International Journal of Informatics and Computation (IJICOM)
Vol. 8, No. 2, 2026
ISSN: 2685-8711, E-ISSN: 2714-5263 DOI: 10.35842/ijicom

Empirical Software Metrics Framework for Evaluating Operational Efficiency and Service Quality in Digital MSME Systems

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Abstract

Digital transformation has become essential for Micro, Small, and Medium Enterprises (MSMEs) to improve operational efficiency and service quality; however, existing studies on digital laundry information systems mainly focus on system development and implementation, with limited attention to objective software evaluation using empirical software engineering approaches. To address this gap, this study proposes an Empirical Software Metrics Framework to evaluate a digital laundry information system using 300 real operational transaction records collected from an MSME environment. The framework integrates four software quality dimensions—performance, quality, productivity, and usability—supported by statistical validation and correlation analysis to provide a comprehensive assessment of software effectiveness. The results show an average Processing Time of 17.98 minutes, Queue Time of 8.13 minutes, and an Error Rate of 7.33%. A before-and-after analysis revealed a 19.42% reduction in Processing Time, while an Independent Sample T-Test confirmed statistically significant improvement ($p < 0.001$). These findings demonstrate that the proposed framework provides a comprehensive, data-driven, and evidence-based approach for evaluating software performance and can serve as a practical reference for improving MSME information systems beyond conventional functional testing.

Keywords:
Empirical Software Engineering, Software Metrics, MSME Information Systems, Operational Efficiency, Digital Laundry System.

1. Introduction

In recent years, the rapid advancement of information technology has significantly transformed how organizations and businesses operate, particularly within the Micro, Small, and Medium Enterprises (MSMEs) sector. Digital transformation has evolved from being a supporting tool into a strategic necessity for maintaining competitiveness, improving operational efficiency, and enabling data-driven decision-making processes [1], [2]. For MSMEs, the adoption of digital technologies plays a critical role in simplifying business processes, enhancing service quality, increasing transparency in operational management, and supporting sustainable business growth [3]. Nevertheless, MSMEs continue to face challenges in adopting digital technologies due to limited resources, low levels of digital literacy, and dependence on traditional operational systems [2], [4]. Previous studies have demonstrated that the integration of information technology can improve operational efficiency, accelerate business processes, and support more accurate and data-driven decision-making [1], [5], [6], [7].

One service sector that has experienced rapid growth is the laundry business. Increasing

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urbanization and changing lifestyles have encouraged the adoption of digital solutions to improve service efficiency and customer satisfaction. However, many laundry MSMEs still rely on manual or semi-digital processes, including handwritten transaction records, non-integrated order management, and limited real-time monitoring capabilities [4], [8], [9]. These limitations frequently result in operational inefficiencies, transaction errors, reduced service quality, and difficulties in conducting operational analysis because of inadequate data management [10], [11]. Consequently, integrated information systems have become increasingly important for automating business processes and improving operational effectiveness.

Previous studies have proposed various web-based and mobile-based laundry information systems that automate transaction management, facilitate order tracking, and integrate digital payment mechanisms [8], [12], [13], [14]. In addition, service-oriented architectures and web services have improved system integration and scalability, while agile development methodologies such as Scrum and Kanban have been widely adopted because of their flexibility and adaptability to changing user requirements [14], [15], [16]. Although these approaches have contributed to improving operational performance and service quality through centralized data management and real-time information access [4], [10], most existing studies primarily emphasize system development and implementation rather than comprehensive software evaluation. System assessment is generally limited to functional testing or user satisfaction evaluation without incorporating quantitative software metrics [8], [13], [15].

From a software engineering perspective, software metrics provide objective measurements of software quality and performance through indicators such as processing time, error rate, reliability, usability, and productivity [17], [18]. Supported by empirical software engineering and data analytics, these metrics enable systematic, evidence-based evaluation using real operational data to improve software quality and organizational decision-making [7], [17], [19]. Furthermore, the emergence of Generative Artificial Intelligence (Generative AI) has accelerated software development, documentation, testing, and code generation processes [19]. Although AI-assisted development tools improve software development efficiency, they do not automatically guarantee software quality and operational effectiveness after deployment. Therefore, objective evaluation through empirical software metrics remains essential to validate software performance using real operational data and evidence-based assessment [20].

Despite the increasing adoption of information systems within MSMEs, the application of software metrics and empirical software engineering approaches for evaluating digital laundry systems remains limited. Most previous studies focus on implementation aspects without extending evaluation toward comprehensive software performance analysis using real operational data [8], [12], [13], [14], [20]. Previous research conducted by Joharini et al. developed an integrated digital laundry application supporting end-to-end business processes, including service management, transaction processing, and real-time monitoring [20]. Although the study demonstrated improvements in operational efficiency and transaction management, the evaluation primarily relied on general performance indicators and did not systematically apply software metrics for comprehensive software assessment. Similar limitations have also been reported in other MSME information system studies, making it difficult to objectively assess software effectiveness and quality using quantitative software engineering approaches [2], [21], [22].

Based on these limitations, this study addresses the need for a comprehensive software evaluation approach capable of objectively measuring software performance, quality, productivity, and usability using empirical software engineering principles and real operational transaction data. Accordingly, this study proposes an Empirical Software Metrics Framework that integrates software metrics, before-and-after analysis, statistical hypothesis testing, and correlation analysis to provide a multidimensional and evidence-

based evaluation of digital laundry information systems. The proposed framework is designed to support software quality assessment, operational efficiency improvement, and data-driven decision-making in MSMEs while serving as a practical reference for other service-oriented information systems.

Unlike previous studies that mainly focused on software development, implementation, or functional testing, this research contributes a comprehensive software evaluation framework validated using 300 real operational transaction records collected from an MSME environment. The framework combines software metrics, empirical software engineering, statistical validation, and correlation analysis into a unified evaluation approach, enabling objective assessment of software effectiveness beyond conventional functional testing. Furthermore, the framework remains relevant in the era of Generative AI, where AI-assisted software development requires systematic and evidence-based evaluation to ensure software quality, reliability, and operational effectiveness.

2. Related Works

Software engineering is a discipline that focuses on the systematic, structured, and measurable development, operation, and evaluation of software systems. In the context of Micro, Small, and Medium Enterprises (MSMEs), software engineering plays an important role in ensuring that information systems are not only functional but also efficient, reliable, maintainable, and scalable [15], [23]. The increasing demand for digital transformation has encouraged MSMEs to adopt information systems to support operational activities, improve data management, enhance decision-making accuracy, and accelerate business processes across various service-oriented sectors [10], [11], [21], [24], [25]. However, MSMEs continue to face challenges such as limited technical expertise, constrained resources, and insufficient system evaluation practices [2], [4]. Agile methodologies, including Scrum and Kanban, have been widely adopted because of their flexibility and ability to accommodate changing user requirements, supporting iterative development and continuous software improvement [15], [16]. Nevertheless, most existing studies emphasize software development rather than systematic evaluation of software quality and operational performance.

Digital transformation has become an important factor in improving MSME competitiveness, operational efficiency, and service quality [1], [2]. In the laundry industry, digital transformation is reflected through the implementation of web-based and mobile-based information systems that support transaction management, order tracking, customer management, and digital payment integration [8], [12], [13], [26], [27]. Previous studies have reported that digital laundry systems improve operational efficiency, reduce manual errors, and support more effective service management while enabling real-time monitoring and greater operational transparency [4], [8], [10], [28], [29]. Although these benefits have been widely reported, most studies primarily focus on system development and deployment, whereas comprehensive evaluations using quantitative software engineering approaches remain limited.

Software metrics provide quantitative measures for evaluating software quality, performance, and operational effectiveness by supporting objective software assessment and continuous improvement [17], [18], [30]. These metrics include performance indicators such as processing time, response time, and service time; quality indicators such as error rate, reliability, and defect occurrence; usability indicators such as user satisfaction and user acceptance; and productivity indicators such as transaction throughput, revenue per employee, and operational efficiency. Previous studies have demonstrated that metric-based approaches improve software quality and support software defect prediction [17], while structured evaluation frameworks such as BAGI and GAPI highlight the importance of quantitative indicators in assessing system effectiveness [18], [31], [32]. Despite these advantages, the application of software metrics within MSME information systems,

particularly digital laundry applications, remains relatively limited because most evaluations continue to rely on functional testing without integrating multiple software metrics into a comprehensive assessment framework.

Empirical Software Engineering (ESE) emphasizes the use of real-world operational data to analyze, evaluate, and improve software systems rather than relying solely on theoretical approaches [17]. This approach is particularly relevant for MSMEs because business processes are dynamic and strongly influenced by operational conditions. Evaluating software using actual transaction data enables more accurate identification of performance issues, software quality concerns, and operational bottlenecks. Recent studies have also shown that data-driven software engineering approaches support performance optimization, defect prediction, and software quality improvement [17], [19]. Furthermore, the rapid advancement of data analytics has strengthened software evaluation by enabling organizations to identify operational patterns, optimize business processes, improve decision-making quality, detect operational bottlenecks, and support quality improvement initiatives [7]. Analytical platforms such as HADES further demonstrate the effectiveness of large-scale analytical approaches for software evaluation [33]. Consequently, integrating software metrics, empirical software engineering, and data analytics provides a robust foundation for comprehensive and evidence-based software evaluation, although such integration remains relatively underexplored in MSME information systems, particularly in domain-specific applications such as digital laundry services.

Based on the reviewed literature, several research gaps remain. Existing studies on digital laundry and MSME information systems predominantly emphasize system development, implementation, and functional deployment rather than comprehensive software performance evaluation [8], [13], [15]. Most evaluations are limited to functional testing or basic usability assessment, with minimal application of quantitative software engineering metrics to assess software quality and operational effectiveness [13]. Furthermore, the use of software metrics within MSME information systems remains limited, particularly in service-oriented business domains, while empirical evaluations using real operational transaction data are still relatively uncommon because many studies rely on prototype testing or user perception surveys [17]. These limitations make it difficult to objectively evaluate software performance under actual operational conditions.

To address these limitations, this study adopts the Empirical Software Metrics Framework, which enables objective, quantitative, and evidence-based software evaluation using real operational transaction data. Unlike previous studies, the proposed framework integrates multiple software quality dimensions, including performance, quality, productivity, and usability, together with before-and-after analysis, statistical validation, and correlation analysis to provide a multidimensional assessment of software effectiveness. This integrated approach not only evaluates software performance from technical and operational perspectives but also provides stronger empirical evidence to support software quality improvement and data-driven decision-making in MSME environments. Therefore, the proposed framework addresses the identified research gaps by offering a comprehensive software evaluation model that can be applied to digital laundry information systems and potentially adapted to other service-oriented MSME applications.

Table 1 presents a comparison between previous studies and the proposed research.

Table 1. Comparison of Previous Studies and Proposed Research

No	Study	Focus	Limitation	Novelty Contribution
1	Ragazou et al. (2023)	Data Analytics	General domain	Applied to MSME laundry systems
2	Lizal et al. (2025)	Laundry System Development	Implementation-focused	Metrics-based software evaluation

3	Ibrahim et al. (2025)	Information System	No software metrics analysis	Integration of software metrics
4	Mutia et al. (2025)	Web-based Laundry System	No empirical evaluation	Empirical software evaluation
5	Basri et al. (2023)	Agile Development	Development-focused	Software performance assessment
6	Joharini et al. (2026)	Integrated Digital Laundry System	Limited evaluation using general indicators	Comprehensive software metrics assessment
7	Cakra et al. (2026)	Agile Laravel Development	Development-focused	Empirical software metrics framework
8	This Study	Empirical Software Metrics Evaluation	–	Integrated framework (performance, quality, productivity, usability, statistical validation, correlation analysis, and real operational data)

As presented in Table 1, previous studies have contributed to the development of digital laundry systems, software engineering practices, agile development, and data analytics in MSME environments [7], [8], [10], [13], [15], [20], [34]. However, most of these studies primarily focus on system development, implementation, or functional evaluation, with limited application of comprehensive software metrics and empirical software engineering approaches for objectively assessing software effectiveness. In addition, evaluations based on real operational transaction data, statistical validation, and multidimensional software quality assessment remain relatively uncommon.

To address these limitations, this study proposes an Empirical Software Metrics Framework that integrates software metrics, empirical software engineering, statistical validation, correlation analysis, and real operational transaction data into a unified software evaluation framework. Unlike previous studies, the proposed framework evaluates software effectiveness across multiple quality dimensions, including performance, quality, productivity, and usability, supported by before-and-after analysis, Independent Sample T-Test, and correlation-based analysis. Using 300 real operational transaction records, the proposed framework provides a comprehensive, objective, and evidence-based assessment of software effectiveness. Therefore, this study extends previous research by offering a practical reference model for evaluating and continuously improving digital laundry information systems as well as other service-oriented MSME applications.

3. Proposed Method

A. Research Design

This study adopts an Empirical Software Engineering (ESE) approach to evaluate the performance of a digital laundry information system operating within an MSME environment. Unlike previous studies that mainly focus on software development and implementation, this research emphasizes software evaluation using quantitative software metrics and real operational data. The study applies a metrics-driven evaluation framework consisting of four dimensions, namely performance, quality, productivity, and usability. These dimensions are integrated to provide a comprehensive assessment of system effectiveness by examining technical performance, operational efficiency, productivity outcomes, and user experience. Through this multidimensional approach, the study aims to evaluate the overall effectiveness of the digital laundry information system from technical, operational, and user perspectives.

B. Research Object and Data Sources

The research object is an integrated digital laundry application previously developed and implemented within an MSME environment. The system supports transaction management, service monitoring, customer management, and digital payment processing.

The study utilizes primary operational data collected directly from the system database. The dataset consists of 300 transaction records involving 80 customers, 4 employees, 4 service types, and 4 payment methods. The collected data include transaction records, processing time data, queue time data, error records, service type information, and customer satisfaction data. These data represent actual operational conditions and therefore provide a reliable basis for empirical evaluation of the digital laundry information system.

C. Research Variables and Software Metrics

The variables used in this study are derived from software metrics and categorized into four dimensions.

Table 2. Research Variables and Software Metrics

Dimension	Metric	Indicator
Performance	Processing Time	Service completion time
Performance	Queue Time	Waiting time before service
Performance	Total Service Time	End-to-end service duration
Quality	Error Rate	Percentage of transaction errors
Quality	Error Type	Distribution of system errors
Productivity	Transaction Throughput	Transactions processed
Productivity	Revenue per Employee	Employee productivity
Usability	Customer Satisfaction	Satisfaction score

D. Research Framework

The proposed framework integrates software metrics, empirical software engineering, and data analytics to evaluate digital laundry systems. The framework begins with operational data collection from the digital laundry system, followed by data preprocessing to ensure data quality and consistency. Subsequently, software metrics are calculated based on the collected data and analyzed through empirical methods to identify patterns, relationships, and system performance characteristics. The results of the empirical analysis are then used for comprehensive system evaluation, which serves as the basis for generating recommendations aimed at improving system effectiveness, efficiency, and overall service quality.

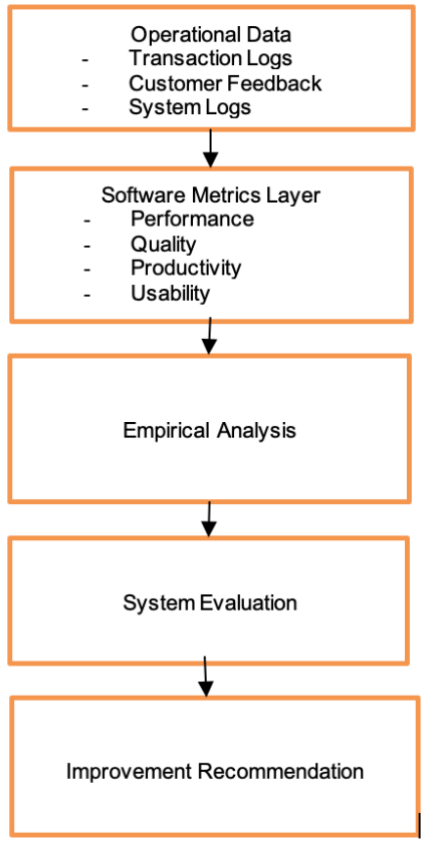

Figure 1. Empirical Software Metrics Framework

E. Data Collection Methods

Data collection was conducted through several complementary methods to ensure data completeness and reliability. First, observation was carried out by directly monitoring the daily operations of the laundry information system to understand how the system functions in real operational settings. Second, documentation techniques were employed by extracting transaction records and operational data from the application database. Third, system log analysis was conducted to collect information related to processing time, queue time, and error records generated by the system during operation. The combination of these methods provides comprehensive and reliable data for the empirical evaluation of the digital laundry information system.

F. Data Analysis Methods

A quantitative analysis approach was employed to evaluate the effectiveness of the digital laundry information system using the proposed Empirical Software Metrics Framework. The analysis was conducted across four software quality dimensions: performance, quality, productivity, and usability. Performance was evaluated using Processing Time, Queue Time, and Total Service Time, while quality was assessed through Error Rate and Error Type Distribution. Productivity was measured using Transactions per Employee and Revenue per Employee, whereas usability was evaluated based on Customer Satisfaction. These metrics were selected to provide a comprehensive and objective assessment of software performance from technical, operational, and user perspectives.

To validate the effectiveness of the proposed framework, a before-and-after analysis was performed to compare system performance before and after implementation. Statistical significance was examined using an Independent Sample T-Test, while correlation analysis was applied to identify relationships among the evaluated software metrics. The combination of quantitative software metrics, statistical validation, and correlation analysis provides empirical evidence of software effectiveness and supports data-driven evaluation and continuous improvement of MSME information systems.

G. Metrics Calculation Techniques

The proposed Empirical Software Metrics Framework employs quantitative software metrics to evaluate the operational performance, quality, productivity, and usability of the digital laundry information system. Each metric was selected because it represents a measurable software engineering indicator derived from real operational transaction data. The mathematical formulations used in this study are described as follows.

$$\text{Error Rate} = \frac{\text{Number of Errors}}{\text{Total Transactions}} \times 100\% \tag{1}$$

where Number of Errors represents the total number of erroneous transactions recorded during the observation period, and Total Transactions denotes the total number of processed transactions. This metric measures the percentage of unsuccessful transactions and serves as an indicator of software reliability and operational quality. A lower error rate indicates higher system stability.

$$\text{Average Time} = \frac{\text{Total Processing Time}}{\text{Number of Transactions}} \tag{2}$$

where Total Processing Time is the cumulative processing duration of all completed transactions, and Number of Transactions represents the total processed transactions. This metric evaluates system responsiveness by measuring the average time required to complete a transaction.

$$\text{Average Queue Time} = \frac{\text{Total Queue Time}}{\text{Number of Transactions}} \tag{3}$$

where Total Queue Time represents the accumulated waiting time before transactions are processed. These metric measures operational waiting efficiency, where lower queue times indicate better service responsiveness.

$$\text{Total Service Time} = \text{Queue Time} + \text{Processing Time} \tag{4}$$

Total Service Time represents the complete duration required to serve a customer, beginning from the waiting stage until transaction completion. This metric reflects the overall operational efficiency of the digital laundry system.

$$\text{RevenueperEmployee} = \sum_{i=1}^{n} \text{Revenue}_i \tag{5}$$

where Revenue_i denotes the revenue generated by an individual transaction handled by a

specific employee. This metric represents the cumulative revenue generated by each employee during the observation period and is used to evaluate employee productivity and operational contribution.

$$\text{Customer Satisfaction} = \frac{\sum \text{Satisfaction Scores}}{\text{Number of Responses}} \tag{6}$$

where Satisfaction Scores represents the total score obtained from customer feedback questionnaires, and Number of Responses denotes the total number of respondents. This metric reflects user perceptions regarding system usability and service quality.

$$\text{Correlation Coefficient (r)} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2}} \tag{7}$$

where xi and yi are paired observations of two software metrics, while $\bar{x}$ and $\bar{y}$ represent their respective mean values. The Pearson correlation coefficient measures the strength and direction of the linear relationship between software metrics, with values ranging from −1 (strong negative correlation) to +1 (strong positive correlation).

$$\text{Independent Sample T} - \text{Test (t)} = \frac{\bar{x_1} - \bar{x_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{8}$$

where $x1^-$ and $x2^-$ denote the mean processing times of the Before and After groups, s_1^2 and s_2^2 represent the corresponding variances, and n_1 and n_2 indicate the sample sizes of each group. The Independent Sample T-Test was employed to determine whether the observed reduction in processing time after system implementation was statistically significant. A significance level of 0.05 was adopted, where a p-value < 0.05 indicates a statistically significant difference between the two groups.

Table 3. Research Stages

Stage	Activity
1	Problem Identification
2	Literature Review
3	Data Collection
4	Data Preprocessing
5	Software Metrics Calculation
6	Statistical Analysis
7	System Evaluation
8	Conclusion

The proposed Empirical Software Metrics Framework was validated to ensure the reliability, credibility, and practical applicability of the research findings. Validation was performed using 300 real operational transaction records collected from an MSME digital laundry system and by applying standardized software metrics to evaluate performance, quality, productivity, and usability. The validation process combined multidimensional software evaluation with before-and-after performance analysis, Independent Sample T-Test for statistical significance testing, and correlation analysis to examine relationships

among software metrics and user perceptions. These complementary validation techniques provide robust empirical evidence of the framework's effectiveness and strengthen both the internal validity and practical applicability of the proposed software evaluation framework in real MSME operational environments.

4. Experimental Setup

This section describes the experimental setup used to evaluate the proposed Empirical Software Metrics Framework, including the dataset, software metrics, and data analysis procedures.

A. Data Collection

The dataset used in this study consists of 300 real operational transaction records collected from a digital laundry information system implemented in an MSME environment. The dataset includes 80 customers, 4 employees, 4 service types, and 4 payment methods, with transaction attributes such as processing time, queue time, transaction amount, employee assignment, error occurrence, customer satisfaction, and system version (before and after implementation). Prior to analysis, all records were preprocessed to ensure data consistency, completeness, and validity.

B. Software Metrics Evaluation

The proposed framework evaluates software effectiveness through four software quality dimensions: performance, quality, productivity, and usability. Performance is measured using Processing Time, Queue Time, and Total Service Time; quality is evaluated through Error Rate and Error Type Distribution; productivity is assessed using Transactions per Employee and Revenue per Employee; and usability is represented by Customer Satisfaction. These metrics provide a multidimensional assessment of software performance from technical, operational, and user perspectives.

C. Data Analysis Procedure

The experimental procedure began with data collection and preprocessing, followed by the calculation of software metrics based on the proposed evaluation framework. System effectiveness was then analyzed using before-and-after comparison, Independent Sample T-Test for statistical validation, and correlation analysis to examine relationships among software quality dimensions. This procedure provides empirical evidence for evaluating operational improvements and validating the effectiveness of the proposed framework.

5. Result and Analysis

A. Dataset Overview

This study evaluates the proposed Empirical Software Metrics Framework using 300 real operational transaction records collected from a digital laundry information system implemented in an MSME environment. The dataset includes information on processing time, queue time, total service time, transaction amount, laundry weight, and customer satisfaction, providing a representative basis for evaluating software performance, quality, productivity, and usability under actual operational conditions.

Table 4. Descriptive Statistics of the Dataset

Variable	Mean	Min	Max
Processing Time (Minutes)	17.98	10	25
Queue Time (Minutes)	8.13	2	15
Total Service Time (Minutes)	26.11	12	40
Transaction Amount (IDR)	65,056	15,058	118,915
Weight (Kg)	4.57	1.0	8.0
Customer Satisfaction	3.98	3	5

Table 4 summarizes the descriptive statistics of the dataset. The average processing time, queue time, and total service time were 17.98, 8.13, and 26.11 minutes, respectively, while the average transaction amount was IDR 65,056 with an average laundry weight of 4.57 kg. In addition, the average customer satisfaction score reached 3.98 out of 5, indicating a generally positive user perception of the implemented system. These descriptive results confirm that the dataset adequately represents daily operational activities and provides a reliable empirical basis for evaluating the effectiveness of the proposed software metrics framework.

B. Performance Analysis

Performance evaluation was conducted using Processing Time, Queue Time, and Total Service Time to assess the operational efficiency of the proposed digital laundry information system. These metrics were selected because they directly represent system responsiveness and service efficiency during daily business operations. Among these indicators, Processing Time serves as the primary performance metric for evaluating the effectiveness of transaction processing.

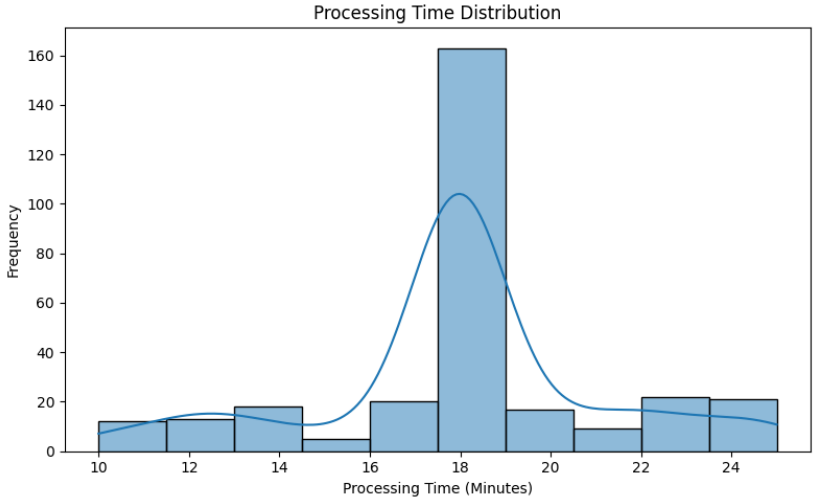

Figure 2. Processing Time Distribution

Figure 2 illustrates the distribution of Processing Time across 300 operational transaction records. Most transactions were completed within approximately 18 minutes, which is consistent with the average processing time reported in Table 4. The relatively concentrated distribution indicates stable system performance with no significant fluctuations during daily operations. These findings suggest that the proposed system provides consistent operational efficiency and supports reliable service delivery. Furthermore, the observed processing time serves as the baseline for the subsequent before-and-after analysis, which is used to statistically validate the operational

improvements achieved after system implementation.

C. Quality Analysis

System quality was evaluated using the Error Rate and Error Type Distribution to assess the reliability of the digital laundry information system during daily operations.

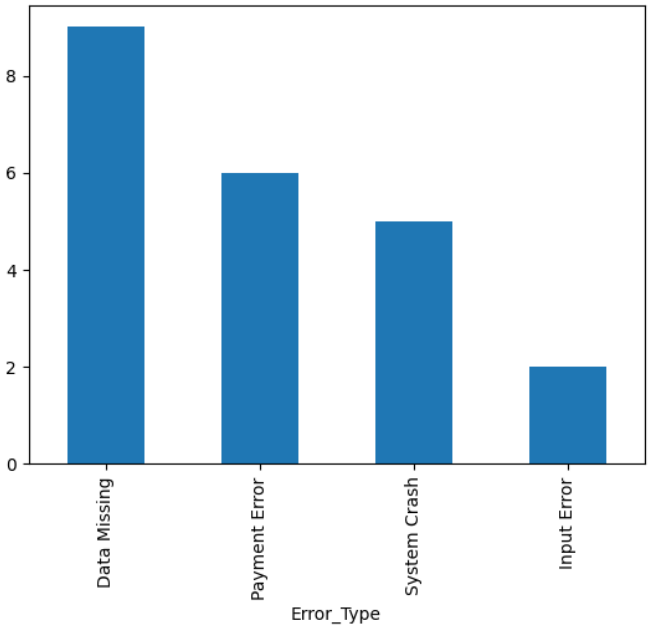

Figure 3. Error Type Distribution

Figure 3 shows that Data Missing was the most frequently occurring error, followed by Payment Error and System Crash. The overall Error Rate was 7.33%, indicating that more than 92% of transactions were processed successfully without system failures. These results suggest that the implemented system provides acceptable operational reliability. However, the predominance of data-related errors indicates that improvements in data validation, input verification, and transaction handling mechanisms could further enhance software quality and reduce operational risks.

D. Productivity Analysis

Productivity was evaluated using Transactions per Employee and Revenue per Employee to measure the contribution of the digital laundry information system to employee performance and operational output.

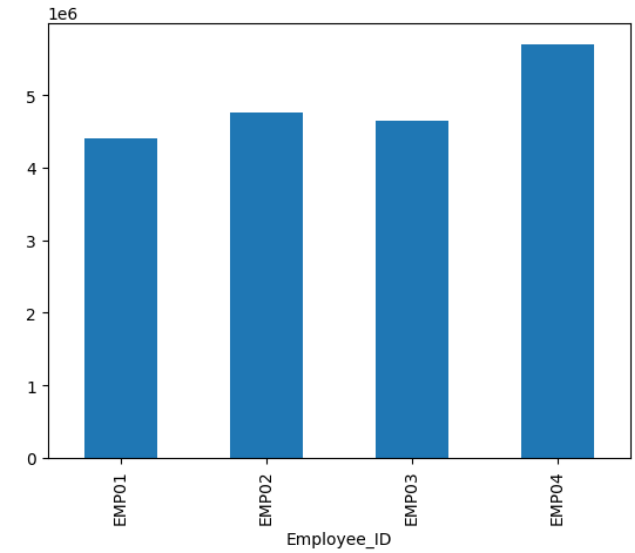

Figure 4. Revenue per Employee

Figure 4 illustrates the revenue generated by each employee during the observation period. EMP04 achieved the highest revenue, whereas EMP01 generated the lowest. These differences indicate variations in employee productivity that may be influenced by workload distribution, service assignments, and transaction volume. The results also demonstrate that the proposed system enables objective monitoring of employee performance, providing useful information for resource allocation and operational decision-making in MSME environments.

E. Before and After System Analysis

The effectiveness of the proposed system was evaluated through a before-and-after analysis of Processing Time. The average processing time decreased from 19.91 minutes before implementation to 16.05 minutes after implementation, representing an operational improvement of 19.42%

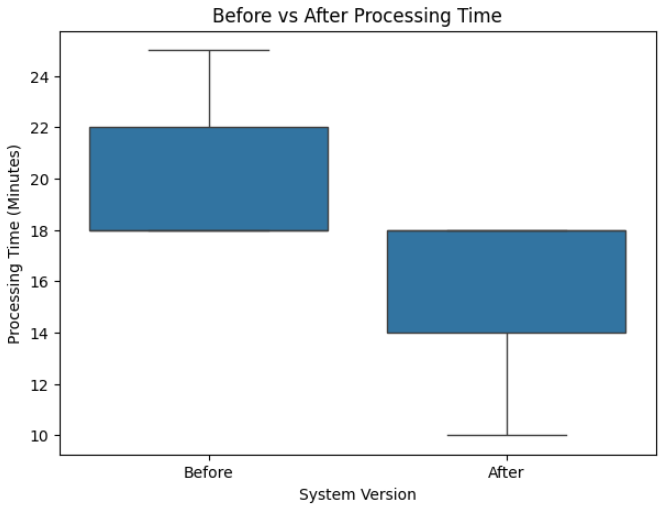

Figure 5. Before vs After Processing Time

Figure 5 demonstrates that the After group consistently exhibits lower processing times than the Before group, indicating improved operational efficiency following system

implementation. Statistical validation using the Independent Sample T-Test produced a t-statistic of 13.075 with a p-value < 0.001, confirming that the observed improvement is statistically significant. These findings provide strong empirical evidence that the proposed Empirical Software Metrics Framework effectively supports the evaluation of operational performance improvements in digital laundry MSME systems.

F. Correlation Analysis

Correlation analysis was performed to examine the relationships among the software metrics used in the proposed evaluation framework.

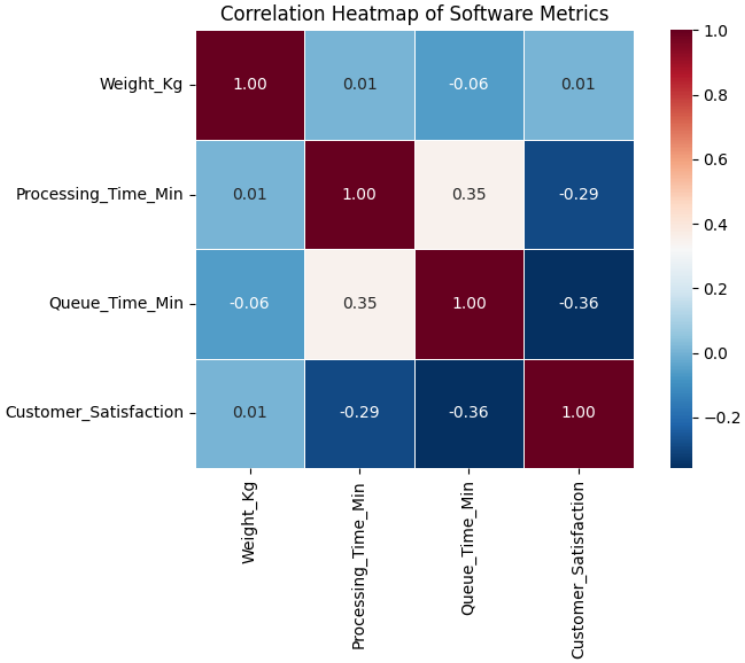

Figure 6. Correlation Heatmap of Software Metrics

Figure 6 shows that Processing Time and Queue Time exhibit a moderate positive correlation (r = 0.35), indicating that longer waiting times are generally associated with longer transaction processing times. Conversely, Customer Satisfaction demonstrates negative correlations with Processing Time (r = -0.29) and Queue Time (r = -0.36), suggesting that improvements in service efficiency contribute to higher levels of customer satisfaction. These findings confirm that operational performance is closely associated with user perceptions, emphasizing the importance of optimizing service processes to improve both software quality and customer experience.

G. Discussion

The experimental results demonstrate that the proposed Empirical Software Metrics Framework effectively evaluates the operational performance of the digital laundry information system using real operational transaction data. The observed reduction in processing time, together with the statistically significant difference identified through the Independent Sample T-Test (p < 0.001), confirms that the implemented system improves operational efficiency. In addition, the relatively low error rate (7.33%) and positive customer satisfaction score (3.98/5) indicate that the system provides reliable service quality and satisfactory user experience.

The correlation analysis further reveals that shorter processing and queue times are associated with higher customer satisfaction, emphasizing the importance of service efficiency in improving user perceptions. Unlike previous studies that primarily focused on system development, implementation, or functional testing [11], [16], [18], this study applies an empirical software engineering perspective by integrating software performance, quality, productivity, usability, statistical validation, and correlation analysis into a unified evaluation framework. Consequently, the proposed framework provides a more comprehensive and objective assessment of software effectiveness and can serve as a practical reference for evaluating MSME information systems.

H. Summary of Findings

Table 5. Summary of Software Metrics Evaluation

Dimension	Metric	Result	Interpretation
Performance	Processing Time	17.98 min	Stable
Performance	Queue Time	8.13 min	Acceptable
Performance	Total Service Time	26.11 min	Moderate
Quality	Error Rate	7.33%	Good
Productivity	Revenue per Employee	Varies	Moderate
Usability	Customer Satisfaction	3.98/5	Positive
Validation	T-Test	$p < 0.001$	Significant Improvement

The overall findings demonstrate that the proposed Empirical Software Metrics Framework effectively evaluates the operational performance of the digital laundry information system using 300 real operational transaction records collected from an MSME environment. The framework successfully integrates performance, quality, productivity, and usability metrics, supported by statistical validation and correlation analysis, to provide a comprehensive and objective assessment of software effectiveness.

The evaluation results indicate stable operational performance, a relatively low Error Rate (7.33%), positive Customer Satisfaction (3.98/5), and a statistically significant improvement in Processing Time ($p < 0.001$) following system implementation. These findings demonstrate that the proposed framework extends beyond conventional functional testing by providing multidimensional software evaluation based on empirical evidence. Therefore, the framework can serve as a practical reference for software quality assessment, continuous system improvement, and decision-making in MSME information systems.

6. Conclusion

This study presented an empirical evaluation of a digital laundry information system using the proposed Empirical Software Metrics Framework within an Empirical Software Engineering (ESE) approach. Unlike previous studies that primarily focused on system development and implementation, this research emphasized objective software evaluation based on 300 real operational transaction records collected from an MSME laundry environment. The proposed framework integrates performance, quality, productivity, and usability metrics, together with statistical validation and correlation analysis, to provide a comprehensive assessment of software effectiveness.

The experimental results demonstrated that the digital laundry information system achieved stable operational performance with an average Processing Time of 17.98 minutes, Queue Time of 8.13 minutes, and Total Service Time of 26.11 minutes. The Before-and-After analysis revealed a 19.42% reduction in Processing Time, while the Independent Sample T-Test ($p < 0.001$) confirmed that the observed improvement was statistically significant. In addition, the system achieved an Error Rate of 7.33% and an average Customer Satisfaction score of 3.98/5, indicating acceptable software quality and positive user experience. Correlation analysis further showed that shorter processing and queue times were associated with higher customer satisfaction, highlighting the importance of operational efficiency in improving service quality.

Overall, the findings demonstrate that the proposed framework extends beyond conventional functional testing by integrating software metrics, empirical operational data, and statistical analysis into a unified evaluation model. This multidimensional approach provides practical guidance for software quality assessment, continuous system improvement, and evidence-based decision-making in MSME information systems. Future research may extend this framework by applying larger and more diverse datasets, evaluating information systems from other service-oriented sectors, and integrating Artificial Intelligence (AI)-based analytics or predictive models to further enhance software performance evaluation and decision support.

Acknowledgment

The authors would like to express their sincere gratitude to the Master of Computer Science Program for its academic guidance and continuous support throughout this research. The authors also gratefully acknowledge the participating Digital Laundry MSME for providing access to real operational transaction data and valuable practical insights that made this empirical study possible.

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