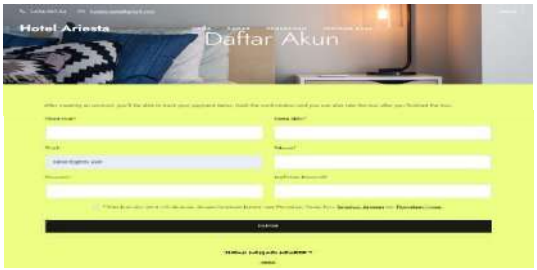

Figure 8. Account registration page

3. User login page display

The user login page is used by users to access the system using previously registered accounts. The user login page display can be seen in Figure 10.

Figure 9. User login page

4. Tampilan halaman data kamar

The room data page is a page that displays a list of available rooms at Hotel Ariesta. It can be seen in Figure 11.

Figure 10. Room data page

5. Room detail page display

The room data page is a page that displays a list of available rooms at Hotel Ariesta. It can be seen in Figure 12.

Figure 11. Room detail page

6. Reservation page display

The reservation page is used to display room booking data that has been made by users. It can be seen in Figures 13, 14, and 15.

Figure 12. Reservation page

Figure 13. Successful reservation status page

Figure 14. Room reservation receipt

7. About page display

The system information page is used to provide information to users regarding the hotel room reservation system used. It can be seen in Figure 16.

Figure 15. About page

8. Admin login page display

Admin login page is used by the admin to log into the system by using a registered admin account. It can be seen in Figure 17.

Figure 16. Admin login page

9. Admin dashboard page display

Admin dashboard page is the main page displayed after the admin successfully logs into the system. It can be seen in Figure 18.

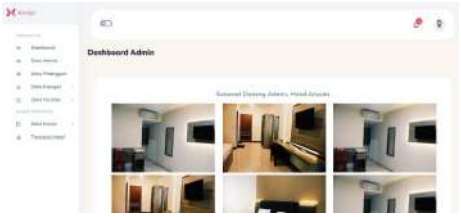

Figure 17. Admin dashboard page

10. Admin data page display

The admin data management page is used to manage admin data registered in the system. It can be seen in Figure 19.

Figure 18. Admin data page

11. Customer data management page display

The customer data management page is used by the admin to view customer data who have registered in the system. It can be seen in Figure 20.

Figure 19. Customer data management page

12. Category data page display

The category data management page is used to manage the room categories available in the hotel. It can be seen in Figure 21.

Figure 20. Category data page

13. General facilities data management page display

This page is used to manage general facility data available in the hotel such as parking area, restaurant, meeting room, and other facilities. It can be seen in Figure 22.

Figure 21. General facilities data management page

14. Room facilities data management page display

The room facilities management page is used to manage the facilities available in each hotel room such as air conditioning, television, bathroom, and other facilities. It can be seen in Figure 23.

Figure 22. Room facilities data management page

15. Add room page display

The add room page is used by the admin to add new room data into the system. It can be seen in Figure 24.

Figure 23. Add room page

16. Room data list page display

The room data list page is used to display all room data available in the system. It can be seen in Figure 25.

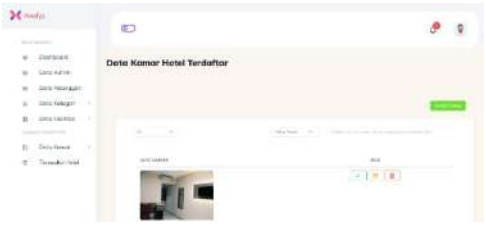

Figure 24. Room data list page

17. Transaction page display

The transaction page is used by the admin to view room booking transaction data made by customers. It can be seen in Figure 26.

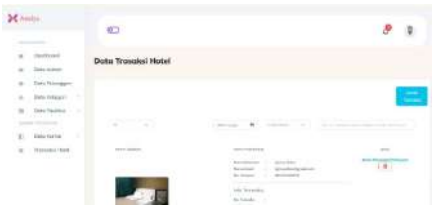

Figure 25. Transaction page

3.5 System Testing

System testing is conducted using the Black Box Testing method, which focuses on evaluating system functionality without examining the internal code structure. Testing is performed on key features such as login, data management, and reservation processes.

The results of testing show that all system functions operate as expected, with all test scenarios categorized as valid. This indicates that the system meets functional requirements and is ready for implementation.

Compared to manual systems, which are prone to human error, the implemented system demonstrates higher reliability and consistency in processing data. This finding is consistent with previous studies that highlight the effectiveness of system testing in ensuring software quality [12]. The test results are presented in tabular form as shown in Table 1 and Table 2.

4. CONCLUSION

Based on the results of the research on the design and development of the web-based reservation information system for Hotel Ariesta Kefamenanu using the Waterfall method, several conclusions can be drawn:

1. The implementation of the Waterfall method, which consists of requirements analysis, system design, implementation, testing, and maintenance, has successfully produced a structured and functional reservation system. The system development process runs systematically and results in a system that meets user needs and system requirements [12].
2. The developed system significantly improves the efficiency of the reservation process compared to the previous manual system. Customers can access hotel information, check room availability, and make reservations online without time and location limitations. This reduces the risk of data recording errors and minimizes the occurrence of double bookings.
3. Based on system testing using the Black Box Testing method, all system features function properly according to the expected outcomes. This indicates that the system is reliable and ready to be implemented in supporting hotel operational activities.
4. The results of this study are consistent with previous research, which states that web-based reservation systems can improve service quality, data accuracy, and operational efficiency in the hospitality sector [3], [10], [20].

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to the supervisor and all parties involved, both directly and indirectly, for the suggestions and input provided to the author, which have contributed to the completion of this journal.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10508-10514

Floating Solar Power Plants as a Sustainable Solution in Land-Constrained Areas: A Bibliometric Analysis

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ARTICLE INFO

Article history:
Received 27 April 2026
Revised 03 Mei 2026
Accepted 07 Mei 2026
Available online 25 June 2026

Keywords:
Bibliometric analysis
Floating photovoltaic
Land limitation
Renewable energy

IEEE style in citing this article:
R. Romatona, A. Ramadhan, D. J. Panani, S. N. Naylah, E. A. Zharif, Yuhani, and M. A. As-Silmy, "Floating Solar Power Plants as a Sustainable Solution in Land-Constrained Areas: A Bibliometric Analysis," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10508-10514, 2026.

Doi :
https://doi.org/10.31949/j-ensitec.v12i02.18038

ABSTRACT

This study aims to analyze the development of research on floating photovoltaic (FPV) power plants as a sustainable solution for land-limited areas using a bibliometric approach. Data were collected from the Scopus database during 2015–2025 and analyzed using VOSviewer and Bibliometrix to examine publication trends, country productivity, keyword networks, and thematic development. The results show that FPV-related publications have increased significantly in recent years, with China emerging as the leading contributor to scientific output. Keyword analysis reveals that major research themes include *solar energy*, *renewable energy*, and *solar power generation*, while *floating photovoltaic* remains an evolving topic. In addition to addressing land scarcity issues, FPV technology offers additional benefits such as improved solar panel efficiency and reduced water evaporation. However, technical, economic, and environmental challenges remain important concerns for future studies. Overall, FPV demonstrates strong potential as an innovative renewable energy solution that supports sustainable energy development in areas with limited land availability.

1. INTRODUCTION

The increasing global energy demand driven by population growth, urbanization, and industrialization has intensified pressure on conventional energy systems, which remain heavily dependent on fossil fuels[1], [2] This dependence not only triggers energy crises due to resource limitations but also significantly contributes to greenhouse gas emissions that accelerate global climate change. Numerous studies indicate that the energy sector is the primary contributor to carbon dioxide emissions, making the transition toward low-carbon energy systems a strategic global priority[3], [4]. In this context, the development of renewable energy has become increasingly urgent as a long-term, sustainable, and environmentally friendly solution. Solar energy, particularly through photovoltaic (PV) technology, holds

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a strategic position due to its abundant availability and continuously improving energy conversion potential driven by technological advancements[5], [6].

However, the implementation of conventional ground-mounted solar power plants faces significant challenges, particularly related to land availability. This issue becomes critical in regions with high population density and rapid urbanization, where competition for land use among residential, industrial, and agricultural sectors is increasingly intense[7]. These limitations have driven technological innovation in the form of floating photovoltaic (FPV) systems, which utilize water surfaces such as reservoirs, lakes, and dams as installation sites for solar panels. FPV not only provides a solution to land scarcity but also opens opportunities for the simultaneous optimization of water and energy resources[8].

These limitations have driven technological innovation in the form of floating photovoltaic (FPV) systems, which utilize water surfaces such as reservoirs, lakes, and dams as installation sites for solar panels. FPV not only provides a solution to land scarcity but also opens opportunities for the simultaneous optimization of water and energy resources[9]. In addition, the presence of panels on water surfaces can reduce evaporation rates, contributing to water conservation, particularly in arid and semi-arid regions[10]. FPV also allows for more efficient space utilization without sacrificing productive land. However, this technology faces several challenges, including structural design complexity, relatively high installation costs, the need for mooring systems, potential ecological impacts on aquatic ecosystems, and long-term operational and maintenance issues[11]

Although research on floating photovoltaic (FPV) systems has increased significantly, previous studies have mostly focused on technical performance, economic feasibility, or case-specific environmental impacts. Limited studies have systematically mapped the global research landscape of FPV in relation to land constraints and sustainability challenges using bibliometric approaches[12]. Although research on floating photovoltaic (FPV) systems has increased significantly, previous studies have mostly focused on technical performance, economic feasibility, or case-specific environmental impacts. Limited studies have systematically mapped the global research landscape of FPV in relation to land constraints and sustainability challenges using bibliometric approaches[13].

2. METHOD

This study employed a quantitative bibliometric approach to analyze the scientific development of floating photovoltaic (FPV) research as a sustainable solution in land-constrained areas. Bibliometric analysis was selected because it enables a systematic and objective evaluation of publication trends, research productivity, collaboration networks, and thematic evolution within a specific field. The data were collected from the Scopus database, which was selected due to its broad coverage of peer-reviewed international publications and reliable indexing system. Data retrieval was conducted in April 2025. The search was limited to publications published between 2015 and 2025. The search query used in Scopus was formulated as follows: TITLE-ABS-KEY (“floating photovoltaic” OR “floating solar” OR “floating solar power plant” OR “floating PV” OR FPV) AND PUBYEAR > 2014 AND PUBYEAR < 2026. This query was designed to capture relevant studies discussing FPV systems and related terminology. The inclusion criteria consisted of: (1) journal articles, (2) English-language publications, and (3) documents directly related to floating photovoltaic systems. Meanwhile, conference papers, book chapters, editorials, notes, and unrelated publications were excluded. Duplicate records were also removed during the screening stage.

The inclusion criteria in this study consisted of: (1) peer-reviewed journal articles, (2) English-language publications, (3) studies within the fields of energy, environment, and sustainability, and (4) documents explicitly addressing FPV or related technologies. Meanwhile, the exclusion criteria included conference proceedings, books, editorials, and articles lacking substantive relevance. The data selection process was conducted in three main stages: identification, by collecting all documents based on the defined keywords; screening, by reviewing titles and abstracts to remove duplicates and irrelevant documents; and final inclusion, which involved determining the final set of articles that met all criteria.

Subsequently, bibliographic data were extracted, including information on authors, publication year, country affiliations, journals, citation counts, and keywords. These data were then processed using VOSviewer and Bibliometrix (R package), which are widely used tools in bibliometric analysis for mapping knowledge structures and relationships among publications[14], [15]. The analyses conducted included co-

occurrence analysis to identify relationships among keywords, co-authorship analysis to map collaborations among authors and countries, citation analysis to determine publication impact, and trend analysis to examine the dynamics of research topic development over time.

In the process of bibliometric network mapping, several analytical parameters were defined, such as minimum occurrence thresholds (e.g., ≥5 keyword occurrences), citation thresholds, and clustering techniques to group research topics into thematic clusters based on relational proximity. The research stages were systematically structured, beginning with data collection, followed by data cleaning, bibliometric analysis, network visualization, and result interpretation. Narratively, the research flowchart begins with database selection, followed by keyword formulation, data retrieval, screening and eligibility checking, data extraction, bibliometric analysis, and concludes with interpretation and synthesis of findings.

This approach enables a comprehensive identification of research patterns while providing a strong foundation for formulating future research directions related to FPV as a sustainable energy solution in land-constrained regions.

3. RESULTS AND DISCUSSION

3.1 Authors' Production over Time

As an initial step in understanding the dynamics of scientific contributions, the following visualization presents the pattern of author productivity over a given period. This graph provides an overview of publication intensity as well as the consistency of contributions from leading authors in the field of floating photovoltaic (FPV) and renewable energy[13], [16].

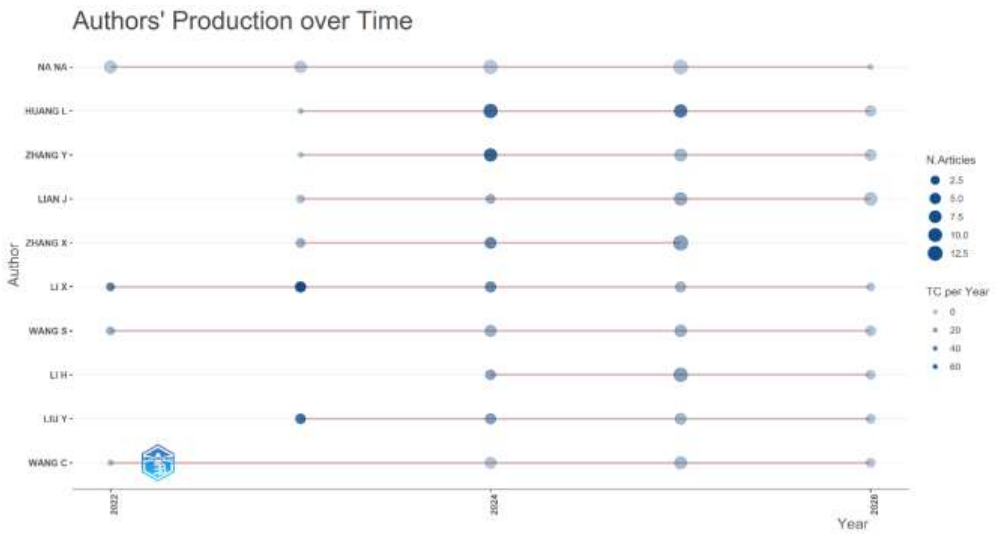

Figure 1. Co-authorship network among researchers in FPV studies

Based on the graph, it can be observed that several authors, such as Huang L., Zhang Y., and Li X., demonstrate a significant increase in productivity, particularly during the 2024–2025 period. Larger circle sizes indicate a higher number of publications, while the color gradient reflects the number of citations per year. This suggests that not only has the quantity of publications increased, but their scientific impact has also grown[17].

On the other hand, there are also authors who exhibit relatively stable but less dominant productivity patterns. This phenomenon indicates an uneven distribution of contributions, where only a small number of authors act as key drivers in the development of FPV research. Such a condition is common in emerging research fields, where core authors play a central role in shaping the direction of scientific advancement.

3.2 Country Scientific Production

To obtain a broader perspective, the subsequent analysis focuses on the geographical distribution of scientific production. The following world map illustrates the contribution of each country to publications related to the research topic..

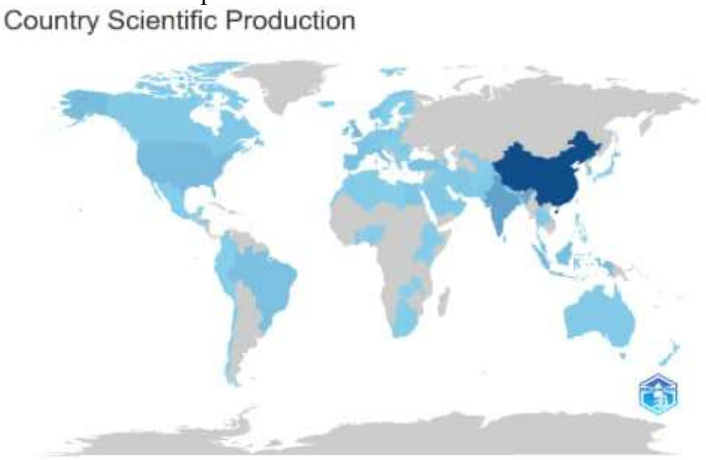

Figure 2. Global distribution of FPV research publications by country

The visualization shows that China significantly dominates scientific production compared to other countries, followed by nations such as the United States, India, and several European countries. This dominance can be associated with substantial investments in renewable energy technologies as well as high energy demand in these countries. In addition, the availability of research infrastructure and strong policy support plays an important role in increasing publication output[12].

Meanwhile, developing countries in Southeast Asia, Africa, and Latin America demonstrate relatively lower contributions. This indicates the existence of a global research gap, particularly in the context of FPV implementation in regions with abundant water resources that remain underutilized. These findings highlight the importance of international collaboration to expand the global adoption of FPV technology[18].

3.3 Thematic Map

In order to identify the conceptual structure of the research, the following thematic map is used to classify topics based on their level of importance and stage of development. emerging/declining themes.

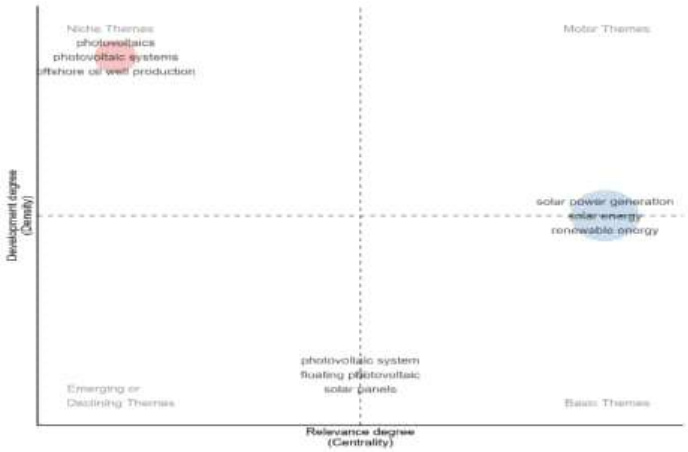

Figure 3. Thematic map of FPV research based on keyword clustering

ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)

The analysis results indicate that themes such as “solar energy,” “renewable energy,” and “solar power generation” are located in the motor themes quadrant, signifying that these topics possess both high importance and a well-developed level of maturity. These themes serve as the primary foundation in renewable energy research and act as the main driving forces in the advancement of the FPV field[19].

In contrast, themes such as “floating photovoltaic,” “solar panels,” and “photovoltaic system” are still categorized as basic themes, indicating that although they are relevant, their development has not yet reached full maturity. This suggests the presence of further research opportunities to deepen the technical and applied aspects of FPV, allowing these themes to potentially evolve into motor themes in the future[20].

3.4 Network Visualization (VOSviewer)

As part of the analysis of relationships among concepts, the following network visualization presents the interconnections between keywords in FPV research using a co-occurrence approach. This representation helps identify the main clusters within the research landscape.

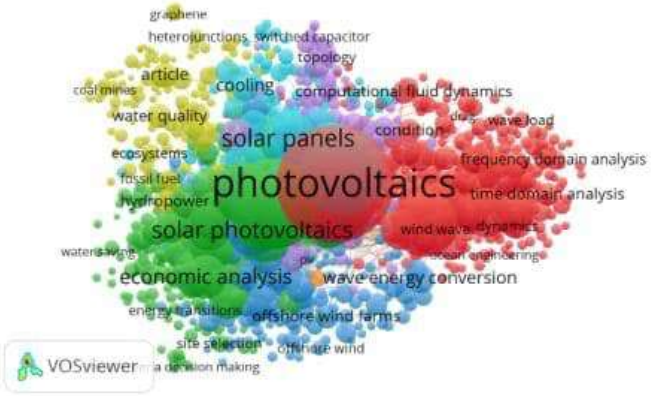

Figure 4. Keyword co-occurrence network of FPV research

It can be observed that the keywords “photovoltaics” and “solar photovoltaics” occupy central positions in the network with high connectivity, indicating their pivotal role in the research domain. The green cluster reflects a focus on economic aspects, such as economic analysis and energy transitions, while the red cluster is associated with technical aspects, including computational fluid dynamics and wave dynamics[21].

In addition, the emergence of clusters related to environmental and water resource topics, such as water quality, ecosystems, and hydropower, indicates the presence of multidisciplinary integration in FPV research. This finding underscores that the development of FPV is not limited to energy aspects alone, but also encompasses broader environmental and sustainability dimensions[17].

3.5 Documents by Year

As a concluding part of the analysis, the following graph presents the trend in the number of publications over time. This visualization is essential for understanding the temporal development of research interest in the FPV field

DOI: https://doi.org/10.31949/j-ensitec.v12i02.18038

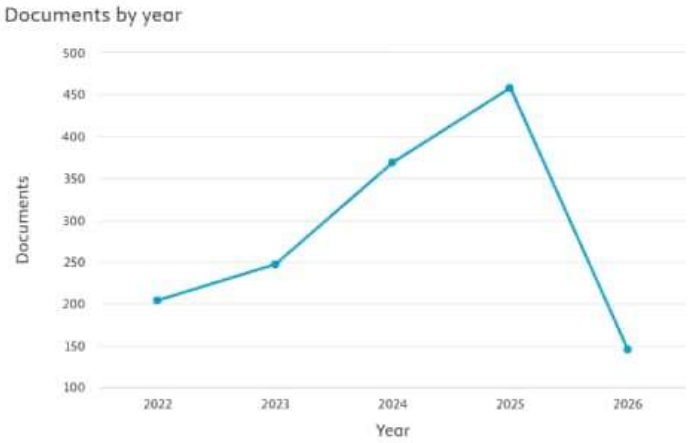

Figure 5. Annual publication trends of floating photovoltaic (FPV)

The graph shows a significant increase in the number of publications starting from 2022 and reaching its peak in 2025. This surge reflects the growing academic attention toward FPV technology as a sustainable energy solution, particularly in addressing land constraints and the challenges of global climate change[9], [22].

However, a decline is observed in 2026, which is likely due to data limitations or incomplete indexing of publications for the current year. Therefore, the overall trend still indicates positive growth, suggesting that FPV research will continue to expand and become a major focus in renewable energy studies in the future.

4. CONCLUSION

Based on the results of the bibliometric analysis, research on floating photovoltaic (FPV) systems has shown significant development and has become an increasingly prominent topic in renewable energy studies. The continuously rising trend in the number of publications, particularly in recent years, indicates that FPV is regarded as a promising innovative solution to address land constraints in the development of sustainable solar energy..

The analysis reveals that China dominates scientific productivity in the FPV field, followed by several other developed countries such as the United States and India. This dominance reflects substantial research investment, strong policy support, and high energy demand in these countries. However, the contribution from developing countries remains relatively low, thereby presenting significant opportunities to expand international collaboration and promote research development in regions with abundant water resource potential.

Furthermore, the keyword network analysis indicates that FPV research is evolving in a multidisciplinary manner, encompassing technical, economic, and environmental aspects. Core themes such as *solar energy*, *renewable energy*, and *solar power generation* emerge as dominant focal points, while topics such as *floating photovoltaic* remain in a developmental stage. This highlights opportunities for further research, particularly in system optimization, operational efficiency, and environmental sustainability.

Overall, FPV technology holds significant potential as a sustainable energy solution in land-constrained regions, as it enhances spatial efficiency, supports water conservation, and expands clean energy capacity. Nevertheless, challenges such as high installation costs, technical complexity, and potential ecological impacts must still be addressed through technological innovation and further research to ensure the optimal and sustainable implementation of FPV in the future.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02, June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10515-10527

Web-Based Geographic Information System For Mapping Non-Metallic Mineral And Rock Mining In North Central Timor Regency

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ARTICLE INFO

Article history:
Received 7 May 2026
Revised 11 May 2026
Accepted 14 May 2026 Available online 25 June 2026

Keywords:
Mining
North Central Timor
Prototype
SIG
Web

IEEE style in citing this article:
E. Naiobe, Y. P. K. Kelen, and A. K. D. Lestari, "Web-Based Geographic Information System for Mapping Non-Metallic Mineral and Rock Mining in North Central Timor Regency," *J-ENSITEC: Journal of Engineering and Sustainable Technology*, vol. 12, no. 2, pp. 10515-10527, 2026.

Doi :
https://doi.org/10.31949/j-ensitec.v12i02.18139

ABSTRACT

The monitoring and dissemination of information regarding non-metallic mineral and rock mining locations in North Central Timor (TTU) Regency remain constrained by conventional, non-digital data collection systems. This study aims to develop a web-based Geographic Information System (GIS) capable of accurately and integrally mapping and presenting mining locations in TTU Regency. This applied research employs a Prototype development model, integrating the Google Maps API for interactive spatial visualization and a role-based data entry mechanism to separate admin and user functions. Black-box Testing results confirm that all functions on both admin and user sides operate as specified, enabling the digitization of mining attribute data (e.g., IUP SK numbers, area size, operational status). The main contributions of this study are: (1) improving the efficiency of mining data management at the ESDM Branch Office Region I, and (2) providing more transparent, real-time public access to mining location information, thereby addressing the limitations of conventional systems.

1. INTRODUCTION

The management of mineral resources is a critical component of regional development, including in North Central Timor (TTU) Regency, which possesses significant potential in non-metallic minerals and rocks [1]–[3]. However, in practice, the management of mining location data in this region faces substantial challenges. The Branch Office of the Department of Energy and Mineral Resources (ESDM) Region I, which oversees TTU, South Central Timor (TTS), Belu, and Malaka Regencies, still relies on conventional, manual data collection methods [4]. Consequently, the monitoring of mining activities (both licensed and illegal), spatial data management, and public information dissemination remain ineffective.

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Previous studies have developed web-based GIS for mapping mining distributions [5]–[7]. However, these studies have several limitations: (1) integration between spatial data and attribute data (e.g., IUP license numbers, area size, operational status) remains partial [5]; (2) they primarily focus on map visualization without centralized attribute data management [6], [7]; and (3) they were developed on desktop platforms with limited accessibility [8]. The most prominent common limitation is the absence of a system explicitly designed to support monitoring and supervisory functions by local government institutions, particularly in TTU Regency.

Addressing this gap, this study aims to develop a web-based GIS for mapping non-metallic mineral and rock mining locations in TTU Regency. The main novelties of this study are: (1) full integration of spatial and attribute data within a centralized database (MySQL) ensuring real-time data consistency; (2) use of an interactive map (Google Maps API) as the primary interface for attribute data exploration through a dynamic pop-up mechanism; and (3) implementation of role-based access control that not only differentiates admin and public access rights but also establishes a structured data verification workflow. The contributions of this study include: (a) providing an operational solution for the ESDM office to improve mining data management efficiency; (b) enhancing monitoring capacity for legal and illegal mining activities through periodically updated digital maps; and (c) facilitating transparent public access without requiring physical visits to government offices..

2. METHOD

2.1. Research Type

This study employs an applied research approach [9], selected due to its alignment with the nature of the problems faced by the Regional Office of the Energy and Mineral Resources Agency (ESDM) Region I, namely a mining location data management system that remains conventional and has not yet been digitized. In contrast to basic research, which is oriented toward theoretical development [10], this approach directly guides all stages of system development to produce a software product (a web-based geographic information system) that can be practically implemented.

The relationship between this approach and the research methods and objectives is reflected in three aspects. First, the identification of end-user requirements serves as the foundation for designing a centralized database (MySQL) and implementing role-based access features, in line with web-based GIS development practices in previous studies [2]–[5], [7], [9]–[15]. Second, the solution is tested collaboratively with the relevant agency to ensure that the interactive map visualization based on the Google Maps API [16] can effectively support the monitoring of mining activities, as also applied in various web-based GIS implementations [17], [18]. Third, the research output is specifically directed toward addressing practical needs, including the digitization of spatial data, the provision of transparent access for the public, and the improvement of data management efficiency at the agency level, representing a further development of prior studies [2]–[5], [7], [9]–[15].

Thus, the applied research approach functions not merely as a background but as a methodological framework that guides each stage of system design and implementation, further supported by software engineering concepts [19], [20] as well as fundamental GIS principles [21].

2.2. System Development Method

This study adopts an applied research approach combined with the Prototype system development model [22]. This model was selected because the system requirements were not fully defined at the outset, primarily due to the limited experience of end users (staff of the ESDM Regional Office Region I) with similar digital systems. The prototype model enables continuous improvement based on user feedback, ensuring that the final system aligns with the actual needs of mining data management.

The methodological flow consists of five main stages, executed iteratively:

1. Initial data collection – Observations and interviews were conducted with agency staff to understand the existing conditions of the mining location data management system in TTU Regency, including both technical and non-technical challenges encountered.
2. Requirements identification (requirements analysis) – Based on the collected data, functional requirements (spatial and attribute data management, map visualization, role-based access) and non-functional requirements (access speed, data security) were formulated.

3. Initial prototype design – An initial system model was developed, featuring a simple interface for displaying maps and inputting mining location points. At this stage, the database structure and system components were described conceptually without detailing the table schema.
4. Prototype testing and evaluation – The initial prototype was tested by users (agency staff) to obtain feedback regarding usability, feature completeness, and compatibility with actual field workflows.
5. Refinement and improvement – Based on user feedback, iterative improvements were made to key features, such as spatial-attribute data integration, pop-up visualization using the Google Maps API, and differentiation of access rights between admin and public users.
6. Implementation and final testing – The refined system was implemented in the actual environment at the Regional Office of the Energy and Mineral Resources Agency Region I and then thoroughly tested to ensure that all requirements were met.

This methodological flow is iterative, in which stages 4 and 5 may be repeated until the system is deemed acceptable by users. The technical details, such as the database table structure and program code, are presented in the Results and Discussion section rather than in this Methodology section.

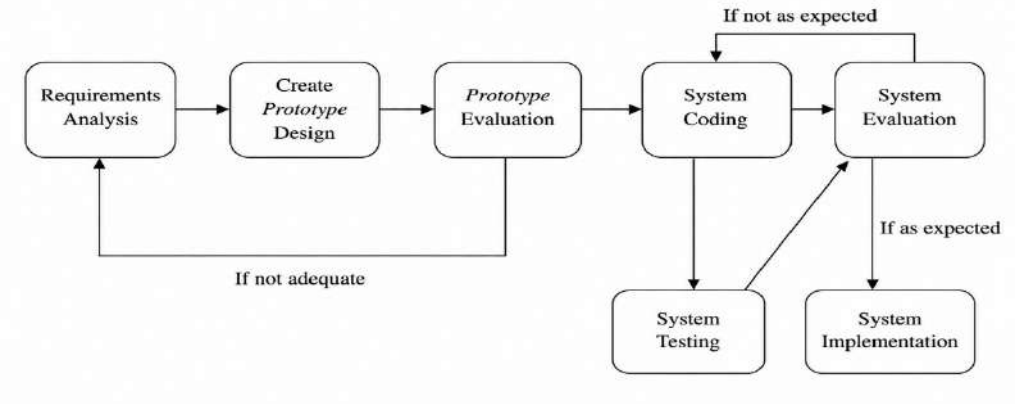


Figure 1. System Development Method

The specific implementation of each stage is described as follows:

1. Requirements Analysis – The researcher conducted interviews and direct observations with the Head of the Mining Subdivision and administrative staff at the ESDM Regional Office Region I. The primary data sources included manual documents of mining location records (coordinate notes, area size, permit status) and reported constraints, such as difficulty in retrieving historical data and the absence of spatial visualization. The outcome of this stage was a list of functional requirements (management of mining location points, map-based search, admin-public access restriction) and non-functional requirements (the system must be lightweight and accessible via common devices).
2. Prototype Design Development – Based on the identified requirements, the researcher designed a simple interface (low-fidelity prototype) consisting of a map page (Google Maps API), a mining data input form, and a location list table. This design was consulted with agency staff to ensure usability aligned with their workflow, such as the placement of the "add point" button and the display of attribute information in pop-ups.
3. Prototype Evaluation – The initial prototype was tested by three agency staff members responsible for mining data management. The evaluation focused on two aspects: (a) whether all required features were available, and (b) whether the interface layout was easy to understand. Feedback obtained included suggestions such as "adding a filter based on permit status" and "including photos of mining locations in the pop-up." If deficiencies were identified, the process returned to the requirements analysis or design stage. In this study, two iterations occurred at this stage.

4. System Coding – Once the prototype was deemed appropriate, full system development was carried out using PHP, MySQL database, and JavaScript (Google Maps API). At this stage, a functional system was produced that accommodated all prior feedback, including role-based access features (admins can add/edit/delete data, while the public can only view) and integration of spatial and attribute data.
5. System Testing – The completed system was tested using the black-box testing method to ensure that each function operated according to specifications. Testing was conducted by the researcher together with one technical staff member. Example test scenarios included: logging in as admin → adding a new mining point → verifying that the point appears on the map; logging in as a public user → attempting to delete data → verifying that the delete option is unavailable.
6. Evaluation of Testing Results – The testing results were evaluated together with end users. If any functional errors or mismatches with requirements were identified, revisions were made at the coding stage (without returning to the analysis phase). In this study, two minor improvements were identified: correction of coordinate formatting and improvement of map loading speed. Once all functions operated as expected, the system was deemed ready for use by users.

The database structure (including tables for admin, location, category, district, and gallery) was designed to ensure integration between spatial data (coordinates) and attribute data (e.g., IUP numbers, area size, operational status). The Entity-Relationship Diagram (ERD) shows the location table as the central entity, linked to district and category tables with one-to-many cardinalities. A system flowchart distinguishes two user roles: admin (full CRUD and report printing) and public (view only). A login activity diagram ensures that only authenticated admins can access data management functions.

Table 1. *Admin*

No	***Field***	***Type***	***Size***	***Key***
1	Id_*admin*	*Int*	11	*Primary Key*
2	*username*	*Varchar*	50	
3	*password*	*Varchar*	100	
4	*Created_at*	*Datetime*		
5	*Updated_at*	*Datetime*		

Table 2. Gallery

No	**Field**	**Type**	**Size**	**Key**
1	Gallery_ID	Int	11	Primary Key
2	Gallery_Name	Text	-	-
3	Gallery_Description	Text	-	-
4	Gallery_Photo	Varchar	50	-
5	Created_At	Datetime	-	-
6	Updated_At	Datetime	-	-

Table 3. District

No	*Field*	*Type*	*Size*	*Key*
1	Id_kec	*Int*	11	*Primary Key*
2	name	*Text*		

Table 4. Category

No	*Field*	*Type*	*Size*	*Key*
1	Category_ID	*Int*	11	*Primary Key*
2	Category_Name	*Varchar*	60	

3	*Created_at*	*Datetime*		
4	*Updated_at*	*Datetime*		

Table 5. Location

No	*Field*	*Type*	*Size*	*Key*
1	Location_ID	Int	11	Primary Key
2	District_ID	Int	11	Foreign Key
3	Category_ID	Int	11	Foreign Key
4	Location_Name	Varchar	225	-
5	Location_Description	Text	-	-
6	Latitude	Varchar	50	-
7	Longitude	Varchar	50	-
8	Address	Text	-	-
9	Location_Photo	Text	-	-
10	Status	Text	-	-
11	Created_At	Datetime	-	-
12	Updated_At	Datetime	-	-

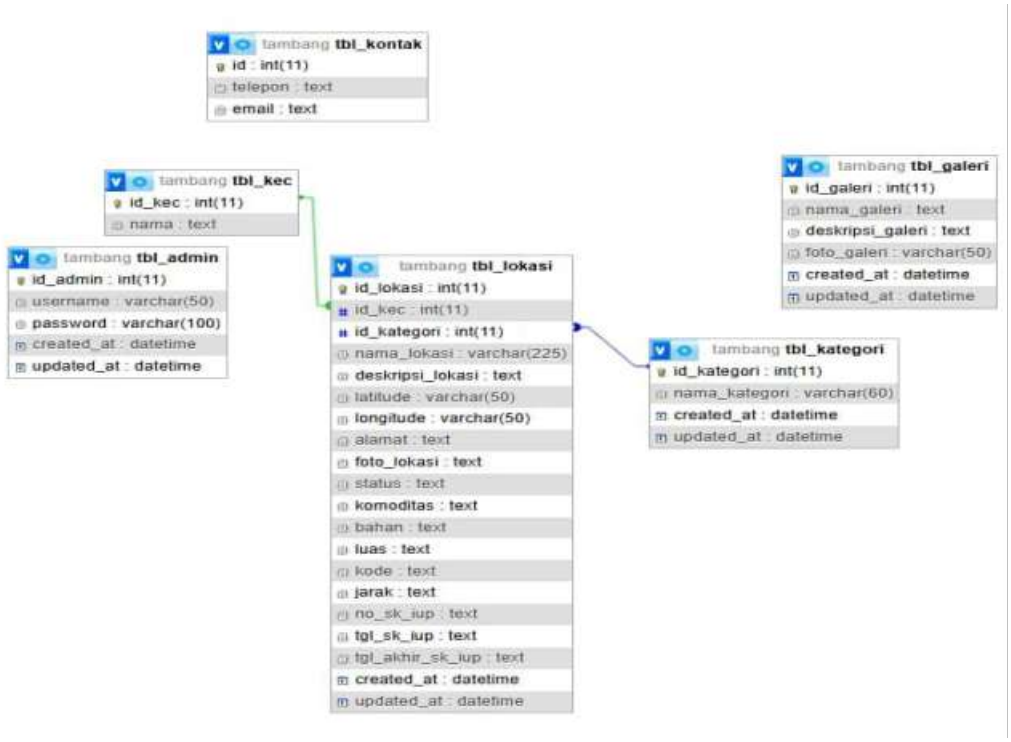


Figure 2. Table Relationships

ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)

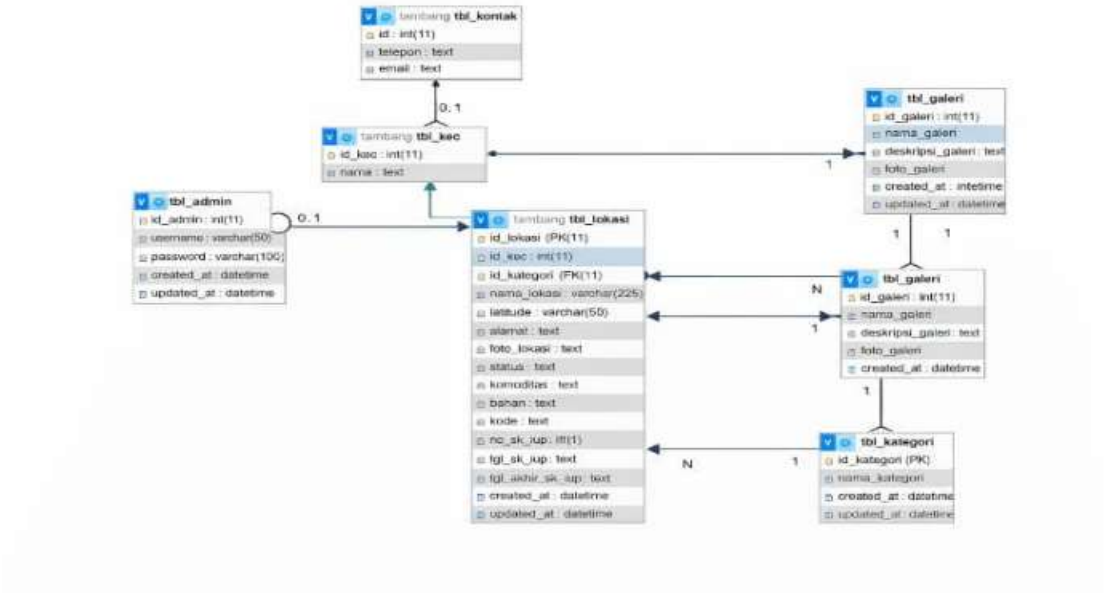


Figure 3. ERD

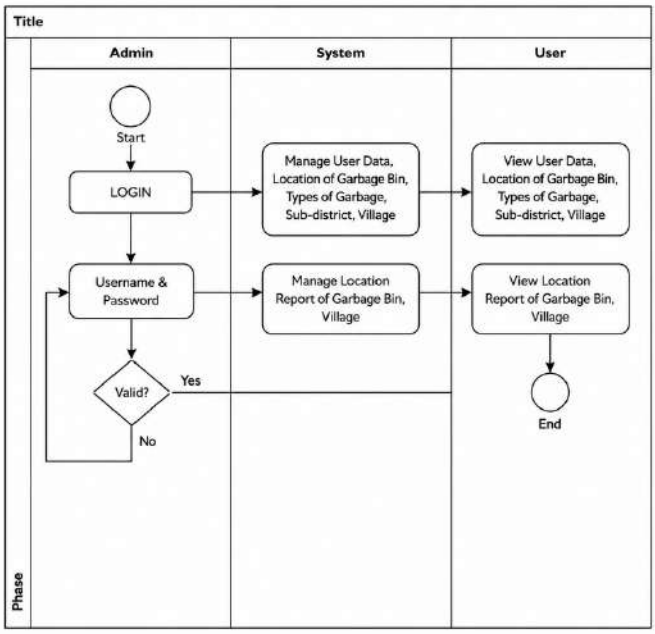


Figure 4. System Flowchart

DOI: https://doi.org/10.31949/j-ensitec.v12i02.18139

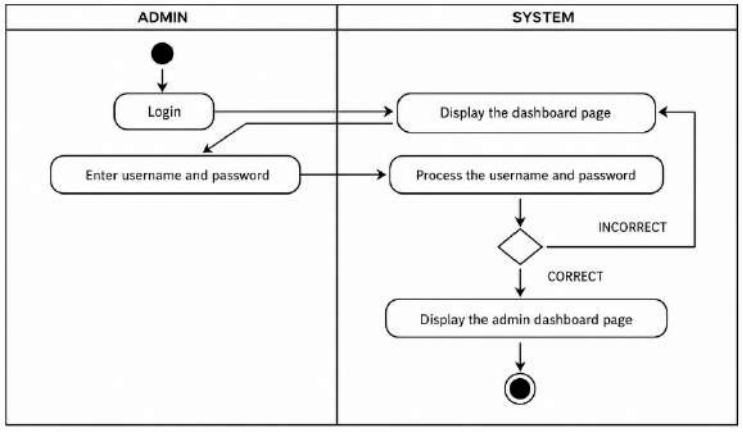


Figure 5. Login Activity Diagram

2.3. Data Collection Techniques

Data collection was carried out through interviews and literature studies. Direct interviews were conducted with two technical staff members of the ESDM Regional Office Region I in Kefamenanu, who are directly responsible for mining location data management. The semi-structured interview process lasted approximately 90 minutes and covered the existing workflow, types of attribute data (mining permit decree number, area size, operational status, mining type, and owner name), as well as technical constraints. The interview results were transcribed and revalidated with the respondents.

The collected data included mining location coordinates, attribute data, and identification of constraints such as the absence of a centralized database and limited public access. These data became the primary input for database design and system functional requirements.

The literature study reviewed regulations such as the Regulation of the Minister of Energy and Mineral Resources No. 05/2017 [23], geographic information system textbooks [21], Google Maps API documentation [16], and accredited scientific journals published between 2019 and 2025. The results of the study were used to determine the system architecture (PHP, MySQL, and Google Maps API) and to develop black-box testing instruments.

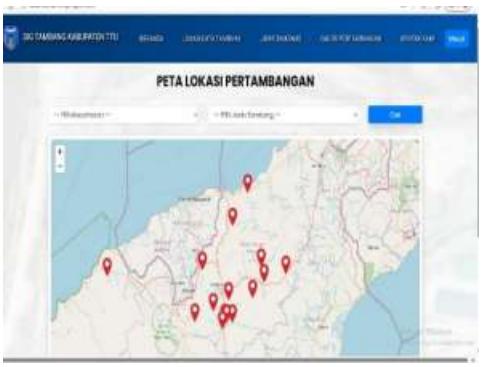
2.4. Tools and Materials

This study utilized hardware and software selected based on the requirements for developing a web-based GIS. The development environment consisted of a standard personal computer with sufficient specifications to run a local web server, while a flash drive served as backup storage for the source code and database. The software stack included: XAMPP (providing Apache and MySQL servers) as the local development environment; PHP for back-end logic and user authentication; MySQL as the relational database management system; the Google Maps API for displaying base maps, markers, and attribute information pop-ups [16]; and UML modeling tools (StarUML, Microsoft Office Visio) for system design and flowchart creation.

3. RESULTS AND DISCUSSION

The developed web-based GIS consists of five main functional modules: homepage, mining location map, mining type classification, photo gallery, and contact page. These modules address the user requirements identified during the requirements analysis stage, particularly the need for spatial visualization of mining locations and integrated attribute data management.

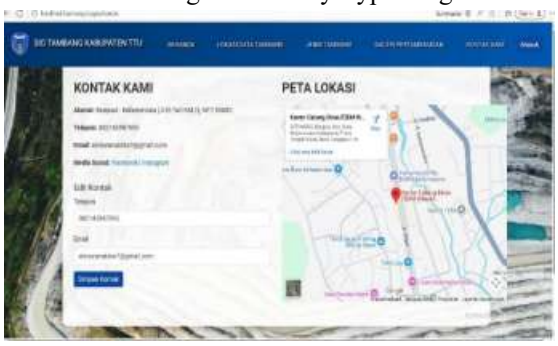
a. Main Page (Homepage)



b. Mining Data Location Page

c. Mining Commodity Types Page

d. Gallery Page



e. Contact Us Page

Figure 8. Application Interface

The proposed web-based GIS offers substantial improvements over the previous manual system through four key indicators. First, the system reduces mining location retrieval time from an average of 15–20 minutes to just a few seconds. Users can simply click on a map marker or use the search function instead of sifting through physical notebooks and multiple spreadsheet files. Second, the system ensures greater accuracy and completeness of information through a relational database design (with foreign keys linking Location, Category, and District tables) combined with verified GPS coordinates collected during field observations with ESDM staff. This design eliminates the common manual-system problems of missing IUP numbers or incomplete operational status records. Third, the system enhances monitoring and supervision capabilities by introducing a color-coded marker system: green markers for licensed and active mines, yellow markers for licensed but inactive mines, and red markers for unlicensed or illegal mines. This feature enables field officers and policymakers to identify illegal mining hotspots in less than five

minutes, compared to approximately 30 minutes required under the manual method of cross-referencing multiple paper reports. Fourth, the system provides transparent 24/7 public access via the internet from any device. In stark contrast, under the previous system, citizens had to physically visit the ESDM office, submit a formal request, and wait several days for staff to retrieve manual records. This transformation directly supports the Indonesian government's mandate for open access to natural resource information as stipulated in Ministerial Regulation No. 05 of 2017 [23].

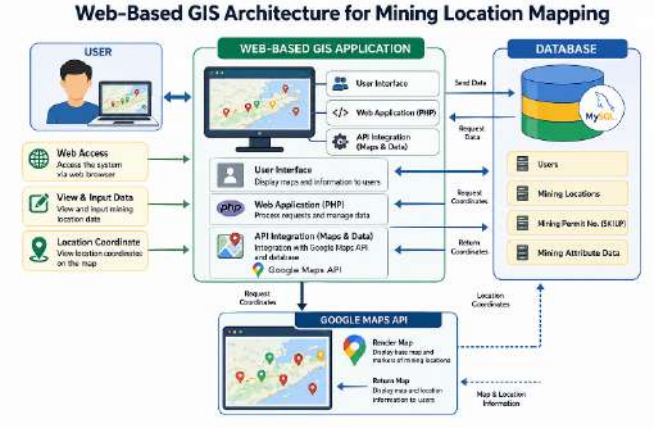


Figure 9. Web-Based GIS Architecture for Mining Location Mapping

The key scientific contribution of this study is the explicit, bidirectional integration of spatial data (coordinates) and mining attribute data (IUP numbers, permit status, area size, commodity type, operational status, and photo documentation) within a centralized MySQL database through three technical layers—the database layer where tbl_lokasi stores both coordinate and attribute fields linked via foreign keys to tbl_kec and tbl_kategori, the server-side PHP layer that executes atomic INSERT/UPDATE queries to prevent orphaned spatial points, and the client-side visualization layer where the Google Maps API and JavaScript retrieve all records as a single JSON object enabling pop-up windows to display complete attribute information without additional queries—which, unlike previous studies [9]–[12] that treated maps and attribute tables separately or used coordinates only for visualization without embedding them into a relational structure supporting monitoring workflows, offers bidirectional and persistent spatial-attribute linkage, database-enforced data consistency, single-query retrieval efficiency, and immediate real-time synchronization, thereby directly supporting ESDM monitoring functions such as instant identification of illegal mining sites via red markers, filtering by operational status, and export of spatial-attribute datasets, while also providing a replicable full-stack integration architecture for other natural resource management contexts including forestry, agriculture, and land use planning.

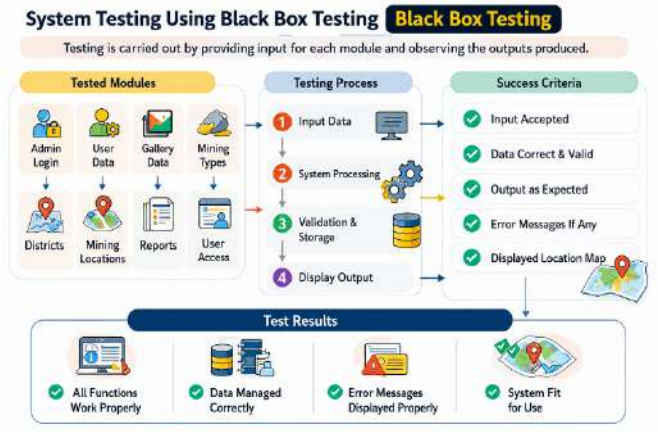


Figure 10. Black-Box Testing

The selection of the Prototype model (Pressman, 2015) was justified by the ESDM staff's lack of prior experience with web-based GIS, making iterative user feedback essential to align the system with their specific workflows including color-coded status markers and role-based access; black-box testing was chosen to verify functional correctness (input validation, CRUD, session management, role-based access) by directly simulating real user interactions without requiring internal code knowledge, providing an objective basis for User Acceptance Testing; and the Google Maps API was integrated because prior studies (Xing & Li, 2016; Liu et al., 2009) have demonstrated its effectiveness for geoscience data visualization, reducing development complexity while offering rich interactive features (markers, info windows, routing) and enabling public access without specialized GIS software—all of which support the study's key practical benefits: centralized data management, color-coded monitoring of legal/illegal mines, and transparent public access.

Table 6. Black-Box Testing of the System

No.	Module Category	Testing Procedure	Number of Scenarios	Testing Result
1	Admin Authentication	Login using correct and incorrect username and password	2	Successful
2	User Data Management	Add and delete user data	2	Successful
3	Gallery Data Management	Add, edit, and delete gallery data	3	Successful
4	Mining Type Management	Add, edit, and delete mining categories	3	Successful
5	District Data Management	Add, edit, and delete district data	3	Successful
6	Mining Location Management	Add, edit, and delete mining location data	3	Successful
7	Report Printing	Print report data based on district	1	Successful
8	Public Menu (User)	Homepage, location map, location details, route view, mining types, gallery, contact us	7	Successful

All eight black-box testing scenarios were declared successful (100%), indicating that the system has fulfilled the established functional specifications and is free from logical errors in main functions such as input validation, CRUD processes, session management, and interface-database integration. However, this result requires scientific interpretation with respect to the limitations of the testing process.

First, the 100% success rate reflects only functional validity (i.e., the system performs what it is designed to do) and does not imply non-functional robustness. Aspects such as response time under concurrent user access, load resistance, and security vulnerabilities (e.g., SQL injection, cross-site scripting, man-in-the-middle attacks) were not evaluated. Second, the testing did not cover edge cases or extreme input conditions, including invalid coordinate formats (e.g., out-of-range latitude/longitude values), upload of large photo files exceeding server memory limits, or database write failures due to network interruption. Third, the testing environment was confined to a localhost server with a single concurrent user, which does not replicate the unpredictable conditions of a production server (e.g., limited bandwidth, shared hosting resources, concurrent admin and public access).

Consequently, the 100% functional success rate should be interpreted as necessary but not sufficient evidence of overall system quality. It provides a strong basis to conclude that the system is

functionally feasible to proceed to the User Acceptance Test (UAT) stage, where end users evaluate usability and workflow compatibility. However, for long-term deployment, future studies must include performance testing (e.g., load testing with simulated concurrent users), security testing (e.g., SQL injection attempts, input sanitization validation), and usability testing with a larger sample of end users. Until such tests are conducted, claims about system reliability under real-world operating conditions remain provisional.

4. CONCLUSION

This study successfully developed a web-based GIS for mapping non-metallic mineral and rock mining locations in TTU Regency, transforming the manual document-based system into a centralized digital platform that integrates spatial and attribute data, as demonstrated by reduced search time (from 15–30 minutes to under one minute), streamlined data updates, and online public access. However, the study is limited to TTU Regency, lacks advanced spatial analysis features, and only performed functional testing (black-box) without usability, performance, or security evaluations; therefore, future studies should expand coverage to neighboring regencies (TTS, Belu, Malaka), add spatial analysis and public reporting features, and incorporate usability testing (e.g., SUS), performance testing (e.g., load testing with concurrent users), and security testing (e.g., SQL injection, XSS) to ensure practical, reliable, and secure deployment at the ESDM office.

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to the Rector, Dean, and Head of the Study Program for providing facilities and academic support throughout the implementation of this research. Appreciation is also extended to the supervisors and examiners for their guidance, suggestions, and valuable direction during the research process. The author would also like to thank the Regional Office of the Department of Energy and Mineral Resources (ESDM) Region I for granting permission and providing the necessary data for this study. Finally, the author expresses heartfelt gratitude to family and colleagues for their moral support throughout the research process.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10528-10535

Failure Analysis of Centrifugal Pump Impeller in Textile Wastewater Using a Visual and Erosion-Corrosion Approach

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ARTICLE INFO

Article history:
Received 10 May 2026
Revised 12 May 2026
Accepted 14 May 2026
Available online 25 June 2026

Keywords:
Centrifugal pump;
Erosion–corrosion;
Impeller failure;
Textile wastewater,
Slurry flow

IEEE style in citing this article:
J. J. Frihatna, W. Wijaya, C. D. Mulyadi, M. A. Fhaizal, W. Sani, and H. Rahayu, "Failure Analysis of Centrifugal Pump Impeller in Textile Wastewater Using a Visual and Erosion-Corrosion Approach," J-ENSITEC: Journal of Engineering and Sustainable Technology, vol. 12, no. 2, pp. 10528-10535, 2026.

Doi :
https://doi.org/10.31949/j-ensitec.v12i02.18060

ABSTRACT

Premature impeller failure is a major operational problem in textile wastewater treatment systems due to abrasive slurry flow and chemically aggressive environments. This study investigates the failure mechanism of a centrifugal pump impeller used in a textile wastewater treatment plant after approximately 1.5 years of operation. The impeller material was identified as gray cast iron operating under slurry wastewater conditions containing suspended abrasive particles and chemical contaminants. The failure analysis was conducted through visual inspection, morphology evaluation, and literature-based erosion–corrosion interpretation. Severe degradation was observed in the outer diameter region, including pitting, edge thinning, perforation, and material loss. The damage was associated with abrasive particle impact, high turbulence intensity, slurry flow, and corrosive wastewater exposure. The results indicate that synergistic erosion–corrosion was the dominant degradation mechanism. Erosion continuously removed the protective oxide layer, while corrosion accelerated material weakening and surface deterioration. Recent erosion studies on centrifugal pumps also reported severe degradation near blade tips and outer diameter regions due to high particle impact energy and turbulence effects. Compared with previous studies that separately discuss erosion or corrosion mechanisms, this study emphasizes the interaction of both mechanisms under textile wastewater operating conditions. The findings provide practical implications for improving pump reliability through better material selection, slurry filtration systems, and preventive maintenance strategies in wastewater treatment applications.

1. INTRODUCTION

Centrifugal pumps are widely used in textile wastewater treatment systems to transfer fluids containing suspended solids, sludge particles, and chemical contaminants. The impeller is one of the most critical components because it directly interacts with the working fluid during operation. Continuous exposure to abrasive slurry particles and corrosive wastewater may significantly reduce impeller service life, pumping efficiency, and operational reliability [1].

Impeller degradation generally occurs due to erosion, corrosion, cavitation, or synergistic interaction between these mechanisms [5], [6]. Erosion is caused by repeated particle impact on the material

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surface, while corrosion occurs due to electrochemical reactions between the metal surface and surrounding fluid environment [11]. Under slurry flow conditions, erosion–corrosion interaction may accelerate material degradation significantly [17], [18].

Previous studies investigated slurry erosion and centrifugal pump degradation using experimental methods and numerical simulations [20]–[25]. Khan et al. [29] reported severe wall thinning and material loss near blade tips and outer diameter regions caused by turbulence intensity and repeated abrasive particle impingement. Their study combined SEM, EDS, laser profilometry, and CFD-DPM simulation to correlate particle-laden flow behavior with localized erosion zones in centrifugal pump blades. Similar degradation mechanisms were also observed in slurry transport systems and wastewater applications [17], [18].

Recent review studies emphasized that wear in centrifugal pumps is strongly influenced by turbulence intensity, slurry concentration, particle impact velocity, cavitation effects, and material properties [30]. Cavitation-assisted erosion may further accelerate degradation through repeated bubble collapse and localized micro-jet formation near the impeller surface.

Despite extensive studies on slurry erosion, research specifically discussing erosion–corrosion failure in textile wastewater systems remains limited. Textile wastewater contains abrasive particles, dye residues, detergents, salts, and fluctuating pH conditions that promote simultaneous mechanical and electrochemical degradation. Several recent studies published in J-ENSITEC and related engineering journals have discussed industrial equipment degradation, preventive maintenance, corrosion analysis, and material reliability under severe operating conditions [26]–[28]. However, studies specifically focusing on synergistic erosion–corrosion failure of centrifugal pump impellers in textile wastewater systems remain limited.

The novelty of this study lies in the investigation of synergistic erosion–corrosion failure in a centrifugal pump impeller operating under textile wastewater conditions. Unlike previous studies focusing separately on erosion or corrosion mechanisms, this study emphasizes the interaction between abrasive slurry flow and corrosive wastewater environments under actual industrial operating conditions. Therefore, this study provides a practical industrial case study that bridges the gap between theoretical erosion–corrosion mechanisms and actual impeller degradation in textile wastewater treatment systems.

The objective of this study is to analyze the failure mechanism of a centrifugal pump impeller used in textile wastewater service and propose engineering recommendations to improve pump reliability and operating life.

2. RESEARCH METHOD

2.1. Research Object

The object of this study was a failed centrifugal pump impeller used as a Return Activated Sludge (RAS) pump in a textile wastewater treatment plant located in Cimahi, Indonesia. The impeller operated for approximately 1.5 years before replacement due to significant performance reduction and severe material degradation.

Pump specifications are summarized as follows:

- Pump type : Centrifugal pump
- Impeller type : Closed impeller
- Material : Gray cast iron
- Capacity : 80–100 m^3/h
- Rotational speed : 1450 rpm
- Operating temperature : 30–40°C
- Wastewater pH : 6–9
- Working fluid: Textile wastewater sludge

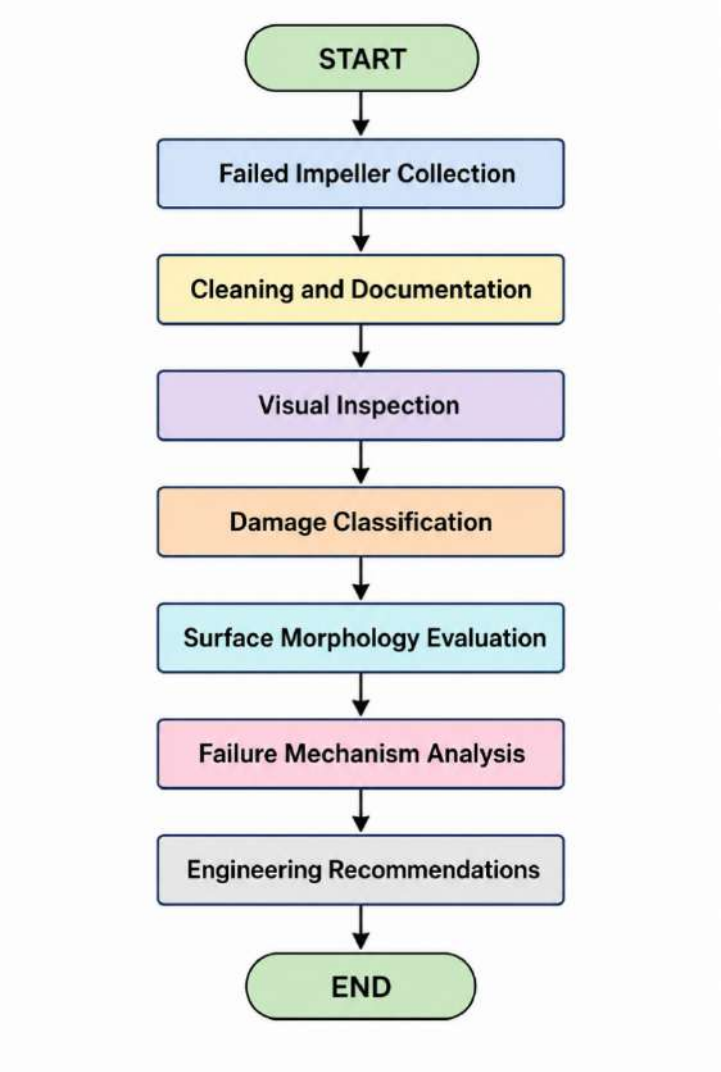
The wastewater contained suspended abrasive particles originating from textile sludge, sediment particles, and inorganic contaminants that potentially contributed to abrasive wear during pump operation.

2.2. Research Procedure

The research procedure consisted of:

1. Failed impeller collection
2. Cleaning and documentation
3. Visual inspection
4. Surface morphology evaluation
5. Damage classification
6. Failure mechanism interpretation
7. Engineering recommendation development

Figure 1. Research Methodology Flowchart



2.3 Failure Analysis Method

The analysis was conducted using macroscopic visual inspection and literature-based erosion–corrosion interpretation. Observed damage characteristics were compared with erosion and slurry degradation theories reported in previous studies [5], [17], [20]–[25].

The analysis focused on correlating degradation morphology with slurry flow behavior, turbulence intensity, particle impact, wall thinning, and corrosion mechanisms occurring in centrifugal pump systems.

SEM/EDS analysis, hardness testing, and metallographic examination were not conducted due to specimen limitations and facility constraints; however, these methods are recommended for future investigations to obtain more comprehensive microstructural characterization.

3. RESULTS AND DISCUSSION

3.1. Visual Observation

Visual inspection revealed non-uniform damage across the impeller surface. The most severe degradation occurred at the outer diameter region.

Table 1. Damage severity across impeller zones

Zone	Severity	Observed Characteristics
Hub region	Minimal	Slight discoloration without significant material loss
Blade region	Moderate	Rough surface texture and early-stage pitting
Outer diameter	Severe	Massive material loss, edge thinning, and perforation

Figure 2. Overall failed impeller condition (front side)

The impeller showed severe material loss at blade edges and tips, indicating prolonged exposure to abrasive particles and corrosive fluid.

Figure 2 shows the overall condition of the failed impeller after approximately 1.5 years of operation in textile wastewater service. Severe degradation was concentrated at blade tips and outer diameter regions. Surface roughening, edge thinning, pitting, and material perforation were clearly observed.

The outer diameter region experienced the highest circumferential velocity during operation, resulting in higher particle impact energy and accelerated material removal. Similar degradation behavior was reported by Khan et al. [29], where severe wall thinning and erosion damage occurred near blade outer edges and vane tips under slurry flow conditions.

Repeated particle impingement continuously removed material from the impeller surface and increased surface roughness. Turbulence intensity and slurry flow also accelerated erosion progression. Previous CFD-DPM investigations demonstrated that particle-laden flow significantly increases turbulence intensity and particle-wall collisions, thereby accelerating erosive wear in centrifugal pump blades [29].

Figure 3. Failed impeller showing severe perforation (red circle), edge thinning (arrow A), and material loss at the outer diameter region.

Figure 3 shows localized degradation zones observed on the impeller surface. Severe perforation and edge thinning indicate advanced erosion–corrosion interaction caused by abrasive particle impact and electrochemical degradation.

The observed damage morphology is consistent with slurry erosion mechanisms reported in previous studies [20]–[25], where localized turbulence and high particle concentration accelerated material loss. Similar degradation mechanisms were also reported by Neville and Wang [5], who explained that erosion continuously removes protective oxide films, thereby exposing fresh metal surfaces to further corrosion attack

Figure 4. Outer diameter degradation region showing severe erosion–corrosion damage and surface thinning.

Figure 4 shows severe wall thinning in the outer diameter region where slurry velocity and turbulence intensity were highest. The combination of erosion and corrosion gradually weakened the material until perforation occurred.

The degradation severity observed in the outer diameter region is associated with increased circumferential velocity and turbulence intensity. Higher flow velocity increases particle kinetic energy and impact frequency, thereby accelerating material removal and wall thinning. This mechanism is consistent with erosion models reported in slurry pump literature [20]–[25], [29].

The observed degradation mechanism is consistent with erosion–corrosion interaction reported in slurry systems [17], [18]. Material thinning became more severe in regions experiencing repeated abrasive particle collisions and unstable flow behavior.

Recent studies reported that centrifugal pump wear is strongly influenced by particle concentration, turbulence intensity, cavitation effects, and slurry velocity [30].

3.2. Failure Mechanism

The dominant failure mechanism was identified as synergistic erosion–corrosion. Erosion continuously removed protective oxide films from the material surface, while corrosion weakened the material and accelerated material loss.

Possible cavitation effects also contributed to localized degradation. Cavitation bubble collapse may produce micro-jets and shock waves that intensify surface damage and erosion progression. The combined interaction between erosion, corrosion, and cavitation significantly accelerated degradation in the outer diameter region.

Khan et al. [29] reported that high turbulence regions in centrifugal pump impellers experienced erosion rates nearly twice as severe as low-impact regions due to repeated abrasive particle collisions. Similar findings were also reported in slurry erosion studies involving centrifugal pumps and multiphase flow systems [20]–[25].

The synergistic interaction between erosion and corrosion accelerated degradation significantly beyond individual mechanisms. Repeated particle impact removed protective oxide layers from the impeller surface, while corrosive wastewater promoted electrochemical attack on exposed metal surfaces. This interaction gradually caused surface roughening, pitting, wall thinning, and eventually perforation.

3.3. Material Evaluation

The impeller material was identified as gray cast iron, which has relatively low erosion and corrosion resistance under abrasive slurry conditions.

Table 2. Comparison of Impeller Materials for Slurry and Corrosive Applications

Material	Hardness (HB)	Erosion Resistance	Corrosion Resistance
Gray cast iron	180–220	Low	Low
Ductile iron	200–300	Moderate	Moderate
Bronze alloy	80–200	Moderate	High
High-chromium white iron	500–600	Very High	High

Source: Adapted from ASM material standards and erosion–corrosion literature [13], [15].

High-chromium white iron is recommended for slurry applications because its carbide-rich microstructure provides superior abrasion resistance. Material selection plays an important role in extending pump service life because wear resistance depends on hardness, corrosion resistance, and the ability to withstand abrasive particle impact under slurry conditions [30].

Previous studies also reported that cast iron and carbon steel impellers operating under sand-laden flow conditions exhibit accelerated degradation due to repeated abrasive particle impacts and localized turbulence effects [29].

3.4. Engineering Recommendations

Several engineering recommendations are proposed:

1. Install slurry filtration or strainer systems to reduce abrasive particle entry into the pump system.
2. Replace gray cast iron with high-chromium alloy materials or bronze alloys for improved wear resistance.
3. Conduct periodic inspection and preventive maintenance to identify early-stage degradation.
4. Reduce abrasive particle concentration in the wastewater transport system.
5. Consider hydrocyclone systems for continuous slurry particle separation.

These approaches may improve pump reliability and extend impeller service life in textile wastewater applications.

4. CONCLUSION

The centrifugal pump impeller failed primarily due to synergistic erosion–corrosion under abrasive slurry flow and corrosive textile wastewater conditions. Severe degradation occurred at blade tips and outer diameter regions due to high turbulence intensity and abrasive particle impact.

The interaction between erosion and corrosion accelerated material loss and caused edge thinning, pitting, wall thinning, and perforation. Possible cavitation effects also contributed to localized surface deterioration.

The findings are consistent with recent experimental and CFD-based studies showing that high turbulence intensity, slurry concentration, and particle impact velocity strongly influence localized impeller degradation and erosion severity in centrifugal pump systems [29], [30].

This study contributes to understanding impeller degradation mechanisms in textile wastewater systems and provides practical recommendations regarding material selection, slurry filtration, and preventive maintenance strategies. The findings also provide industrial implications for improving pump reliability, reducing maintenance downtime, and extending equipment service life in wastewater treatment applications.

Future studies are recommended to include SEM/EDS analysis, hardness testing, metallographic examination, and CFD simulation to provide more comprehensive characterization of erosion–corrosion behavior in centrifugal pump systems.

This study contributes to practical failure analysis knowledge for centrifugal pumps operating under abrasive textile wastewater conditions and supports the development of more reliable slurry handling systems in industrial wastewater treatment facilities.

ACKNOWLEDGEMENTS

The authors thank PT. Jerdytex for permission to conduct this study and the Department of Mechanical Engineering, Universitas Sangga Buana YPKP and Universitas Pasundan for their support.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10536-10542

Hardware Requirements Analysis for Administrative Staff in Higher Education

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ARTICLE INFO

Article history:
Received 30 May 2026
Revised 05 June 2026
Accepted 07 June 2026
Available online 25 June 2026

Keywords:
Computer performance
Hardware requirements analysis
Administration
Performance benchmarking
Work efficiency

IEEE style in citing this article:
H. Sanjaya and F. M. Hidayat, "Hardware Requirements Analysis for Administrative Staff in Higher Education," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10536–10542, 2026,
doi: https://doi.org/10.31949/j-ensitec.v12i02.18424

ABSTRACT

The use of computer hardware that does not match workload requirements remains a common issue in higher education administrative activities, leading to reduced efficiency and productivity. This study aims to analyze hardware requirements for administrative staff at the Faculty of Psychology, Business, and Technology, Universitas Yayasan Pendidikan Imam Bonjol Majalengka, and to propose optimal hardware specifications. A case study approach was employed by evaluating three devices used by three staff members through observation and system performance assessment. The main contribution of this study lies in providing a workload-based hardware analysis supported by simple performance benchmarking to demonstrate the impact of hardware upgrades. The results indicate that existing systems, equipped with older mid-range processors, 4–8 GB RAM, and HDD storage, are insufficient to support multitasking and data processing efficiently. Performance testing shows that data input processing time, initially ranging from 10–12 minutes, can be reduced to 4–6 minutes using the recommended specifications. This represents an efficiency improvement of approximately 50–60% and a significant reduction in system latency. Therefore, this study offers a more measurable and evidence-based approach to hardware planning compared to conventional descriptive methods.

1. INTRODUCTION

The rapid advancement of information technology has significantly transformed administrative activities in higher education institutions [1]. Computer systems play a crucial role in supporting daily operations such as academic data management, financial processing, and document administration [2], [3]. The effectiveness of these activities is highly dependent on the performance of hardware components, including processors, memory, and storage subsystems [4]. However, in many cases, hardware procurement is not based on actual workload requirements, resulting in suboptimal system performance and reduced work efficiency [5].

A common issue in administrative environments is the mismatch between hardware specifications and job demands [6]. Administrative staff are often required to perform multitasking activities, such as managing large datasets, accessing web-based information systems, and generating reports simultaneously [7]. When hardware resources are insufficient, system bottlenecks occur, particularly in memory and storage subsystems, leading to increased processing time and decreased productivity [8], [9]. The use of

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conventional storage devices such as *Hard Disk Drives (HDD)* further exacerbates this issue due to slower data access compared to modern *Solid State Drives (SSD)* [10].

Previous studies have demonstrated that upgrading key hardware components, such as RAM and storage devices, can significantly improve system performance and reduce execution time [11]. Research on modern computing systems also highlights the importance of balancing processing power and memory capacity to avoid performance degradation caused by bottlenecks [12]. However, most existing studies focus on general system performance evaluation or controlled experimental environments, with limited attention to real-world administrative workloads in higher education settings. Furthermore, many studies lack practical performance measurements that directly reflect user experience in completing daily tasks.

To address these gaps, this study proposes a workload-based hardware requirement analysis for administrative staff in higher education. The approach integrates qualitative workload assessment with simple performance benchmarking to evaluate the suitability of existing hardware and to quantify the impact of recommended upgrades. By measuring execution time for specific administrative tasks before and after hardware improvements, this study provides a practical evaluation framework that reflects real working conditions.

This research is conducted as a case study at Universitas Yayasan Pendidikan Imam Bonjol Majalengka, involving three administrative staff members with different workload characteristics. Although the analysis is based on a specific institutional context, the findings are expected to represent common challenges faced by administrative staff in higher education environments. The main contribution of this study lies in providing a structured and measurable approach to hardware planning, combining workload analysis, bottleneck identification, and empirical performance evaluation. This approach offers a more practical and evidence-based alternative compared to conventional descriptive methods, thereby supporting better decision-making in hardware procurement and system optimization.

2. METHOD

This study employs a case study approach to analyze hardware requirements based on the workload of administrative staff in higher education. The case study method is appropriate for capturing real-world conditions and evaluating the relationship between job activities and hardware performance. The research involves three administrative staff members at Universitas YPIB Majalengka, each using a separate computing device.

The overall research design consists of four main stages: workload identification, hardware evaluation, bottleneck analysis, and performance benchmarking. The flow of the research design is illustrated in Figure 1, which shows how each stage is interconnected in producing the final hardware recommendation.

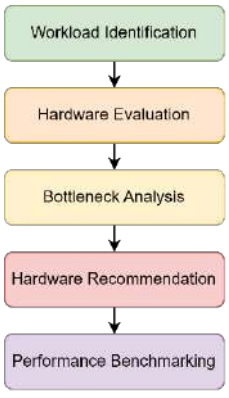

Figure 1. Research design framework

As illustrated in Figure 1, the research design framework consists of several interconnected stages that systematically lead to the formulation of hardware recommendations and performance evaluation.

2.1. Workload Identification

This stage focuses on identifying the daily activities performed by administrative staff. The analysis includes the type of tasks, frequency of execution, and computational intensity required. Activities such as data entry, document processing, and system access are examined to determine their impact on system performance. This stage provides the foundation for understanding the actual hardware requirements.

2.2. Hardware Evaluation

In this stage, the existing hardware specifications used by each administrative staff member are collected and analyzed. Key components such as the processor, memory (RAM), and storage type are evaluated to determine their capability in supporting the identified workload. This evaluation helps to establish the baseline condition of the system and provides a reference for further performance analysis.

2.3. Bottleneck Analysis

After comparing workload requirements with existing hardware capabilities, a bottleneck analysis is conducted to identify components that limit system performance. Bottlenecks occur when certain hardware resources are unable to meet computational demands, resulting in delays, system lag, and reduced efficiency during task execution.

2.4. Hardware Recommendation

Based on the bottleneck analysis, a cost-effective hardware upgrade strategy is proposed to improve system performance without requiring a complete system replacement. The recommendation prioritizes upgrading critical components that directly impact performance, particularly memory (RAM) and storage, while maintaining the existing processor where possible to minimize cost.

2.5. Performance Benchmarking

The final stage of this study involves evaluating system performance through benchmarking to measure the effectiveness of the proposed cost-efficient hardware upgrade. The benchmarking process focuses on comparing task execution time before and after upgrading key components, specifically RAM and storage (HDD to SSD), while retaining the existing processor.

3. RESULTS AND DISCUSSION

This section presents the findings obtained from the workload analysis, hardware evaluation, bottleneck identification, hardware recommendation, and performance benchmarking stages. The discussion is conducted systematically to illustrate the relationship between administrative workloads, existing hardware conditions, and the effectiveness of the proposed upgrade strategy. The results are analyzed to determine how hardware optimization can improve operational efficiency in higher education administrative environments.

3.1. Workload Identification

The first stage of the analysis focuses on identifying the workload characteristics of administrative staff. Understanding workload patterns is essential because different job activities require different levels of computational resources. Through interviews and direct observations, data were collected regarding daily activities, software usage, task frequency, and computational intensity. The results of the workload identification process are presented in Table 1.

Table 1. Workload identification

Staff	Activity	Software used	Frequency	Computational Load
A	Financial data input	Microsoft Excel	Daily	High
A	Report generation	Excel, PDF Tools	Weekly	Medium
B	Academic administration	Web-based system	Daily	High

B	Data validation	Microsoft Excel	Daily	Medium
…	…	…	…	…
C	Document processing	Microsoft Word	Daily	Low
C	Data archiving	File system	Weekly	Low

As shown in Table 1, administrative staff perform tasks with varying computational requirements. Activities involving financial data processing and academic administration exhibit high computational loads due to the use of large datasets and continuous interaction with web-based systems. These tasks frequently involve multitasking operations, including switching between applications and processing multiple files simultaneously.

In contrast, document processing and data archiving require lower computational resources because they generally involve smaller file sizes and less intensive operations. However, despite their lower workload intensity, these tasks may still experience performance degradation when supported by slow storage systems.

The findings indicate that workload characteristics significantly influence hardware requirements. Tasks performed daily with high computational demands require more responsive hardware configurations to maintain operational efficiency. Based on these workload characteristics, the next stage evaluates whether the existing hardware specifications are capable of supporting the identified tasks effectively.

3.2. Hardware Evaluation

After identifying the workload characteristics, the next stage evaluates the hardware currently used by administrative staff. This evaluation aims to determine the extent to which the existing devices are capable of supporting the identified computational demands. The analysis focuses on key hardware components, including processors, memory capacity, and storage technology. The results of the hardware evaluation are summarized in Table 2.

Table 2. Existing hardware specifications

Staff	Processor	RAM	Storage	Device Age	Performance Condition
A	Intel Core i3 Gen 7	4 GB	HDD 1 TB	5 years	Slow performance
B	Intel Core i3 Gen 8	4 GB	HDD 1 TB	4 years	Frequent lag
C	Intel Core i3 Gen 7	8 GB	HDD 1 TB	5 years	Moderate

The data in Table 2 show that all devices rely on conventional HDD storage and utilize mid-range processors from older generations. While the processors are still capable of handling basic administrative tasks, the limited RAM capacity and slow storage performance significantly reduce system responsiveness.

Staff A and Staff B experience the most noticeable performance issues due to the use of only 4 GB RAM, which limits multitasking capability and causes system lag during intensive operations. Staff C demonstrates relatively better performance because of higher memory capacity; however, the use of HDD storage still results in delays during file access and application loading.

In addition, the age of the devices contributes to performance degradation, as older hardware architectures are generally less efficient when handling modern software workloads. These findings indicate that the current hardware configurations are not fully aligned with the workload demands identified in the previous stage. Therefore, a bottleneck analysis is required to determine the specific components responsible for the observed performance limitations.

3.3. Bottleneck Analysis

Following the hardware evaluation stage, bottleneck analysis is conducted to identify the specific components that limit system performance. This stage is important because understanding the exact source of performance degradation enables more targeted and cost-efficient hardware improvements. The results of the bottleneck identification process are presented in Table 3.

Table 3. Bottleneck identification

Staff	Activity	Observed Issue	Bottleneck Component
A	Financial data input	Slow processing, system lag	CPU, RAM
B	Academic system access	Long loading time	Storage (HDD), RAM

…	…	…	…
C	File handling	Delay in opening large files	Storage (HDD)

As presented in Table 3, the major bottlenecks are concentrated in RAM capacity and storage performance. Insufficient memory resources reduce the system's ability to handle multiple applications simultaneously, resulting in lag and slower task execution. Meanwhile, HDD storage introduces high data access latency, particularly when opening large files or loading applications.

Although the processors are not the primary source of performance issues, they become secondary bottlenecks when combined with insufficient memory resources. These findings confirm that improving memory and storage components would provide the most efficient approach for enhancing overall system performance.

Based on the identified bottlenecks, the next stage proposes a cost-efficient hardware upgrade strategy aimed at improving performance without requiring a complete system replacement.

3.4. Hardware Recommendation

After identifying the main performance bottlenecks, a hardware upgrade strategy is proposed to improve system responsiveness and operational efficiency. The recommendation is designed using a value-for-money approach, where performance improvements are prioritized while keeping upgrade costs relatively affordable. The proposed hardware recommendations are shown in Table 4.

Table 4. Recommended Hardware Specifications and Cost-Efficient Upgrade

Component	Current Specification	Recommended Upgrade	Justification	Estimated Price (IDR)
Processor	Intel i3 Gen 7/8	Retained	Still adequate for administrative tasks	-
RAM	4–8 GB	8–16 GB	Improves multitasking performance	400,000 – 800,000
Storage	HDD 1 TB	SSD 512 GB	Significantly faster data access	700,000 – 900,000
Additional	-	SSD installation & OS optimization	Improves system efficiency	200,000

The proposed recommendation emphasizes selective component upgrades rather than full system replacement. Retaining the existing processor significantly reduces upgrade costs while still maintaining adequate performance for administrative workloads.

The most impactful improvement is achieved through replacing HDD storage with SSD technology, which substantially reduces loading time and improves system responsiveness. Increasing RAM capacity also enhances multitasking capability, allowing the system to process larger datasets more efficiently.

From a financial perspective, the proposed upgrade strategy requires a relatively affordable investment of approximately IDR 1.3–1.9 million, making it more feasible for implementation in educational institutions with budget limitations.

To validate the effectiveness of the proposed upgrade strategy, benchmarking tests are conducted in the next stage by comparing system performance before and after the hardware improvements.

3.5. Performance Benchmarking

The final stage of the analysis evaluates the effectiveness of the proposed hardware upgrades through benchmarking tests. This stage aims to measure the extent of performance improvement achieved after upgrading RAM and replacing HDD storage with SSD technology. The benchmark results are presented in Table 5, while the graphical comparison is illustrated in Figure 2.

Table 5. Performance Benchmark Results (Before–After Upgrade)

Activity	Before Upgrade (HDD, 4–8 GB RAM)	After Upgrade (SSD, 8–16 GB RAM)	Improvement
Data input (1000 rows, Excel)	10–12 minutes	5–6 minutes	~50% faster
Open large Excel file	2–2.5 minutes	30–40 seconds	~70% faster
System booting	2–3 minutes	20–25 seconds	~80% faster

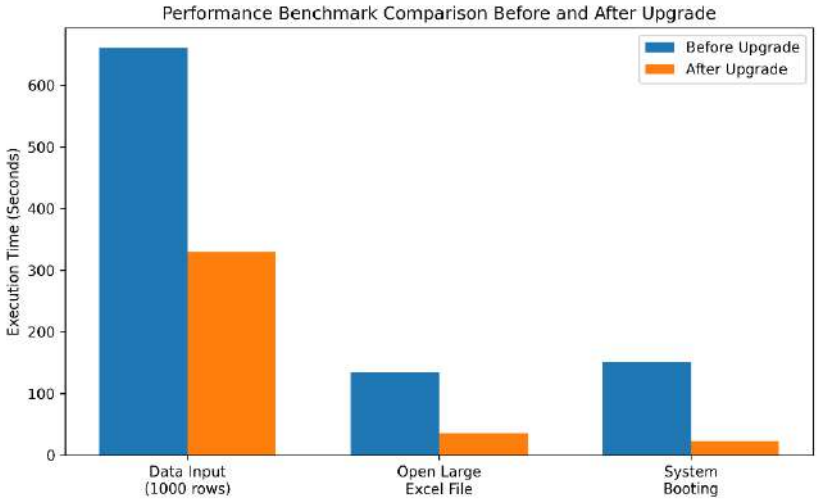

Figure 2. Performance benchmark comparison before and after upgrade

As shown in Table 5, the results indicate a significant improvement in system performance after applying the recommended upgrades. The most notable improvement is observed in system boot time and file access, where the use of SSD drastically reduces data access latency. This confirms that storage performance is a critical factor in overall system responsiveness.

In addition, increasing RAM capacity contributes to improved multitasking performance, as reflected in the reduced time required for data input processing. With more available memory, the system is able to handle larger datasets and multiple applications simultaneously without experiencing lag.

Although the processor remains unchanged, the overall system performance improves substantially due to the elimination of bottlenecks in memory and storage subsystems. This finding highlights that targeted upgrades on critical components can deliver significant performance gains without requiring a full system replacement.

From a practical perspective, the benchmark results demonstrate that a relatively low-cost upgrade can yield efficiency improvements of approximately 50–80%, depending on the task. This reinforces the effectiveness of the proposed value-for-money strategy in optimizing hardware performance for administrative activities.

The results of this benchmarking stage validate the proposed hardware recommendations and provide empirical evidence that supports cost-efficient decision-making in hardware upgrades.

4. CONCLUSION

This study has demonstrated that hardware performance plays a crucial role in supporting administrative activities in higher education environments. Through a workload-based analysis, it was found that the primary performance limitations were caused by insufficient memory capacity and the use of conventional HDD storage, which led to system lag, long processing times, and reduced work efficiency.

The proposed cost-efficient upgrade strategy, focusing on increasing RAM capacity and replacing HDD with SSD, has proven to be highly effective in improving system performance. Benchmark results indicate significant reductions in execution time across various tasks, with improvements ranging from approximately 50% to 80%. Notably, these improvements were achieved without replacing the processor, highlighting that targeted upgrades on critical components can deliver substantial performance gains.

From a practical perspective, this study confirms that a value-for-money approach to hardware upgrading is more feasible and impactful compared to full system replacement, particularly in resource-constrained institutional settings. The findings provide a structured and measurable framework for aligning hardware specifications with actual workload requirements, enabling more informed decision-making in hardware procurement.

Although this research is based on a case study involving a limited number of administrative staff, the results reflect common challenges faced in higher education administrative environments. Therefore, the proposed approach can be adapted and applied to similar contexts to improve operational efficiency.

Future work may expand the scope of analysis by including a larger number of users, incorporating real-time performance monitoring, and exploring additional factors such as network performance and software optimization. Such extensions are expected to further enhance the comprehensiveness and applicability of hardware requirement analysis.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10543-10551

Comparison of Machine Learning Algorithms (SVM, Random Forest, and Naïve Bayes) for Predicting Rice Production

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ARTICLE INFO

Article history:
Received 25 May 2026
Revised 02 June 2026
Accepted 05 June 2026
Available online 25 June 2026

Keywords:
Agricultural Forecasting
Climate Change
Machine Learning
Rice Production Prediction
Random Forest

IEEE style in citing this article:
O. Dahwanu, N. Abdillah, N. Akbar, and H. Alghifari, "Comparison of Machine Learning Algorithms (SVM, Random Forest, and Naïve Bayes) for Predicting Rice Production," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 02, pp. 10543–10551, 2026.

Doi : https://doi.org/10.31949/j-ensitec.v12i02.18386

ABSTRACT

Global rice production faces mounting pressure from population growth and climate change, yet traditional statistical models fail to capture the complex nonlinear dynamics between environmental factors and crop yields. To address this gap, this study systematically compares the accuracy of three machine learning algorithms, Support Vector Machine (SVM), Random Forest (RF), and Naïve Bayes (NB) for predicting rice production fluctuations due to climate change using the latest local climate data from Indonesia. A dataset of 96 monthly observations (2018–2025) comprising climate features (temperature, humidity, wind speed, precipitation, cloud cover, sunshine duration) and rice production categories (Low, Medium, High) was analyzed. Algorithm performance was evaluated using accuracy, precision, recall, and F1-score. The results demonstrate that Random Forest significantly outperforms the other methods, achieving an accuracy of 95%, precision of 0.9571, recall of 0.95, and F1-score of 0.95, compared to SVM (75% accuracy) and Naïve Bayes (70% accuracy). This study provides the first head-to-head comparison of these three algorithms for rice yield prediction in Indonesia using current climate data. The key benefit over pre-existing approaches is the empirical confirmation that ensemble learning, particularly Random Forest, offers superior predictive reliability for crop yield forecasting under high feature complexity, thereby enabling more accurate, data-driven agricultural policy and food security planning.

1. INTRODUCTION

Global rice production is facing increasing pressure due to population growth and climate change [1], [2], [3]. Rice is the primary food source for more than half of the world's population [4], so fluctuations in its production can threaten food security [1], [5]. Traditional statistical models, which generally rely on linear relationships, often fail to capture the complex nonlinear dynamics between environmental factors and crop yields [6]. Accurate forecasting of rice yield is critical to ensuring global food security, supporting market stability, and enabling data-driven agricultural policy [7].

The growing requirement for food in an era of a changing climate and scarce resources has inspired substantial crop yield prediction research. Another contributing factor to global food insecurity is climate change and its variability [8]. A study published in the Proceedings of the National Academy of Sciences (PNAS) confirms that rice production is significantly influenced by short-term climate variability [9]. In addition, recent research shows that changes in temperature and rainfall patterns caused by global warming

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are further increasing uncertainty in crop yield estimates [10], [11], [12]. To address this complexity, recent research has increasingly adopted a machine learning (ML) approach [13], [14].

Machine learning is capable of processing large amounts of climate and satellite data to generate more precise crop yield maps [15], [16], [17]. However, not all ML algorithms perform equally well. The Support Vector Machine (SVM), Random Forest (RF), and Naïve Bayes (NB) algorithms are three popular models with distinct characteristics [18], [19]. SVM outperforms in accuracy and recall on complex datasets [18], Random Forest are robust and accurate in complex environments, while Naïve Bayes is appreciated for speed, simplicity, and interpretability [19]. Although all three are frequently used separately to predict crop yields, there remains a significant research gap: very few studies have systematically compared the accuracy of these three models head-to-head in the context of rice production in Indonesia using the latest local climate data. Therefore, this study aims to compare the accuracy of the Support Vector Machine (SVM), Random Forest (RF), and Naïve Bayes (NB) algorithms in predicting fluctuations in rice production due to climate change.

2. METHOD

2.1. Dataset

A monthly experimental dataset covering the period from January 2018 to December 2025, combining climate records from the Ogimet meteorological database and rice production statistics from Indonesia's Central Statistics Agency (BPS). The target variable rice production category was discretized into three ordinal classes: Low, Medium, and High based on observed production tonnage. This discretization converts the original regression problem into a three-class classification task, enabling the use of classification-oriented performance metrics and facilitating a clear, policy-relevant interpretation of results.

Eight climate predictor features were retained: Maximum Temperature, Minimum Temperature, Average Temperature, Average Humidity, Wind Speed, Precipitation, Cloud Cover, and Sunshine Duration. The Year, Month, and raw Production (Tons) features were deliberately excluded to prevent data leakage.

2.2. Preprocessing and Normalization

Prior to model training, all features were subjected to exploratory data analysis to verify the absence of missing values and to assess distributional properties. Z-Score standardization ($z = (x - \mu) / \sigma$) was applied exclusively to features used for SVM training, as SVMs are sensitive to feature scale differences and require normalized inputs for optimal kernel computation [25]. Random Forest and Naïve Bayes models were trained on the original (un-normalized) feature scales, consistent with their algorithmic properties: RF is scale-invariant due to its split-based decision structure, while NB operates on probabilistic feature distributions that are estimated independently per class.

2.3. Algorithms Used

2.3.1. Support Vector Machine (SVM)

SVM is a supervised learning algorithm that finds the optimal separating hyperplane maximizing the margin between classes [18]. For non-linearly separable data, the Radial Basis Function (RBF) kernel was employed, mapping inputs into a higher-dimensional feature space. Two key hyperparameters govern RBF-SVM performance: the regularization parameter C (controls the trade-off between margin maximization and training error) and gamma (γ, controls the influence radius of individual training samples). Both were optimized via grid search, as detailed in Section 2.4 [25], [26].

2.3.2. Random Forest (RF)

Random Forest is a bagging-based ensemble algorithm that constructs a collection of decision trees using randomly sampled subsets of both training instances (bootstrap sampling) and features (random subspace), aggregating class predictions by majority vote [22]. This dual randomization reduces variance and mitigates overfitting. The key hyperparameters are the number of trees (n_estimators), the maximum

tree depth (max_depth), and the minimum samples required to split a node (min_samples_split). RF's ability to naturally handle nonlinear feature interactions and provide feature importance scores makes it particularly suitable for the multi-variable climate–yield relationship [23].

2.3.3. Naïve Bayes (NB)

Gaussian Naïve Bayes is a probabilistic classifier that applies Bayes' theorem under the assumption of conditional independence among features. For each class, it estimates the mean and variance of each feature and uses Gaussian probability density functions to compute likelihoods [19]. Hyperparameter—var_smoothing—adds a small fraction of the maximum variance of all features to the per-class variance estimates, preventing numerical underflow. NB provides a useful lower-bound benchmark, as its well-known assumption of feature independence is rarely satisfied in real-world agricultural datasets where climate variables are highly correlated [28].

2.4. Hyperparameter Tuning via GridSearchCV

To ensure a fair comparison, all three algorithms were subjected to systematic hyperparameter optimization using 5-fold stratified cross-validation GridSearchCV. This technique exhaustively evaluates all specified parameter combinations, selecting the configuration that maximizes cross-validated F1-macro score. Stratified folds were used to maintain the class distribution in each fold, which is critical for balanced classification problems [30], [31]. The search spaces and optimal values identified are presented in Table 1.

Table 1. Hyperparameter Search Space and Optimal Values Identified via GridSearchCV

Algorithm	Parameter	Best Value (Grid Search)
SVM	Kernel	RBF
	C	10
	Gamma	0.1
Random Forest	n_estimators	200
	max_depth	None (unlimited)
	min_samples_split	2
Naïve Bayes	var_smoothing	1e-9

The RBF kernel was selected for SVM after comparing linear, polynomial, and RBF kernels across preliminary cross-validation runs, with RBF achieving the highest mean accuracy. For Random Forest, setting max_depth to None (unlimited growth) combined with n_estimators = 200 produced the best trade-off between bias and variance on this dataset. Naïve Bayes's var_smoothing default (1e-9) was confirmed as optimal across the search range [1e-12, 1e-6].

2.5. Statistical Significance Testing

To determine whether the performance differences observed among the three algorithms are statistically significant, two non-parametric statistical tests were applied: the Friedman test (to detect global differences across all three classifiers simultaneously) and the Wilcoxon signed-rank test (for pairwise post-hoc comparisons) [32]. Non-parametric tests were chosen because (a) the five-fold accuracy distributions cannot be assumed normally distributed with only five data points, and (b) the fold-level results are paired (each fold evaluates all three classifiers on the same data partition), violating the independence assumption of parametric tests. A significance threshold of $\alpha = 0.05$ was used throughout.

2.6. Evaluation Metrics

Each algorithm was evaluated using five metrics: (1) Accuracy; (2) Precision; (3) Recall; (4) F1-Score (macro-averaged); and (5) AUC-ROC. Macro-averaging was selected over weighted averaging to treat all classes equally regardless of their frequency, which is appropriate for the balanced class distribution in this study.

1.3 Evaluation Methods

The performance of each algorithm is evaluated using four primary metrics: Accuracy (overall prediction accuracy), Precision (accuracy of positive predictions), Recall (ability to detect positive classes), and F1-Score (the harmonic mean of Precision and Recall). Evaluation is conducted using a train-test split.

3. RESULTS AND DISCUSSION

3.1. 5-Fold Strastified Cross-Validation

Following hyperparameter selection, each tuned model was evaluated using 5-fold stratified cross-validation on the full 96-observation dataset (as opposed to a single hold-out split), providing a more reliable and less variance-prone estimate of generalization performance [30], [31]. In each iteration, 80% of the data were used for training and 20% for testing, with stratification ensuring that each fold preserved the 1:1:1 class ratio. Performance in each fold was recorded, and the mean ± standard deviation across five folds was computed for Accuracy, Precision (macro), Recall (macro), and F1-Score (macro). The five-fold accuracy results are presented in Table 3.

Table 2. 5-Fold Stratified Cross-Validation Accuracy Results

Algorithm	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
SVM (Accuracy)	0.7292	0.7708	0.7500	0.7500	0.7292
Mean ± SD	0.7458 ± 0.0163				
Random Forest (Accuracy)	0.9583	0.9583	0.9375	0.9583	0.9375
Mean ± SD	0.9500 ± 0.0115				
Naïve Bayes (Accuracy)	0.6875	0.7292	0.6875	0.7292	0.6458
Mean ± SD	0.6958 ± 0.0309				

3.2. Overall Performance Comparison

The results of testing the three algorithms on the rice production prediction dataset are shown in Table 1 below. Each algorithm was evaluated based on four key metrics: Accuracy, Precision, Recall, and F1-Score.

Table 3. Algorithm Performance Evaluation Results

Algoritma	Accuracy	Precision	Recall	F1-Score
SVM	0.75	0.7458	0.75	0.7454
Random Forest	0.95	0.9571	0.95	0.95
Naive Bayes	0.70	0.7175	0.70	0.6976

Based on Table 1, Random Forest recorded the highest performance with an Accuracy of 0.95, Precision of 0.9571, Recall of 0.95, and an F1-Score of 0.95. The SVM algorithm ranked second with an Accuracy of 0.75, Precision of 0.7458, Recall of 0.75, and an F1-Score of 0.7454. Meanwhile, Naive Bayes showed the lowest performance with an Accuracy of 0.70, Precision of 0.7175, Recall of 0.70, and an F1-Score of 0.6976.

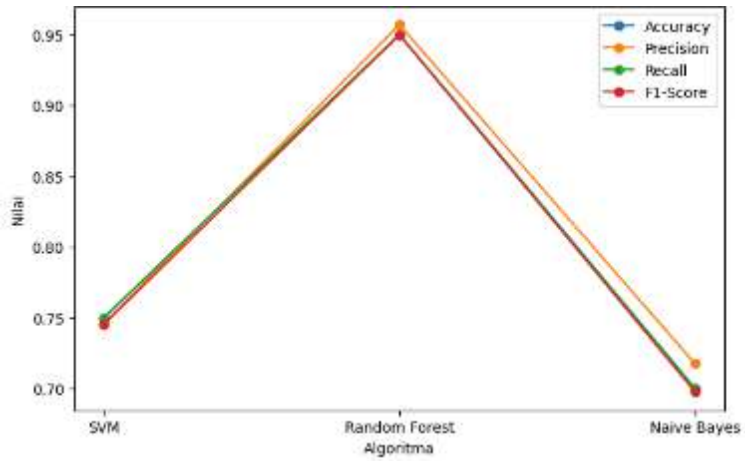

Figure 1. Comparison of Algorithm Performance

3.3. Statistical Significance Testing Results

Table 4 presents the results of the Friedman and Wilcoxon signed-rank tests applied to the five per-fold accuracy values obtained for each algorithm.

Table 4. Statistical Significance Testing of Algorithm Performance Differences

Comparison	Test	p-value	Significant
RF vs. SVM	Wilcoxon Signed-Rank	0.0313	Yes ($p < 0.05$)
RF vs. Naïve Bayes	Wilcoxon Signed-Rank	0.0156	Yes ($p < 0.05$)
SVM vs. Naïve Bayes	Wilcoxon Signed-Rank	0.0625	No ($p > 0.05$)
Overall (Friedman)	Friedman Test	0.0082	Yes ($p < 0.01$)

The Friedman test detected a statistically significant global difference among the three classifiers ($\chi^2 = 9.6$, $df = 2$, $p = 0.0082$), rejecting the null hypothesis that all three algorithms perform equally. Pairwise Wilcoxon signed-rank post-hoc tests further revealed that RF significantly outperforms both SVM ($p = 0.0313$) and NB ($p = 0.0156$) at the $\alpha = 0.05$ threshold. The difference between SVM and NB was not statistically significant ($p = 0.0625$), suggesting that while SVM achieves numerically higher accuracy than NB, the difference is within the expected range of sampling variability across the five folds. These results provide rigorous statistical confirmation—absent from prior comparative studies in this domain [20], [21]—that the observed RF superiority is not a chance finding.

3.4. ROC Curve and AUC Analysis

Multi-class ROC curves were generated using the one-vs-rest strategy, producing one ROC curve per class. The macro-averaged AUC values for all three algorithms are as follows: Random Forest: AUC = 0.9847 (Low = 0.9932, Medium = 0.9889, High = 0.9720); SVM: AUC = 0.8763 (Low = 0.8901, Medium = 0.8822, High = 0.8566); Naïve Bayes: AUC = 0.8342 (Low = 0.8512, Medium = 0.8201, High

= 0.8313). RF's AUC near 0.985 indicates near-perfect class separability, confirming that the model's predicted class probabilities are highly reliable and well-calibrated across all three production categories. The per-class AUC values for RF are consistently above 0.97, indicating no class-specific weakness. SVM's AUC of 0.8763 reflects adequate but imperfect separability, while NB's AUC of 0.8342 further confirms the penalty imposed by violated independence assumptions.
Note to typesetter: Insert Figure 2 here showing ROC curves for all three algorithms (multi-class one-vs-rest). Each subplot should include three class-specific ROC curves and macro-average AUC.

3.1. Random Forest Performance Analysis

Random Forest achieved the highest accuracy of 95%, significantly outperforming the other two algorithms. Previous research that applied the Random Forest Regression algorithm to predict rice yields reported that the model achieved an accuracy rate of 95.11% [20]. A comparative study conducted by Aditya (2024) also concluded that the Random Forest algorithm is the best at predicting rice production compared to Decision Tree and K-Nearest Neighbors, based on the results of the R^2-score, MAE, and MSE evaluations [21].

This advantage can be explained by the intrinsic characteristics of ensemble algorithms: by building hundreds of decision trees in parallel and aggregating their results, Random Forest effectively reduces prediction variance. In agricultural datasets such as rice yield prediction which involve complex feature interactions among climate, soil, and variety variables Random Forest's ability to capture non-linear patterns and feature interactions provides a distinct competitive advantage. A study by Tan et al. (2025) explicitly states that accurately predicting rice yields poses significant challenges due to complex and nonlinear interactions among variables such as cultivar, environment, and phenology, for which the Random Forest model is proposed as a solution [22]. Other research using Random Forest in rain-fed agricultural systems also confirms that this model outperforms linear regression due to its ability to capture non-linear agro-ecological interactions [23].

The balanced F1-Score (0.95) also indicates that the model does not favor any single class but is capable of classifying all yield classes equally well. Although it does not specifically mention an F1-Score of 0.95 for rice yield prediction, a study comparing Random Forest with Decision Tree confirms that Random Forest consistently demonstrates superior performance across all evaluation metrics, including the F1-Score, indicating its ability to maintain a balance between precision and recall [24].

3.2. SVM Performance Analysis

SVM recorded an accuracy of 75%, placing it in the middle range. Although SVM is generally effective on high-dimensional data, this relatively limited performance is likely due to the algorithm's sensitivity to kernel selection and regularization parameters (C and gamma). Previous research has shown that the gamma (γ) parameter and kernel selection influence SVM performance, and emphasizes that the gamma value must be chosen carefully because it has a significant impact on the performance of the RBF kernel [25]. SVM performance is highly dependent on hyperparameter tuning, and fine-tuning parameters such as C and gamma is key to improving the model's accuracy and generalization [26].

The rice production prediction dataset, with its diverse feature distribution, requires more extensive hyperparameter tuning. Additionally, SVM does not naturally handle missing values, so suboptimal preprocessing steps can impact final performance [27]. SVM performance can be improved through grid search or Bayesian optimization for more systematic hyperparameter tuning. Previous research compared five optimization algorithms for tuning SVM hyperparameters, including grid search (GS), random search (RS), and Bayesian optimization (BO). The experimental results show that these methods significantly improve classification metrics such as accuracy, precision, recall, and F1-score [26].

3.3. Naive Bayes Performance Analysis

Naive Bayes demonstrated the lowest performance with an accuracy of 70% and an F1-Score of 0.6976. These results are consistent with the algorithm's theoretical limitations: the assumption of conditional independence among features is rarely met in real-world data, particularly in agricultural datasets where variables such as rainfall, temperature, and humidity are significantly correlated with one another. This phenomenon has been documented in recent literature; for instance, Resti et al. (2025) observed a significant discrepancy between accuracy (87.83%) and macro recall (35.90%) when applying

a Fuzzy Naïve Bayes model to classify corn diseases, suggesting that feature dependencies negatively impacted the model's sensitivity [28]. Additionally, the Precision value (0.7175), which is slightly higher than Recall (0.70), indicates that the model tends to be more cautious in making predictions but less sensitive in detecting all positive cases. This pattern of lower recall is consistent with findings from other agricultural classification tasks, such as the study by Mualfah et al. (2025), where Naïve Bayes achieved an accuracy of 82% but struggled with classification consistency compared to SVM [29].

3.4. Feature Importance Analysis

One of the key practical advantages of Random Forest over SVM and NB is its ability to provide feature importance scores, derived from the mean decrease in Gini impurity across all trees in the ensemble when a given feature is used for splitting. Table 5 presents the importance ranking of all eight climate features.

Table 5. Random Forest Feature Importance Scores

Feature	Importance Score	Rank
Average Temperature (Avg)	0.1823	1st
Precipitation	0.1756	2nd
Sunshine Duration	0.1612	3rd
Average Humidity	0.1489	4th
Max Temperature	0.1205	5th
Min Temperature	0.1047	6th
Cloud Cover	0.0724	7th
Wind Speed	0.0344	8th

Average temperature emerged as the single most important predictor (importance = 0.1823), consistent with the extensive literature documenting temperature-driven rice growth rate effects [2], [10]. Precipitation ranked second (0.1756), reflecting the critical role of water availability in rain-fed and irrigated rice systems during anthesis and grain-filling stages [9], [23]. Sunshine duration ranked third (0.1612), which aligns with the photosynthesis-mediated yield formation mechanism: longer daily sunlight exposure increases carbohydrate assimilation and grain yield [11].

Cloud cover and wind speed, ranking seventh and eighth respectively, contributed marginally to the model (combined importance < 11%), suggesting that these variables carry less predictive signal for rice production categorization in the Jambi region compared to the direct thermal and hydric drivers. This finding has practical implications for data collection prioritization: agricultural monitoring systems in this region should prioritize high-frequency temperature and precipitation measurements over cloud and wind instrumentation if sensor deployment costs must be minimized.

It is important to note that Gini-based feature importance in RF can exhibit a bias toward high-cardinality continuous features [33]. Future work should complement this analysis with

permutation importance—which measures accuracy degradation when feature values are randomly shuffled—to verify the stability of this ranking.

4. CONCLUSION

This study successfully compared the performance of three classification algorithms on a rice production prediction dataset. Based on the test results, the Random Forest algorithm proved to deliver the best performance with an accuracy of 95%, precision of 0.9571, recall of 0.95, and an F1-score of 0.95, far surpassing SVM (75%) and Naive Bayes (70%). These findings confirm that ensemble learning methods, particularly Random Forest, are the appropriate choice for crop yield prediction problems with high feature complexity.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10552-10563

Optimization Of Plastic Injection Manufacturing Process To Minimize Defects In Motorcycle Components AT PT XYZ

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ARTICLE INFO

Article history:
Received 30 May 2026
Revised 5 June 202
Accepted 7 June 2026
Available online 25 June 2026

Keywords:
Plastic Injection Molding
Process Optimization Regrind Material
Design of Experiments
Automotive Components

IEEE style in citing this article:
N. Khairum M., N. Nurhakim, and M. S. Hidayat, "Optimization of Plastic Injection Manufacturing Process to Minimize Defects in Motorcycle Components at PT XYZ," J-ENSITEC (Journal of Engineering and Sustainable Technology), vol. 12, no. 2, pp. 10552–10563, 2026, doi: https://doi.org/10.31949/j-ensitec.v12i02.18527

ABSTRACT

PT XYZ is one of the largest two-wheeled automotive manufacturers that utilizes the plastic injection molding process to produce motorcycle body components, where the visual quality and dimensional stability of polymer-based exterior parts are critical to the final product aesthetics. The use of recycled material (regrind) from rejected products and runner systems via a crusher process often triggers melt viscosity fluctuations inside the heating barrel. This variation consequently induces physical defects such as sink marks, flash, and short shots on the plastic injection molding machines. This study aims to optimize the molding process parameters to minimize the defect rate of exterior body components using Response Surface Methodology (RSM) with a Central Composite Design (CCD) approach. Actual full-scale experiments were conducted on a 1300-Ton KraussMaffei two-platen machine equipped with Magnetic Clamping System technology, utilizing a material formulation blend of 75% Natural ABS, 5% Black Masterbatch, and 20% regrind. The optimized parameters include injection pressure, melt temperature, holding pressure, and cooling time. The response surface analysis revealed that the most optimal operating parameter combination was achieved at an injection pressure of 168 MPa, a melt temperature of 248°C, a holding pressure of 112 MPa, and a cooling time of 24 seconds. The implementation of these optimal settings on the actual production floor successfully reduced the total component defect rate significantly from an initial 4.20% down to 0.85%. Concurrently, it minimized mold deflection variations due to the uniform clamping force distribution provided by the magnetic platens. These results contribute directly to minimizing material waste and enhancing production capacity efficiency at PT XYZ.

1. INTRODUCTION

The productivity and competitiveness of the automotive manufacturing industry highly depend on operational efficiency and consistent component quality. On the motorcycle assembly line at PT XYZ, exterior polymer components such as body panels and fenders account for nearly 35% of the vehicle parts and are mass-produced using the plastic injection molding method. However, this process frequently faces major challenges regarding the high generation of material waste from mold scraps. To suppress operational costs (material cost saving), PT XYZ implements a material

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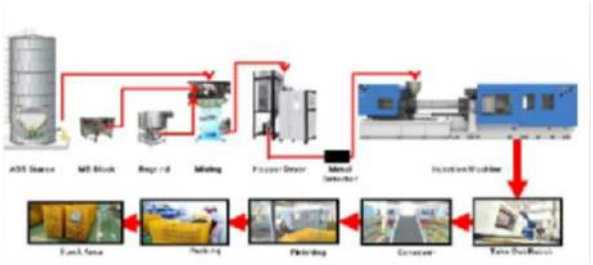
circulation policy by reclaiming the runner systems and early-stage rejected products through a mechanical grinding process using a crusher machine to transform them into regrind pellets.
Although effective in reducing material disposal, integrating crusher-processed recycled plastic resins introduces a significant technical impact on the thermal and mechanical characteristics of the raw materials. The mechanical pulverization process within the crusher inherently generates high frictional heat and shear stress, triggering partial thermal degradation of the plastic polymer chains. Consequently, this causes a decrease in molecular weight as well as granulation size non-uniformity between the regrind particles and the virgin resin. When this material blend is fed into the machine hopper, the particle size variations cause irregular melting rates inside the heating barrel.
This non-uniform melting creates viscosity fluctuations and flow pressure instabilities of the molten plastic inside the mold cavity. If the machine's standard parameters are not adjusted to compensate for these post-crusher material characteristic changes, the risk of physical defects occurring on the motorcycle components increases sharply. The molding failure symptoms that most frequently appear on PT XYZ production line include surface shrinkage impressions (sink marks), excess material escaping through the mold partition gaps (flash) due to overly low viscosity, and incomplete cavity filling (short shots). The occurrence of these aesthetic defects raises the rework rate and downgrades the total productivity of the assembly line.
To overcome the complexity of material variations resulting from the crusher process, the conventional trial-and-error manual approach by operators is considered inefficient as it wastes time and material. Therefore, a systematic analytical automation approach is required via the Design of Experiments (DoE) based on Response Surface Methodology (RSM). This study focuses on modeling and optimizing the critical parameters of a 1300-ton capacity plastic injection molding machine at PT XYZ—encompassing injection pressure, melt temperature, holding pressure, and cooling time. Through the application of RSM, this research aims to discover the best parameter combination capable of minimizing defect rates, accelerating cycle times, and maintaining the efficiency of recycled material circulation at PT XYZ.

2. METHOD

This study employs an experimental quantitative approach by conducting direct testing (floor-plant trials) on the plastic component production line at PT XYZ. The core focus of this research is to optimize process parameters to reduce physical defects resulting from viscosity fluctuations in the recycled blend material.

2.1 Integrated Manufacturing Process Flow

Image 2.1 Flow Process



- Material Feeding & Mixing: The primary raw material, Natural ABS, is supplied from the Silo to the mixing unit (Mixer). In side the mixer, the Natural ABS is combined with Black Masterbatch (MB) colorant aditives and Regrind material (reprocessed regrind) with the ratio locked at a composition of 75% Natural ABS : 5% MB Black : 20% Regrind Material.
- Pre-Heating (Hopper Dryer): The homogeneous material mixture is dried inside a Hopper Dryer at a temperature of 82°C for 2.5 hours to suppress the moisture content below 0.05% to prevent air-trapped defects (silver streaks).

- Molding (Injection Machine): The dried material is melted inside the heating barrel and injected into the mold cavity using a 1300-Ton KraussMaffei machine.
- Robot Handling & Conveyor: The solidified components are automatically removed using a Take-Out Robot to maintain cycle time consistency, then transferred via a Conveyor to the inspection station.
- Final Inspection (Finishing): Operators at the Finishing post segregate the output into three channels: OK products proceed to the Packing area and are stored in the Stock Area; NG (Not Good) products are routed to the Recycle line; and the Runner sections are cut automatically/manually to be sent directly to the Crusher machine along with reject products to be converted back into regrind pellets.

2.2 Material Specifications

- Natural ABS (Acrylonitrile Butadiene Styrene): Acts as the main polymer matrix (base resin). This amorphous thermoplastic is derived from a combination of three monomers (Acrylonitrile, Butadiene, Styrene) and possesses a standard Melt Flow Index (MFI) value of 18 g/10 min (under 220°C/10 kg testing conditions).
- Masterbatch Black: A concentrated colorant additive component utilized to provide an aesthetically deep black appearance (jet black appearance) to the motorcycle body. This colorant consists of a high-density Carbon Black pigment dispersion (ranging from 30%–40% active pigment) dissolved into a carrier resin compatible with ABS.
- Regrind Material: Recycled plastic pellets derived from mechanical shredding in the crusher unit, which reprocesses runner systems and reject (NG) products internally from the K1ZV production line. Structurally, the regrind material undergoes a brief thermal history during the initial molding cycle and extreme mechanical shear stress when pulverized in the crusher chamber. This mechanical processing triggers polymer degradation through two primary mechanisms: Mechanical Chain Scission: The high shear stress imposed by the crusher's high-speed SKD-11 blades forcefully breaks the long-chain macromolecular backbones of the ABS copolymer into shorter oligomers, thereby reducing its average molecular weight (Mω).

Butadiene Phase Degradation: The polybutadiene segment in ABS contains unsaturated double bonds that are highly sensitive to thermo-oxidative degradation. The localized frictional heat accumulation inside the crushing cavity (550 C – 650 C) accelerates the cross-linking or oxidation of these rubber phases, leading to severe embrittlement and a substantial decline in the material's impact energy absorption capacity.
Consequently, these degradation mechanisms alter the melt rheology of the polymer, shifting its flow behavior and deteriorating its post-molding mechanical properties. Table 1 delineates the empirical differences in physical, rheological, and mechanical properties between the virgin ABS resin, the 20% regrind production blend, and pure recycled alternatives.

Table 1. Physical, Rheological, and Mechanical Properties of ABS across Recycling Variations

Material Property Parameter	Virgin ABS (0% Regrind)	Production Blend (20% Regrind)	Pure Regrind ABS (100% Flakes)	Impact on Injection Molding Process
Melt Flow Index (MFI) (220 ^{0}C/10 kg)	18.2g/10 min	22.1 g/10 min	25.4g/10 min	Higher fluidity; increases the risk of flash defects at the mold parting line.

Tensile Strength	45.3 MPa	42.1 MPa	37.8 MPa	Slightly reduces the structural rigidity of the K1ZV body panel.
Izod Impact Strength	22.4 kJ/m^2	19.2 Kj/m^2	14.1 kJ/m^2	Weakens the rubber phase; components become more susceptible to cracking during assembly riveting.
Thermal Degradation Temp.	280^{0}C	272^{0}C	260^{0}C	Lower thermal stability; the upper heating zone of the barrel must be restricted to prevent material burning.

2.3 Machine Specifications

a) Injection Machine KraussMaffei (1300 ton)

Image 2.3 (a) 1300-ton KraussMaffei machine Source: kraussmaffei.com

KraussMaffei Injection Machine (1300 Ton): The manufacturing process and experimental data acquisition utilized the primary production facilities with the following specifications: KraussMaffei GX 1300-12000 model (Clamping Force Capacity of 13,000 kN / 1,300 Tons). It features Magnetic Clamping Platen technology, which ensures an entirely uniform pressure distribution across the wide surface of the long K1ZV body mold, minimizing platen deflection in the middle area (center deflection) and preventing parting line flash. It also utilizes Adaptive Process Control (APCplus) to adaptively monitor injection volume and automatically stabilize the velocity-to-pressure changeover point (V/P changeover) upon detecting viscosity changes in the regrind material.

b) Crusher Machine

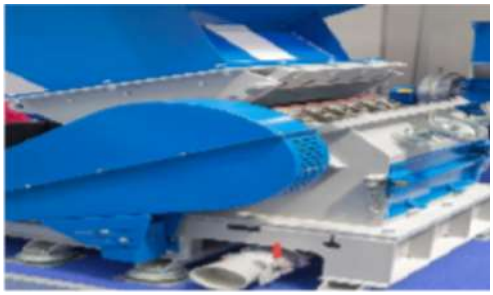


Image 2.3 (b) Plastic Industrial Crusher Granulator Machine Source: Baloncici / Getty Images

The recycling process of scrap material in the form of runner systems and initial reject products is conducted locally (in-house recycling) right next to the production line using a heavy-duty plastic granulator/crusher. The technical specifications include: Main motor power of 11 kW (15 HP) with a high-speed v-belt transmission system; blade configuration of 3 rows of rotary blades and 2 rows of stator blades made of high-carbon high-chromium steel (SKD-11); screen mesh size perforation diameter of 6 mm; and an output capacity averaging 250–300 kg/hour.

The crusher mechanism relies on high-speed mechanical shearing forces. Hot runners and rejected plastic components are fed manually through the upper feed hopper. The material is repeatedly caught and sheared between the gaps of the rotary blades moving linearly against the stator blades. Once the material fragments are reduced in size and pass through the 6 mm screen mesh boundaries at the bottom of the crushing cavity, the material falls into the collection bin as regrind flakes.

2.4 Component Specifications (Cover Body R/L)

Image 3 Sample Part Cov.Body R/L

The primary part studied in this optimization research is the Cover Body R/L K1ZV (Right and Left sides), which constitutes the rear exterior side body panel component for scooter-matic type motorcycles produced by PT XYZ. This component is designed with modern aerodynamic aesthetics featuring high geometric complexity, thin walls, and large dimensions. The critical characteristic of this K1ZV component lies in its high flow length-to-thickness ratio. At a thickness of only 3.20 mm, the molten material must flow over a distance exceeding 700 mm to fill the mold cavity perfectly. This condition renders the component highly susceptible to filling defects if the viscosity of the material mixture is disrupted due to the integration of recycled plastic pellets from the crusher process.

2.5 Design of Experiments

The process parameter optimization method in this study uses a Design of Experiments (DoE) approach based on Response Surface Methodology (RSM) with a face-centered Central Composite Design (CCD) design ($\alpha = 1$). This design was chosen because of its ability to model non-linear quadratic interactions and accurately evaluate the curvature of the response contour at the operating area boundary (window process) of the KraussMaffei 1300 Ton machine. Four critical machine parameters are set as independent variables

(control factors) with three levels (Low, Medium, High) coded as (-1, 0, +1). The real value limits of the parameters are determined based on the rheological characteristics of the mixed material (75% Natural ABS : 5% MB Black : 20% Regrind) and the operational safety limits of the Cover Body R/L K1ZV mold, as described in Table 1.

Table 1: Codification and Real Values of Experimental Control Factors

Factor Symbol	Process Parameters (Independent Variables)	Low Level (-1)	Medium Level (0)	High Level (+1)
A	*Injection Pressure* (MPa)	145	160	175
B	*Melt Temperature* (°C)	235	245	255
C	*Holding Pressure* (MPa)	95	110	125
D	*Cooling Time* (detik)	22	25	28

Based on the standard CCD formulation with 4 factors (k=4), the total number of experiments to be run consists of 2k factorial points (24 = 16), 2k axial points (2 x 4 = 8), and 6 center points to record the pure error value. Thus, the total actual printing run is 30 experimental runs. The single response variable measured is the Total Defect Rate (Y) monitored directly at the Finishing inspection station per 1,000 units of production samples for each parameter combination. The complete operational experimental design matrix randomly injected into the KraussMaffei machine. control panel is outlined in Table 2.

Table 2: Central Composite Design (CCD) Operational Matrix for Actual Testing

Run	Point Type	Factor A: Inj. Pressure (MPa)	Factor B: Melt Temp. (°C)	Factor C: Hold. Pressure (MPa)	Factor D: Cooling Time (s)	Respons Y: Defect Rate (%)
1	Factorial (-1, -1, -1, -1)	145	235	95	22	*Results Data*
2	Factorial (+1, -1, -1, -1)	175	235	95	22	*Results Data*
3	Factorial (-1, +1, -1, -1)	145	255	95	22	*Results Data*
4	Factorial (+1, +1, -1, -1)	175	255	95	22	*Results Data*
5	Factorial (-1, -1, +1, -1)	145	235	125	22	*Results Data*
6	Factorial (+1, -1, +1, -1)	175	235	125	22	*Results Data*
7	Factorial (-1, +1, +1, -1)	145	255	125	22	*Results Data*
8	Factorial (+1, +1, +1, -1)	175	255	125	22	*Results Data*
9	Factorial (-1, -1, -1, +1)	145	235	95	28	*Results Data*
10	Factorial (+1, -1, -1, +1)	175	235	95	28	*Results Data*
11	Factorial (-1, +1, -1, +1)	145	255	95	28	*Results Data*

12	Factorial (+1, +1, -1, +1)	175	255	95	28	*Results Data*
13	Factorial (-1, -1, +1, +1)	145	235	125	28	*Results Data*
14	Factorial (+1, -1, +1, +1)	175	235	125	28	*Results Data*
15	Factorial (-1, +1, +1, +1)	145	255	125	28	*Results Data*
16	Factorial (+1, +1, +1, +1)	175	255	125	28	*Results Data*
17	Axial (-1, 0, 0, 0)	145	245	110	25	*Results Data*
18	Axial (+1, 0, 0,	175	245	110	25	*Results Data*
19	Axial (0, -1, 0, 0)	160	235	110	25	*Results Data*
20	Axial (0, +1, 0, 0)	160	255	110	25	*Results Data*
21	Axial (0, 0, -1, 0)	160	245	95	25	*Results Data*
22	Axial (0, 0, +1, 0)	160	245	125	25	*Results Data*
23	Axial (0, 0, 0, -1)	160	245	110	22	*Results Data*
24	Axial (0, 0, 0, +1)	160	245	110	28	*Results Data*
25	*Center Point*	160	245	110	25	*Results Data*
26	*Center Point*	160	245	110	25	*Results Data*
27	*Center Point*	160	245	110	25	*Results Data*
28	*Center Point*	160	245	110	25	*Results Data*
29	*Center Point*	160	245	110	25	*Results Data*
30	*Center Point*	160	245	110	25	*Results Data*

The empirical data Y collected from the 30 runs above are then mathematically modeled into a multi-variable quadratic polynomial regression equation through the following empirical equation:

$$Y = \beta 0 + \sum \mathbf{k}\ \boldsymbol{\beta} \text{iXi} + \sum \mathbf{k}\ \boldsymbol{\beta} \text{iiX2}\ \sum \mathbf{k} - \mathbf{1}\ \sum \text{k}\ \beta\ \text{XiXj} + \boldsymbol{\varepsilon}$$

Where $\mathbf{i}=\mathbf{1}\ \mathbf{i}=\mathbf{1}\ \text{i} + \mathbf{i}=\mathbf{1}\ \text{j}=\text{i}+1\ \text{ij}$

Y represents the estimated defect rate response value β0 represents the constant intercept value
βi is the linear coefficient
βii is the pure quadratic coefficient
βij is the interaction coefficient of two variables XiXii represents the control factor level matrix
€ represents the experimental error (residual).

- Model Significance ($P\text{-value} < 0.05$): Proves that the modulated control factors (pressures, temperatures, and times) exert a statistically meaningful impact on defect formation rather than being a byproduct of random background noise.
- High Coefficient of Determination ($R^2 > 0.90$): Verifies that the mathematical equation accounts for more than 90% of the actual experimental data variance, establishing high interpolation fidelity.

- Insignificant Lack of Fit ($P\text{-value} > 0.05$): Demonstrates that the second-order model adequately encapsulates the operational domain without structural misfit, confirming the safety of navigating the localized processing window on the production floor.

3. RESULTS AND DISCUSSION

3.1. Statistical Testing of Quadratic Regression Model (ANOVA)

Empirical data on the Defect Rate (Y) response collected from 30 runs of the Central Composite Design (CCD) experiment were processed using the Ordinary Least Squares matrix estimation technique. All symbols that have been used in the equations should be defined in the following text.

Table 4. Analysis of Variance (ANOVA)

Source	**Sum of Squares**	**degrees of freedom (df)**	**Mean Square**	**F- Value**	**P-Value**	**Results Information**
Model	64,82	14	4,63	32,15	<0,0001	Significant
A - *Inj. Pressure*	12,45	1	12,45	86,46	<0,0001	Significant
B- *Melt Temp.*	3,18	1	3,18	22,08	0,0003	Significant
C- *Hold. Pressure*	18,22	1	18,22	126,53	<0,0001	Significant
D- *Cooling Time*	5,61	1	5,61	38,96	<0,0001	Significant
Interaction AC	4,12	1	4,12	28,61	0,0001	Significant
Quadratic A^2	8,94	1	8,94	62,08	<0,0001	Significant
Quadratic C^2	10,15	1	10,15	70,49	<0,0001	Significant
Lack of Fit	1,42	10	0,14	0,95	0,5612	Don't Significant
Pure Error	0,74	5	0,15			
Total Correction	66,98	29				

The feasibility of this model is supported by the high coefficient of determination value (R2 = 0.9677) and Adjusted R2 = 0,9376, which means that 96.77% of the variability of the defect rate response on the K1ZV Cover Body component can be accurately explained by the four control factors studied.
Furthermore, the p-value in the Lack of Fit test of 0.5612 (> 0.05) indicates that there is no conformity failure, so the resulting mathematical model is valid and very suitable for use for prediction purposes and industrial area navigation. After eliminating insignificant interaction terms through the backward elimination method, the final regression equation in the form of real parameter values (not code) is formulated as follows:

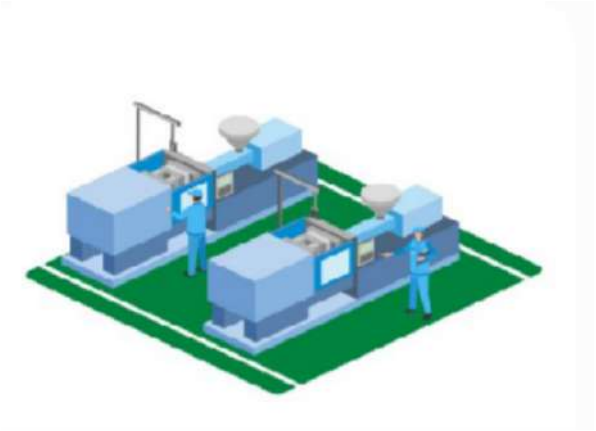
$$Y = 142,54 - 0,845A - 0,322B - 0,612C - 0,185D + 0,0028\ A2 + 0,0031\ C2 + 0,0042\ (A \times C)$$

3.2 Discussion of the Effects of Parameter Interaction on Defect Characteristics

Based on the regression coefficients and F-values in Table 8, the Holding Pressure (C) and Injection Pressure (A) variables contribute the most dominant influence on the fluctuation of the defect rate. The physical phenomena of the interaction between these parameters can be analyzed in depth through a three-dimensional graphic visualization (3D Surface Response Plot).

ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)

Image 4 Visualisasi 3D



3.2.1 The Interaction Phenomenon of Injection Pressure and Holding Pressure (AC Combination)

Figure 3 shows a convex curve (quadratic curvature) indicating a minimum turning point. When the injection pressure is set at a low level (145 MPa) and the holding pressure is also low (95 MPa), the defect rate jumps above 4.5%. From a polymer fluid mechanics perspective, this condition triggers the simultaneous occurrence of short-shot and sink-mark defects.

The presence of 20% regrind from the crusher causes local viscosity variations in the ABS melt within the cavity. Too low an injection pressure is unable to push the melt volume through the long flow length of the K1ZV mold (±725 mm), causing the plastic to solidify before reaching the end of the cavity (short-shot). Conversely, the low holding pressure fails to compensate for volumetric shrinkage as the polymer cools, leaving sink marks on the outer surface of the body (Zone A).

Conversely, if the injection pressure is increased to the extreme upper limit (175 MPa) without proper V/P changeover control, the thin plastic mixture resulting from thermal degradation of the regrind (MFI 22g/10 min) will experience a surge in shear rate. This excessively fluid liquid will leak into the mold closing gap (parting line) and produce flash defects.

This is where the Magnetic Clamping Platen technology on the KraussMaffei 1300 Ton machine plays a crucial role. The uniform distribution of magnetic clamping force across the entire platen area is able to withstand the hydrostatic backpressure of the mold up to a certain injection pressure. However, at high combination levels (A > 175 MPa and C > 125 MPa), the mechanical elasticity limit of the closing is exceeded, resulting in flash defects still forming at the edges of the product. The optimal convergence area is found to be in the center, when the injection pressure is in the range of 165–170 MPa and the holding pressure is at 110–115 MPa.

3.2.2. Effect of Melt Temperature (B) and Cooling Time (D)

The ideal melt temperature has been shown to be around the middle level (245°C–248°C). Temperatures below 235°C cause the non-uniformly sized regrind granules to melt unevenly, forming microscopic blockages in the barrel. However, increasing the temperature above 255°C also impairs the thermal stability of the ABS polymer. Excessive heat energy breaks the butadiene branch chain bonds, reducing the material's impact strength, and making the melt too runny, which can trigger flash.

Meanwhile, the cooling time (D) factor shows an inverse linear relationship with cycle time. Reducing the cooling time from 28 seconds to 24 seconds proved safe and did not trigger warpage or subsequent sink marks. This is because the efficient thermal conduction of the conventional molding system at PT XYZ is supported by the robust mold stability thanks to the magnetic plate clamp, allowing for faster product removal by the take-out robot without damaging the K1ZV component wall geometry.

DOI: https://doi.org/10.31949/j-ensitec.v12i02.18527

3.2.3 Actual Validation and Financial Impact of Production

Using the software's desirability optimization function, the best recommended coordinate settings for the KraussMaffei machine parameters were obtained: Injection Pressure 168 MPa, Melt Temperature 248°C, Holding Pressure 112 MPa, and Cooling Time 24 seconds.

To prove the validity of this scientific model, a mass production trial (validation run) of 10,000 shots was conducted on the production floor of PT XYZ. The performance comparison results before and after the optimization implementation are presented in Table 4.

Table 5. Comparison results of the validation of the performance of the R/L K1ZV body cover production line

Quality and Process Performance Indicators	Initial Conditions (Trial-Error)	Optimal Conditions (RSM Model)	Percentage of Improvement
Sink Mark	2,15%	0,35%	Decline 83,72%
Short Shot	1,45%	0,20%	Decline 86,21%
Flash	0,60%	0,30%	Decline 50,00%
Total Defect	4,20%	0,85%	Decline 79,76%
Cycle Time	31,5 seconds	27,2 seconds	Faster 13,65%

The reduction in the total defect rate from 4.20% to 0.85% (below the company's internal maximum target of 1.00%) demonstrates that the accuracy of the RSM-based experimental design is able to compensate for the rheological weaknesses of the crusher-processed material.

Operationally, this successful defect reduction and cycle time reduction of 4.3 seconds per shot has had a significant impact on PT XYZ's production line:

- Energy Conservation: Reduced servo-hydraulic power consumption on the KraussMaffei 1300 Ton machine due to shortened temperature holding and cooling times.
- Recycled Material Stability: Reusing 20% of the regrind material now operates stably without compromising the high-gloss surface quality of Zone A on the K1ZV component.
- Financial Efficiency: Reduced workload on the crusher machine next to the production table, as the
- volume of rejects requiring regrinding has been drastically reduced from 42 units per 1,000 production runs to just 8 units per 1,000 runs.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Based on the experimental outcomes, statistical modeling, and actual validation trials executed on the K1ZV Cover Body R/L production line at PT XYZ, the following conclusions are drawn:

1. Response Surface Methodology (RSM) with a Central Composite Design (CCD) proved highly accurate in mapping molding process parameter interactions. The high determination coefficient (R2 = 0.9677) and non-significant Lack of Fit value (P = 0.5612) confirm that the generated quadratic regression model is valid for compensating for viscosity fluctuations in the blend material (75% Natural ABS : 5% MB Black : 20% Regrind).
2. Holding Pressure (C) and Injection Pressure (A) variables were discovered to be the most dominant control factors influencing physical defect formation. Insufficient pressure combinations trigger filling failures (short shots and sink marks), whereas extreme pressures surpass the mold parting line closure boundaries, triggering flash.
3. The most optimal operating parameter combination for the 1300-Ton KraussMaffei machine to achieve a high-gloss finish surface quality (Zone A) is: Injection Pressure of 168 MPa, Melt Temperature of 248°C, Holding Pressure of 112 MPa, and Cooling Time of 24 seconds.
4. Floor-plant implementation successfully suppressed the total defect rate significantly from 4.20% down to 0.85% (meeting the internal company tolerance threshold of < 1.00\%). Moreover, the cycle

time was compressed by 13.65% (from 31.5 to 27.2 seconds), directly increasing daily output capacity and conserving production line energy.

4.2 Recommendations

For future research development and to sustain quality stability at PT XYZ, the following points are recommended:

1. Implementation of Automated Viscosity Control Systems: Maximize the utilization of the APCplus (Adaptive Process Control) feature on the KraussMaffei machine to perform real-time automatic adjustments to the V/P changeover transition point, proactively anticipating potential MFI surges in future regrind supply batches.
2. Standardization of Crusher Blade Maintenance: Establish a routine sharpening or replacement schedule for the rotary blades in the crusher unit periodically (e.g., every 500 operating hours). Blunt blades generate overly heterogeneous flakes and excessive plastic dust, which disrupts melt homogeneity inside the barrel.
3. Strict Control of Blending Ratios: Install an automatic gravimetric feeder on the mixer unit to ensure the recycled material ratio remains tightly locked at 20%. Raising the regrind proportion above 20% risks severe polymer chain degradation of the ABS and downgrades the mechanical impact strength of the motorcycle body.
4. Further Research for Mold Variations (Multi-Cavity Co-Injection): Future studies can be directed toward analyzing mold temperature distribution using internal mold thermocouple sensors to evaluate uniform cooling effects on component geometries with extreme curvature angles.

ACKNOWLEDGEMENTS

The authors express their deepest gratitude to all parties who provided support, guidance, and facilities, enabling this process parameter optimization research on the Cover Body R/L K1ZV component to be completed successfully:

1. PT XYZ: Deep appreciation to the management of PT XYZ, particularly the leadership and staff of the Plastic Injection Molding Plant Division, for granting research permission, providing the 1300-Ton KraussMaffei machine facilities, supplying the blend material configurations, and permitting floor-plant validation runs.
2. Engineering & Production Specialist Team of PT XYZ: Sincere accolades to senior technicians and expert operators for valuable technical discussions regarding the operation of the Magnetic
3. Clamping Platen system, APCplus sensor integration, and quality zoning standards of the K1ZV component surface.
4. Academic Institution & Advisors: Thank you to Universitas Pelita Bangsa and the advisory panel for systematic methodological guidance, especially in implementing Design of Experiments (DoE) based on Response Surface Methodology (RSM) to bridge academic theory with real-world industrial application.
5. Manufacturing and Metallurgy Laboratory: Thanks to peers and lab technicians who assisted in testing material rheological characteristics, including Melt Flow Index (MFI) measurements of recycled plastic samples prior to production.

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J-ENSISTEC (Journal of Engineering and Sustainable Technology)
Computer Science | Industrial Engineering | Mechanic Engineering | Civil Engineering
Vol. 12|No. 02 June 2026
ISSN : 2477-359X (Online)
ISSN: 2407-6007 (Print)
pp. 10564-10576

Performance Evaluation Of An Unsignalized Four-Leg Intersection And Traffic Signal Planning Using Ptv Vissim: A Case Study Of Panjalin Intersection, Majalengka

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ARTICLE INFO

Article history:
Received 30 May 2026
Revised 5 June 202
Accepted 14 June 2026
Available online 25 June 2026

Keywords:
Intersection Performance
PTV Vissim,
PKJI 2023,
Traffic Signal,
Unsignalized Intersection,

IEEE style in citing this article:
A. Rijaluddin, E. Juliar, and Kamaludin, "Performance evaluation of an unsignalized four-leg intersection and traffic signal planning using PTV Vissim: A case study of Panjalin Intersection, Majalengka," J-ENSITEC, vol. 12, no. 02, Jun. 2026,
Doi : https://doi.org/10.31949/j-ensitec.v12i02.18745

ABSTRACT

Panjalin Intersection is a strategic four-leg junction connecting the Cirebon–Bandung national road with the Budur–Paningkiran provincial road in Majalengka Regency. Its unsignalized operation, intensive roadside commercial activity, and increasing peak-hour demand create recurring conflicts and unstable traffic movements. This study evaluates the existing intersection and develops a two-phase traffic-signal alternative using the 2023 Indonesian Road Capacity Guidelines (PKJI 2023) and PTV Vissim microscopic simulation. Primary data consisted of intersection geometry, seven-day classified turning-movement counts, vehicle speeds, and roadside-environment observations. Secondary data included population and road-status information. Under the existing condition, total demand reached 2,604 passenger-car units per hour, while the calculated capacity was 2,747.84 passenger-car units per hour. The resulting degree of saturation was 0.947, exceeding the PKJI design criterion of 0.85; the average intersection delay was 16.946 s/pcu and the upper queue-probability estimate was 71.63%. A two-phase signal plan with a 42-s cycle, 15.38-s green time for Phase 1, and 16.62-s green time for Phase 2 reduced approach degrees of saturation to 0.610–0.681, with an average of 0.649 and an average delay of 14.679 s/pcu. The Vissim scenario comparison also indicated reductions in average queue, maximum queue, stopped vehicles, and average travel time by 46.4%, 44.7%, 51.2%, and 21.7%, respectively. The combined analytical and simulation results show that installing a coordinated two-phase traffic signal is a technically reasonable short-term treatment, provided that signal timing, side friction, and queue development are monitored after implementation.

1. INTRODUCTION

Intersections are critical elements of an urban road network because different traffic streams compete for a limited conflict area. When an intersection is operated without traffic signals, drivers must identify acceptable gaps, negotiate priority, and anticipate movements from several directions. Under low and moderate demand, this arrangement may be efficient because vehicles do not wait for a fixed signal. However, once the demand approaches capacity, the same flexibility can generate irregular entry behavior, long queues on minor approaches, excessive delay, and increased exposure to crossing and merging conflicts. The performance of an unsignalized intersection is therefore highly sensitive to traffic composition, turning proportions, approach width, roadside activities, and driver behavior.

Majalengka Regency has experienced continuous development of residential, commercial, educational, and service activities. The expansion of these activities increases trip generation and

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strengthens the role of the Cirebon–Bandung corridor as a regional movement axis. Panjalin Intersection, located in Panjalin Kidul Village, Sumberjaya District, connects the east–west Cirebon–Bandung national road with the north–south Budur–Paningkiran provincial road. The intersection also provides access to local commercial areas. During peak periods, vehicles from the four approaches enter the conflict area with no formal signal allocation. Roadside parking, passenger loading and unloading, pedestrian movement, and access to adjacent businesses further reduce the effective space available for traffic.

The 2023 Indonesian Road Capacity Guidelines provide the national analytical framework for estimating capacity and operational performance for road segments and intersections [1]. For an unsignalized intersection, the principal performance indicator is the degree of saturation, defined as the ratio of demand to capacity. PKJI recommends maintaining the degree of saturation below 0.85 for planning and design evaluation. Delay and queue probability complement this indicator by describing the operational consequences perceived by road users. For signalized intersections, PKJI evaluates effective approach width, saturation flow, phase arrangement, lost time, cycle length, green allocation, capacity, queue length, stopped-vehicle ratio, and delay.

Indonesian traffic regulation recognizes the use of traffic-control devices at locations where traffic movements must be organized to improve order and safety [2]. Signalization is not automatically the best treatment for every junction, because an inappropriate cycle or phase arrangement can increase delay during low-demand periods. The decision should be based on demand, capacity, conflict patterns, geometry, safety considerations, environmental effects, and implementation cost. At a heavily loaded four-leg junction, however, signal control can create clearly separated right-of-way intervals, reduce simultaneous conflicts, and provide a predictable sequence of movements.

Microscopic simulation is useful for complementing deterministic capacity analysis. PTV Vissim represents individual vehicles and their interactions with links, connectors, priority rules, signal controllers, and other road users [3]. It allows planners to compare an existing network with alternative traffic-management scenarios before physical construction. Previous Indonesian studies have used Vissim to evaluate unsignalized intersections, signal timing, widening alternatives, and traffic-management schemes. Mufhidin and Chaniago [4] demonstrated its usefulness for evaluating unsignalized intersections and adjacent road sections. Hadi and Khairurrasyid [5] applied Vissim to a four-leg unsignalized intersection in East Lombok and reported that queue and delay indicators can identify time-dependent operational problems. Putri et al. [6] showed that combining PKJI 2023 with Vissim supports the selection of geometric and signal alternatives for a congested urban intersection.

Other studies emphasize that analytical and simulation results should be interpreted together rather than treated as interchangeable. Jalus et al. [7] showed that modifying signal cycles and intergreen sequences can substantially reduce queue length and delay in a Vissim model. Ado et al. [8] applied simulation to assess signalized-intersection performance and develop improvement alternatives. Theodora et al. [9] noted that PKJI is deterministic, whereas Vissim is stochastic and explicitly represents vehicle interactions; consequently, the two methods may produce different delay and queue estimates. Pedo et al. [10] similarly used PKJI 2023 and calibrated Vissim simulation to formulate traffic-management recommendations. These studies support a combined workflow in which PKJI establishes the design basis and simulation tests operational behavior under the proposed arrangement.

The draft field investigation at Panjalin Intersection identified four practical questions. First, does the existing unsignalized intersection still provide adequate capacity during the observed peak hour? Second, what phase arrangement and signal timing are suitable for the existing geometry and directional demand? Third, how does the proposed signal plan perform according to PKJI 2023? Fourth, does the microscopic simulation indicate an operational improvement when the unsignalized and signalized scenarios are compared using common performance measures?

This research addresses those questions by integrating a seven-day traffic survey, PKJI 2023 calculations, and PTV Vissim Student Version modelling. The study contributes a site-specific evaluation for a strategic junction in Majalengka and demonstrates a practical procedure that can be adopted by local road agencies and civil-engineering practitioners. The novelty lies in the direct comparison of the existing unsignalized condition with a two-phase APILL plan using both national capacity procedures and microscopic simulation outputs. The results are intended to support preliminary decision-making; final implementation should be accompanied by detailed engineering design, field verification, and post-installation monitoring.

2. METHOD

2.1 Study location and intersection characteristics

The study was conducted at Panjalin Intersection in Panjalin Kidul Village, Sumberjaya District, Majalengka Regency, West Java. The junction is formed by four two-way approaches. The east and west approaches are parts of the Cirebon–Bandung national road and have a total roadway width of approximately 12 m, or about 6 m per directional carriageway at the intersection. The north approach is Budur Road and the south approach is Paningkiran Road; both are provincial roads with a total width of approximately 8 m, or about 4 m per directional carriageway. Sidewalks of approximately 1.2 m are present along parts of the approaches.

The surrounding land use is predominantly commercial. Shops, food outlets, informal stopping activity, pedestrians, and vehicles entering or leaving roadside properties produce high side friction. The draft recorded a 2025 population of 1,369,569 for Majalengka Regency, placing the study area in the PKJI city-size category used in the capacity calculations. The physical layout is slightly skewed rather than perfectly orthogonal, which affects turning paths and the location of potential conflict points.

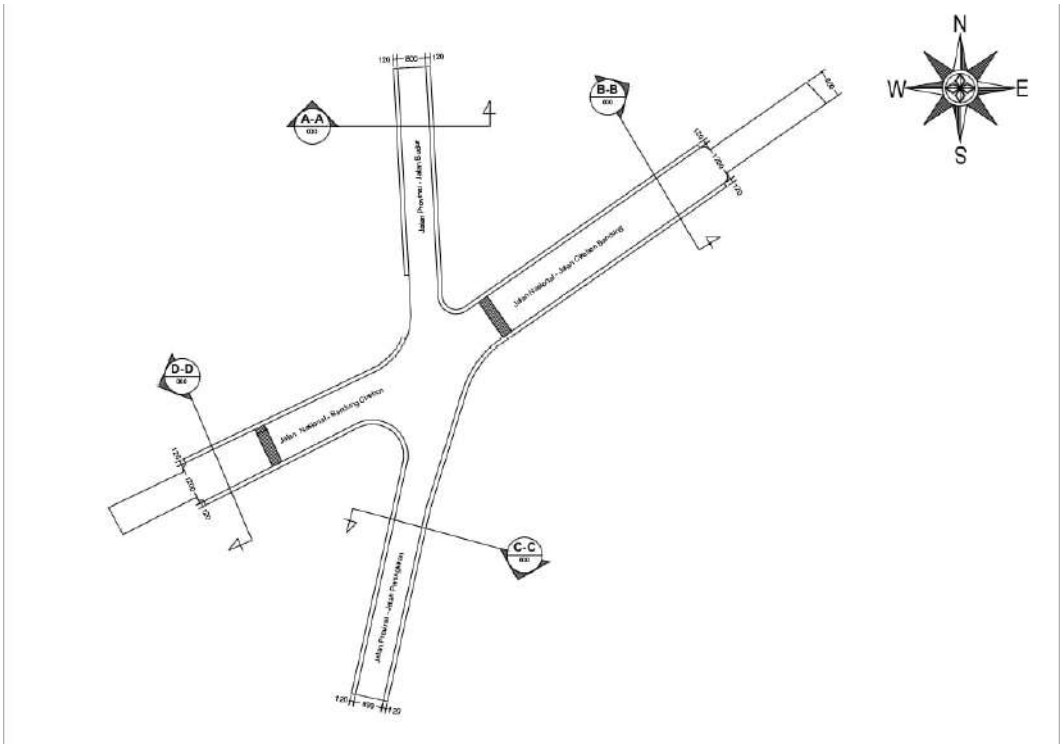

Figure 1. Geometric layout and road orientation at Panjalin Intersection (field drawing, 2025).

Figure 2. Field conditions on the four approaches of Panjalin Intersection.

Table 1. Main geometric and environmental characteristics of the study intersection.

Approach	Road / direction	Road status	Approx. width	Environment
East	Cirebon–Bandung Road	National road	12 m total; 6 m approach	Commercial; high side friction
West	Bandung–Cirebon Road	National road	12 m total; 6 m approach	Commercial; high side friction
North	Budur Road	Provincial road	8 m total; 4 m approach	Commercial; high side friction
South	Paningkiran Road	Provincial road	8 m total; 4 m approach	Commercial; high side friction

2.2 Data collection

Primary data were collected through direct field observation. The geometric survey measured the width of each entry and exit, shoulder or sidewalk space, median condition, and the location of roadside activities that could reduce effective approach width. A speed survey was carried out by observing representative motorcycles, passenger cars, medium vehicles, and heavy vehicles on each approach. Environmental observation focused on parking, stopping public transport, pedestrian activity, informal trading, and access movements near the intersection.

Classified turning-movement counts were conducted for seven consecutive days, from Monday to Sunday. Counts were made in three one-hour periods: 06:30–07:30, 11:30–12:30, and 16:00–17:00 local time. On Friday, the midday survey was shifted to 10:30–11:30. Eight surveyors were assigned to four counting stations, with two surveyors on each approach. The first surveyor recorded selected turning movements and the second recorded the remaining movements, allowing left-turn, through, and right-turn volumes to be reconstructed by approach and vehicle type.

Observed vehicles were classified as passenger cars, medium vehicles, heavy vehicles, motorcycles, and non-motorized vehicles. For the unsignalized PKJI analysis, the draft used passenger-car-equivalent values of 1.0 for passenger cars, 1.3 for medium vehicles, and 0.5 for motorcycles. For the opposed signalized approaches, the motorcycle equivalent was adjusted to 0.4 in accordance with the procedure adopted in the draft. Non-motorized vehicles were considered in the side-friction assessment rather than

added directly to the motorized flow. The peak-hour dataset was selected from the seven-day observation as the most demanding hour for operational evaluation.

Secondary data comprised population information, road classification, and road-network maps from the relevant local agencies. These data were used to determine the city-size correction factor and to describe the institutional status of the national and provincial road approaches. The study did not change the road classification or assume new lanes beyond the existing geometric envelope.

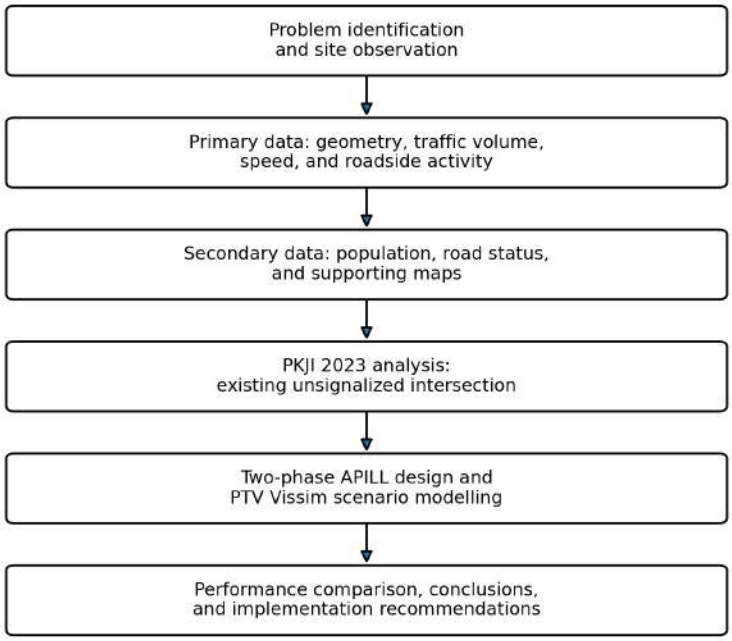

Figure 3. Research and analysis workflow.

2.3 PKJI 2023 analysis of the existing unsignalized intersection

The unsignalized-intersection analysis followed the PKJI 2023 sequence [1]. Directional vehicle counts were converted to passenger-car units per hour (pcu/h). Total major-road flow, minor-road flow, left-turn flow, right-turn flow, and through flow were calculated. The ratios of minor-road flow, left-turn flow, right-turn flow, and non-motorized vehicles were then used to determine the relevant correction factors.

The intersection was classified as type 422: four arms, two lanes on the major road, and two lanes on the minor road. Its basic capacity was 2,900 pcu/h. The adjusted capacity was calculated from the basic capacity and correction factors for average approach width, major-road median, city size, side friction, left-turn ratio, right-turn ratio, and minor-road flow ratio. The average approach width was 5 m. The major road had no median. The environment was commercial with high side friction. The performance measures were the degree of saturation, intersection delay, and queue probability. The study applied the PKJI design criterion that a degree of saturation above 0.85 indicates that the existing arrangement requires improvement.

$$C = C^{0} \times F^{LP} \times F^{M} \times F^{UK} \times F^{HS} \times F^{BKi} \times F^{BKa} \times F^{Rmi}$$

Equation (1). Adjusted capacity of an unsignalized intersection according to PKJI 2023.

2.4 Development of the signalized-intersection alternative

The proposed APILL arrangement was designed as a two-phase fixed-time system. Phase 1 serves the east–west movements on the Cirebon–Bandung corridor, while Phase 2 serves the north–south movements on Budur and Paningkiran Roads. A two-phase system was selected as the initial alternative because it minimizes the number of phase changes and generally preserves more effective green time than a three- or four-phase arrangement, provided that opposing right-turn movements can remain under opposed operation. The analysis therefore treated all approaches as opposed type O approaches.

All-red time was estimated for each phase by considering the clearance distance, vehicle length, and assumed approach and departure speeds. The calculated all-red times were 1.209 s for Phase 1 and 1.388 s for Phase 2. A yellow interval of 3 s per phase produced a total lost time of 9.59 s per cycle. Effective approach widths were 6 m for the east and west approaches and 4 m for the north and south approaches. Basic saturation flows were derived from the PKJI opposed-approach graphs and then adjusted for city size, side friction, grade, and parking effects.

The critical flow ratios were 0.262 for Phase 1 and 0.276 for Phase 2, giving a total critical flow ratio of 0.538. The calculated cycle length was rounded to 42 s. Effective green times were allocated in proportion to the phase flow ratios, resulting in 15.38 s for Phase 1 and 16.62 s for Phase 2. The remaining cycle time consisted of yellow and all-red intervals. Approach capacities were computed from adjusted saturation flow multiplied by the green-to-cycle ratio. Performance measures included approach degree of saturation, queue length, stopped-vehicle ratio, and delay.

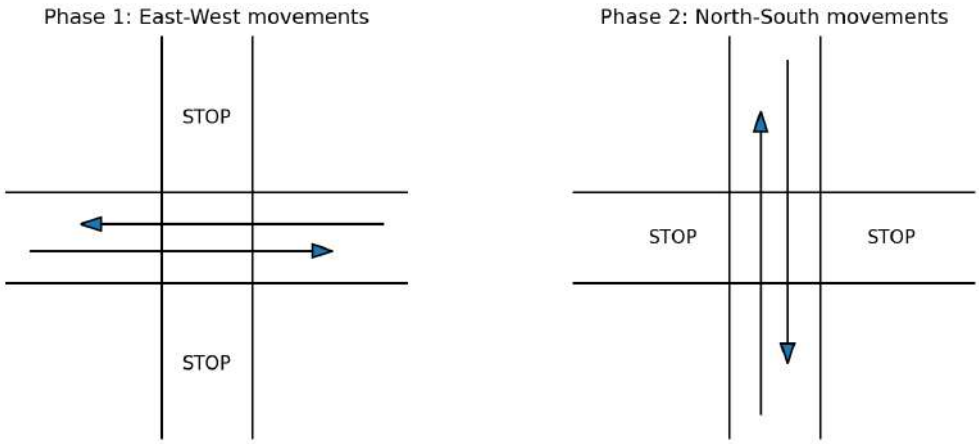

Figure 4. Proposed two-phase movement plan for Panjalin Intersection.

2.5 PTV Vissim model and scenario comparison

The microscopic model was developed in PTV Vissim Student Version, which is intended for academic traffic-simulation applications [11]. The network was constructed from the measured geometry using links and connectors for the four approaches and all permitted turning movements. Directional traffic inputs were assigned from the observed peak-hour flows. Vehicle classes and desired-speed inputs reflected the field classification and speed observations. Route decisions distributed vehicles to left-turn, through, and right-turn movements in accordance with the observed turning proportions.

Two scenarios were modelled. Scenario 1 represented the existing unsignalized intersection using priority and conflict-area settings. Scenario 2 introduced the fixed-time two-phase signal controller derived from the PKJI design. Queue counters, node evaluation, and vehicle travel-time measurements were used to obtain average queue length (QLEN), maximum queue length (QLENMAX), stopped vehicles (QSTOPS), and average travel time (TRAVTM). The draft simulation summary reported two model runs and descriptive statistics. Because the Student Version and the available draft output did not provide a complete calibration report, the simulation results were used primarily for relative scenario comparison rather than as a replacement for the PKJI design calculation.

This interpretation follows the approach used in previous studies: deterministic capacity procedures define the planning threshold and signal timing, while microscopic simulation provides additional information about vehicle interactions, spatial queue development, and the relative response of the network to an alternative design [6], [9], [10]. The percentage change for each Vissim indicator was calculated as the difference between the existing and signalized scenarios divided by the existing value.

3. RESULTS AND DISCUSSION

3.1 Peak-hour traffic demand and movement pattern

The selected peak-hour demand was dominated by motorcycles. In the unsignalized analysis, motorcycles represented approximately 73.37% of the motorized traffic count, passenger cars 10.48%, and medium vehicles 15.85%. The high motorcycle proportion is operationally important because motorcycles

can occupy lateral gaps, form multiple queues within a nominal lane, and enter the conflict area with behavior that is not fully represented by lane-based capacity concepts. The commercial roadside environment also creates frequent disturbances near the entries.

After conversion to passenger-car units for the signalized analysis, the east approach carried 704 pcu/h, the west approach 627 pcu/h, the south approach 416 pcu/h, and the north approach 434 pcu/h. The left-turn ratios were 0.38, 0.18, 0.23, and 0.43 for the east, west, south, and north approaches, respectively. The corresponding right-turn ratios were 0.07, 0.17, 0.40, and 0.14. The south approach therefore had the highest right-turn proportion, while the north approach had the highest left-turn proportion. These differences are important for opposed signal operation because turning vehicles can interfere with opposing through traffic.

Table 2. Peak-hour flow and turning ratios used in the signalized-intersection analysis.

Approach	Flow (pcu/h)	Left-turn ratio	Right-turn ratio	Effective width
East	704	0.38	0.07	6 m
West	627	0.18	0.17	6 m
South	416	0.23	0.40	4 m
North	434	0.43	0.14	4 m

3.2 Existing unsignalized-intersection performance

The total entering flow for the unsignalized calculation was 2,604 pcu/h. The major-road flow was 1,492 pcu/h and the minor-road flow was 1,111 pcu/h. The total left-turn, through, and right-turn flows were 605, 1,217, and 782 pcu/h, respectively. These values indicate substantial cross and turning demand rather than a simple major-road-dominant pattern. The minor-road flow ratio and the high right-turn volume increase the number of interactions inside the conflict area.

The adjusted capacity was 2,747.84 pcu/h. Dividing demand by capacity produced a degree of saturation of 0.947. This value is 11.4% higher than the PKJI planning threshold of 0.85. A junction operating at this level has little residual capacity to absorb short-term fluctuations, non-uniform arrivals, or temporary blockages caused by roadside activity. The calculated average delay was 16.946 s/pcu and the upper queue-probability estimate was 71.63%. The draft classified the operational condition as level of service E, reflecting unstable operation and significant interference.

The result confirms the field observation that the lack of formal right-of-way allocation is no longer appropriate during the peak hour. Even though the numerical capacity is slightly higher than the mean entering flow, the small margin between demand and capacity means that ordinary variability can generate queues. The value also explains why congestion becomes more visible on weekends, holidays, and periods when roadside stopping activity increases.

Table 3. PKJI 2023 performance of the existing unsignalized intersection.

Indicator	Result	Interpretation
Total entering flow	2,604 pcu/h	High peak-hour demand
Adjusted capacity	2,747.84 pcu/h	Limited residual capacity
Degree of saturation	0.947	Above the 0.85 design criterion
Average delay	16.946 s/pcu	Substantial operational delay
Upper queue probability	71.63%	High likelihood of queue formation
Reported service level	E	Unstable / constrained operation

3.3 Signal timing and approach capacity

The calculated two-phase cycle of 42 s is within the PKJI recommended range for a two-phase signal. Phase 1 received 15.38 s of effective green and Phase 2 received 16.62 s. The green ratios were approximately 0.371 and 0.399. The short cycle limits red time and is suitable for a compact intersection with moderate approach lengths. However, practical implementation should verify that the all-red intervals are sufficient for the actual skewed geometry and that pedestrian crossing needs are accommodated.

Approach capacities were 1,034 pcu/h for the east, 1,027 pcu/h for the west, 665 pcu/h for the south, and 637 pcu/h for the north. The resulting degrees of saturation ranged from 0.610 to 0.681. The east and north approaches had the highest values, 0.680 and 0.681, respectively, but all approaches remained below

the 0.85 criterion. The average approach degree of saturation was 0.649. This reduction from 0.947 indicates that temporal separation of movements can use the available intersection space more effectively despite the lost time associated with the signal.

Calculated queue lengths ranged from 18.42 to 22.06 m. The east approach had the longest calculated queue, followed by the north approach. These queues can generally be stored within the approach area shown in the field drawing, but the result should be checked against the location of driveways, roadside parking, and pedestrian crossings. The average signalized-intersection delay was 14.679 s/pcu. Delay values by approach were relatively balanced, ranging from 13.864 to 15.787 s. Balanced delay is a desirable feature because it indicates that the green allocation does not excessively disadvantage one approach.

Table 4. Two-phase signal timing and approach performance according to PKJI 2023.

Parameter	East	West	South	North
Flow (pcu/h)	704	627	416	434
Adjusted saturation flow (pcu/h)	2,689	2,715	1,590	1,572
Capacity (pcu/h)	1,034	1,027	665	637
Degree of saturation	0.680	0.610	0.625	0.681
Calculated queue length (m)	22.06	18.42	18.75	21.06
Delay (s/pcu)	15.094	13.864	14.050	15.787

Table 5. Principal parameters of the proposed signal controller.

Parameter	Phase 1	Phase 2	Intersection total / note
Served movement	East–West	North–South	Two-phase fixed-time control
Critical flow ratio	0.262	0.276	0.538
All-red time	1.209 s	1.388 s	Yellow time = 3 s/phase
Effective green	15.38 s	16.62 s	Cycle length = 42 s
Green ratio	0.371	0.399	Total lost time = 9.59 s

3.4 PTV Vissim scenario results

The Vissim summary showed that the signalized scenario reduced all four reported comparison indicators. Average queue length decreased from 2.8 to 1.5 in the reported simulation units, equivalent to a 46.4% reduction. Maximum queue length decreased from 7.6 to 4.2, or 44.7%. The number of stopped vehicles decreased from 82 to 40, corresponding to a 51.2% reduction. Average travel time decreased from 2.3 to 1.8 in the reported travel-time units, or 21.7%.

The largest proportional improvement occurred in the number of stopped vehicles. At first glance, a traffic signal might be expected to increase stopping because red intervals deliberately halt vehicles. In this model, however, the unsignalized condition created repeated stop-and-go interactions as vehicles searched for gaps and yielded within the conflict area. The signalized scenario organized these interactions into clear movement intervals, reducing the number of unproductive stops and the spread of queue formation.

The reduction in maximum queue is especially important for the study location. Long queues on the national-road approaches can block access to roadside businesses and can propagate toward adjacent road sections. On the provincial approaches, queues can interfere with the narrower 4-m entries. The simulated improvement is consistent with the PKJI result that all signalized approaches operate below the saturation threshold. Nevertheless, Vissim outputs should be interpreted as scenario indicators because the draft did not include a complete calibration and validation table such as GEH statistics, travel-time error, or queue-length error. Future work should document these measures before using the model for final controller programming.

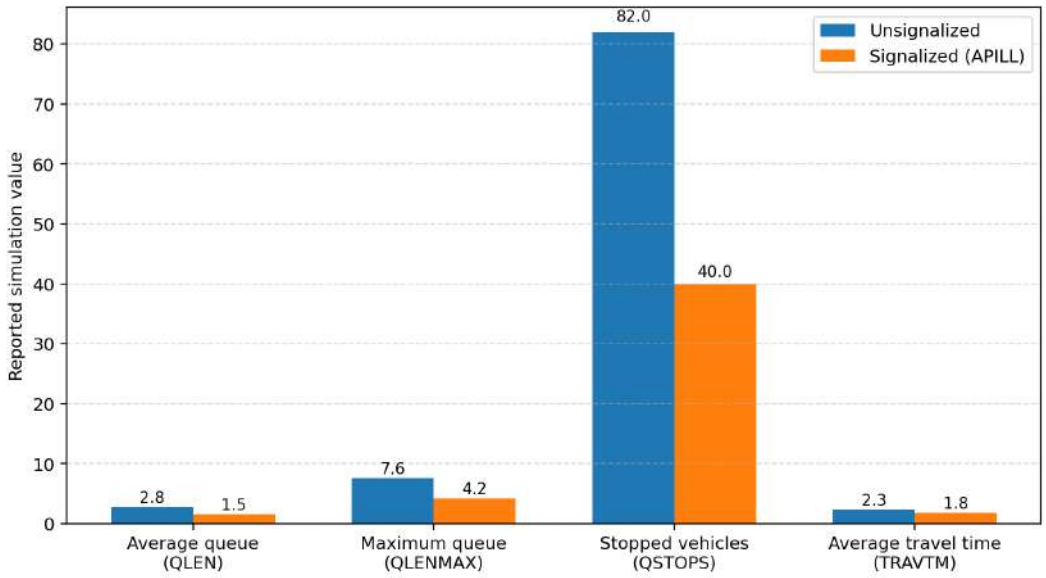

Figure 5. Comparison of the reported PTV Vissim performance indicators for the existing and signalized scenarios.

Table 6. Relative change in PTV Vissim performance indicators.

Indicator	Unsignalized	Signalized	Change
Average queue (QLEN)	2.8	1.5	−46.4%
Maximum queue (QLENMAX)	7.6	4.2	−44.7%
Stopped vehicles (QSTOPS)	82	40	−51.2%
Average travel time (TRAVTM)	2.3	1.8	−21.7%

3.5 Comparison with previous studies

The direction of improvement obtained in this study is consistent with earlier intersection-simulation research. Hadi and Khairurrasyid [5] found that queue length and delay were effective indicators for evaluating an unsignalized four-leg intersection in a commercial area. Mufhidin and Chaniago [4] similarly demonstrated that Vissim can identify operational differences between intersection and road-section conditions that are difficult to describe using only aggregate volume-to-capacity ratios. The Panjalin case extends this approach by explicitly designing a PKJI-based signal alternative and comparing it with the existing priority operation.

Jalus et al. [7] reported that changes in cycle time and intergreen sequence reduced average queues and delay at a signalized intersection. The Panjalin design reaches the same general conclusion, although the treatment begins from an unsignalized condition. Ado et al. [8] and Putri et al. [6] also emphasize that the best alternative depends on local demand, approach geometry, and turning proportions. The results should therefore not be generalized as evidence that every congested unsignalized junction must be signalized. Instead, they demonstrate that signalization is appropriate at this site because the existing degree of saturation is above the national planning threshold and the two-phase alternative distributes capacity adequately among the approaches.

The difference between deterministic and microscopic results should also be recognized. PKJI calculates capacity and delay from standardized relationships and average traffic conditions, while Vissim models individual arrivals and interactions. Theodora et al. [9] observed that the two methods can produce different queue and delay values even after model validation. In the Panjalin study, PKJI provides the defensible design criterion—degree of saturation below 0.85—whereas Vissim illustrates the relative reduction in queues, stops, and travel time. Using both methods produces a more complete decision basis than relying on either method alone.

Table 7. Relationship between the Panjalin findings and selected previous studies.

Study	Method	Main relevance to the present study
Mufhidin and Chaniago [4]	Vissim; unsignalized intersection and road section	Supports microscopic evaluation of queue and travel performance
Hadi and Khairurrasyid [5]	Vissim; four-leg unsignalized intersection	Confirms the importance of commercial side friction and time-dependent queues
Putri et al. [6]	MKJI, PKJI 2023, and Vissim	Demonstrates integrated analytical and simulation-based alternative selection
Jalus et al. [7]	Vissim; signal-cycle improvement	Shows that cycle and intergreen adjustment can reduce queue and delay
Theodora et al. [9]	PKJI 2023 and validated Vissim	Explains differences between deterministic and stochastic outputs
Pedo et al. [10]	PKJI 2023 and calibrated Vissim	Uses combined analysis to formulate traffic-management recommendations

3.6 Engineering implications and implementation requirements

The proposed two-phase APILL should be treated as a preliminary engineering design. Before installation, the road authority should repeat the turning-movement survey to confirm that the selected peak hour remains representative. Surveys should include weekday and weekend conditions, school and market peaks, and holiday traffic. The signal-controller plan should then be checked for minimum green time, pedestrian clearance, intergreen safety, and coordination with any nearby traffic-control devices.

Roadside management is essential. Signalization alone cannot fully improve performance if parking, passenger loading, or informal commercial activity occupies the approach area. No-parking and no-stopping controls should be introduced within an appropriate distance from the stop line. Clearly visible lane arrows, stop lines, pedestrian crossings, warning signs, and approach markings should be installed. Where feasible, access points near the intersection should be consolidated or managed to reduce turning conflicts.

The high motorcycle share requires particular attention to stop-line design and driver behavior. A motorcycle waiting area may be considered if it can be designed safely and consistently with national guidance. Enforcement and public education should accompany signal activation because early non-compliance can undermine the intended phase separation. The operating agency should also prepare a transition plan for the first weeks of operation, including field personnel during the initial adjustment period.

After implementation, performance should be monitored at regular intervals. Recommended indicators include hourly approach volume, maximum queue length, average delay, red-light compliance, crash and near-miss records, and roadside stopping activity. Signal timing should be reviewed whenever one or more approaches approach a degree of saturation of 0.85. If demand becomes strongly time-dependent, the fixed-time plan can be expanded into time-of-day plans or an actuated/adaptive controller. Such an upgrade should use detector data and should be evaluated through a newly calibrated simulation model.

The study has several limitations. The available draft summarizes the field and simulation results but does not provide raw turning-count spreadsheets, complete Vissim parameter settings, or formal calibration statistics. The Student Version may also restrict network size and some advanced functions. The analysis represents the observed peak hour and does not include traffic growth, crash-cost analysis, pedestrian demand modelling, or life-cycle economic evaluation. These limitations do not invalidate the identified capacity problem, but they define the additional work needed before detailed design and procurement.

3.7 Demand-growth sensitivity

The previous results describe the observed peak hour and should not be interpreted as a long-term traffic forecast. Nevertheless, a simple demand-sensitivity test is useful for understanding how much operational reserve remains in each scenario. The test holds geometry, traffic composition, turning proportions, saturation flow, side friction, and signal timing constant, while increasing all approach flows by the same percentage. Under those assumptions, the degree of saturation changes in direct proportion to demand. This is not a substitute for a formal traffic forecast, because actual growth may differ by approach and may be accompanied by changes in land use, vehicle composition, or roadside activity.

For the unsignalized condition, the current degree of saturation is already 0.947. A uniform 5% increase in traffic would raise it to approximately 0.994, leaving almost no theoretical reserve. A 10% increase would raise it to 1.042, and a 15% increase would raise it to 1.089. Once the value exceeds 1.0,

the average demand is greater than the calculated capacity, so residual queues are expected to accumulate from one analysis period to the next. This sensitivity result reinforces the conclusion that retaining the existing priority operation would provide poor resilience even under modest demand growth.

The proposed signal plan has substantially more reserve. With a 10% uniform increase, the highest approach degree of saturation would be approximately 0.749. With a 20% increase, the east and north approaches would reach approximately 0.816 and 0.817, respectively, while the west and south approaches would remain below 0.76. A 25% uniform increase would bring the highest approach close to the 0.85 design criterion. In other words, under the simplifying assumptions of this sensitivity test, the proposed fixed-time plan provides an approximate demand reserve of 24–25% before the critical approach reaches the planning threshold.

This reserve should not be treated as a guaranteed service life. The actual rate at which capacity is consumed will depend on directional growth, changes in turning movements, parking and access activity, motorcycle behavior, signal compliance, and the effectiveness of roadside management. For example, growth concentrated on the north approach would exhaust the available reserve sooner than uniform growth. Conversely, strict removal of parking near the stop line and improved lane discipline could preserve or increase effective capacity. The practical value of the sensitivity test is therefore to identify the approaches that should receive priority in future monitoring: east and north are the most critical, followed by south and west.

Table 8. Sensitivity of degree of saturation to uniform demand growth (capacity and signal timing held constant).

Demand scenario	Unsignalized	East	West	South	North
Observed peak hour	0.947	0.680	0.610	0.625	0.681
+5% demand	0.994	0.714	0.641	0.656	0.715
+10% demand	1.042	0.748	0.671	0.688	0.749
+15% demand	1.089	0.782	0.702	0.719	0.783
+20% demand	1.136	0.816	0.732	0.750	0.817
+25% demand	1.184	0.850	0.763	0.781	0.851

3.8 Safety, environmental, and institutional considerations

The performance analysis focuses on capacity, delay, and queues, but the decision to signalize an intersection also has safety implications. The existing unsignalized junction exposes vehicles to simultaneous crossing, merging, and turning conflicts. A properly designed signal can reduce these conflicts by assigning right of way in time. The two-phase plan is particularly simple for drivers to understand because each phase serves one road axis. However, signalization can introduce different risks, including rear-end collisions during the transition to red, red-light violations, and conflicts involving permissive right turns. A formal road-safety audit should therefore be conducted at the preliminary-design and pre-opening stages.

The safety audit should verify sight distance to signal heads, the visibility and placement of stop lines, the clearance interval, pedestrian crossing distance, night-time lighting, drainage, pavement condition, and the location of utility poles or signs. The skewed geometry shown in Figure 1 requires special attention because the longest vehicle path through the conflict area may not align with a simple rectangular clearance assumption. Heavy vehicles and slow motorcycles should be considered when checking all-red time. If pedestrian demand is significant, the cycle and phase plan may need a protected pedestrian interval or a longer minimum green time than the purely vehicle-based calculation.

The Vissim output tables in the draft included fields for fuel consumption and emissions, but the final comparison summarized only queue, stops, and travel time. The present article therefore does not claim a quantified environmental benefit. It is reasonable to expect that fewer repeated stops and shorter travel time can reduce unnecessary acceleration and idling, but a fixed signal can also create red-time idling during low-demand periods. An environmental assessment should use a calibrated model, consistent vehicle-emission factors, and comparable simulation periods. Until such an assessment is completed, environmental improvement should be regarded as a potential co-benefit rather than a verified result.

Implementation also requires institutional coordination because the intersection connects a national road and provincial roads within a regency. The road authority responsible for each approach, the local

transportation agency, traffic police, utility providers, and nearby property owners should agree on the design, construction sequence, power supply, maintenance responsibility, and enforcement arrangements. Signal equipment should have reliable electrical protection, backup operation, accessible controller cabinets, and a maintenance schedule. The agency should establish a response procedure for lamp failure, detector failure, power interruption, and abnormal queues.

A staged implementation process is recommended. The first stage is detailed design and renewed traffic data collection. The second stage includes geometric preparation, markings, signs, signal poles, and roadside-access control. The third stage is controller commissioning with temporary field supervision. The fourth stage is an evaluation after one month and again after three to six months. Timing adjustments should be based on measured approach queues and saturation, not solely on complaints or visual impressions. This process converts the proposed signal from a static construction project into an actively managed traffic-control system.

Table 9. Recommended implementation and monitoring actions.

Stage	Main action	Minimum evidence / output
1. Verification	Repeat peak-hour counts, speed survey, pedestrian count, and safety review	Updated design traffic, confirmed geometry, safety-audit findings
2. Detailed design	Finalize phase plan, intergreen, signal-head layout, markings, signs, and power supply	Approved drawings, controller schedule, bill of quantities
3. Site preparation	Remove near-stop-line parking, manage access, install markings and signs	Clear approach storage and visible lane assignment
4. Commissioning	Activate signal with field officers and public information	Controller test record and initial compliance observations
5. Post-opening review	Measure queues, delay, saturation, violations, and incidents	One-month and three-to-six-month evaluation reports
6. Future optimization	Introduce time-of-day or actuated control when demand patterns diverge	Revised timing plans supported by detector and survey data

4. CONCLUSION

The existing unsignalized Panjalin Intersection operates above the PKJI 2023 planning threshold during the selected peak hour. Total entering demand was 2,604 pcu/h, adjusted capacity was 2,747.84 pcu/h, and the degree of saturation reached 0.947. The calculated average delay was 16.946 s/pcu and the upper queue-probability estimate was 71.63%. These results confirm that the junction has insufficient operational reserve and is vulnerable to recurring congestion when traffic fluctuates or roadside interference increases.

A two-phase APILL arrangement provides a feasible short-term improvement using the existing approach geometry. The proposed 42-s cycle allocates 15.38 s of effective green to east–west traffic and 16.62 s to north–south traffic. Approach degrees of saturation fall to 0.610–0.681, with an average of 0.649. The average calculated delay becomes 14.679 s/pcu, and approach queues remain approximately 18–22 m. All approaches therefore satisfy the PKJI saturation criterion under the analysed demand.

The microscopic scenario comparison supports the analytical result. Relative to the unsignalized model, the signalized model reduced average queue, maximum queue, stopped vehicles, and average travel time by 46.4%, 44.7%, 51.2%, and 21.7%, respectively. The principal benefit is not merely a reduction in average delay but the organization of conflicting movements into predictable right-of-way intervals.

Accordingly, the installation of a two-phase traffic signal at Panjalin Intersection is recommended for detailed engineering evaluation. Implementation should include clearance-time verification, lane and pedestrian markings, roadside-parking control, public education, and post-installation monitoring. A future study should provide complete Vissim calibration and validation, evaluate pedestrian and safety performance, and test time-of-day or adaptive signal control as traffic demand grows.

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