HEURISTIC
Vol. 23, No. 1, April 2026
ISSN(p) 1693-8232
ISSN(e) 2723-1585

Critical Waste Reduction in Flexible Packaging Printing Process Using Lean-DMAIC Approach

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Article history:
Received: 24 April 2026
Accepted: 2 July 2026
Published: 3 July 2026

Keywords:
Flexible Packaging;
Lean DMAIC;
Printing Process;
Process Improvement;
Waste Reduction

ABSTRACT

The printing process in flexible packaging manufacturing is highly sensitive to operational inefficiencies, as it involves machine setup, color adjustments, material handling, inspection activities, and coordination across departments. Inefficiencies in this process may lead to defects, work-in-process accumulation, increased waiting time, and reduced performance of the production flow. This study aims to identify, prioritize, and reduce critical waste in the printing process of a flexible packaging manufacturing system using the Lean-DMAIC approach. A quantitative case study was conducted using process flow, cycle time, lead time, production, and waste occurrence data collected from January to December 2025. In the define stage, Value Stream Mapping (VSM) was used to describe the production flow and identify process inefficiencies. In the measure stage, seven types of waste were quantified and prioritized using Pareto analysis. The analysis stage used Root Cause Analysis (RCA) and Failure Mode and Effects Analysis (FMEA) to identify root causes and assess risk levels using the Risk Priority Number (RPN). The results show that defects, inventory, and waiting are the dominant wastes, contributing to approximately 80% of total waste. Defects have the highest RPN value of 567, indicating the most critical problem. The proposed improvement actions reduced defect waste from 13.20% to 6.15%, inventory waste from 11.25% to 4.30%, and waiting waste from 6.49% to 3.95%. These findings indicate that integrating Lean-DMAIC, VSM, Pareto analysis, RCA, and FMEA provides a structured, effective approach to reducing critical waste in flexible packaging printing operations.

INTRODUCTION

The development of an increasingly competitive manufacturing industry requires companies to maintain product quality while improving the efficiency of their production processes. This demand is also very relevant in the flexible packaging industry, as the sector must consistently meet customer specifications, maintain packaging visual quality, and maintain delivery reliability in a dynamic production environment. In this context, process improvement efforts are a fundamental need to enable the company not only to meet market needs but also to maintain its operational competitiveness [1], [2].

In a flexible packaging production system, the printing process is one of the most critical stages because it conveys product information and shapes the packaging's

appearance. This process is also prone to inefficiencies because it involves machine setup, color adjustment, register stabilization, print inspection, material transfer, and coordination between parts before and during the process. These characteristics make the printing process sensitive not only to quality defects but also to disruptions in process flow and non-value-added activities [2], [3].

One widely used approach to improve this condition is lean manufacturing, which focuses on reducing waste, improving process flow, and strengthening value-added activities. In the packaging industry, a lean approach has been used to improve operational performance through tools such as value stream mapping, standardized work, visual management, and control of non-value-added activities [4]. Thus, this approach remains relevant for analyzing waste in the printing process, which involves extensive interactions among machines, operators, materials, and information flows [3].

However, recent studies on flexible packaging have mostly focused on material sustainability and end-of-life management, including the development of sustainable materials, recyclability challenges in multilayer packaging, and barriers to the circular economy in flexible plastic packaging [5], [6], [7], [8]. These studies show that environmental and post-use issues have received considerable academic attention. At the same time, several studies have started to discuss the adoption of lean, green lean, and six sigma practices in flexible packaging and related manufacturing sectors [3], [5]. However, these studies generally discuss process improvement at a broader organizational or operational level. In contrast, specific analysis of critical waste in the printing process remains limited.

The printing process in flexible packaging has operational characteristics distinct from those of other production stages. It requires accurate machine setup, color adjustment, register control, material transfer, print inspection, and coordination between production, quality control, R&D, PPIC, and customers. In practice, these activities may create several types of waste, especially defects, work-in-process inventory, and waiting time. Defects may occur due to unstable process settings and inconsistent color control. Inventory may increase when printed materials cannot be processed further due to delivery or scheduling uncertainty. Waiting may occur when operators must wait for product standard approval or confirmation from related departments. Therefore, the main problem addressed in this study is the lack of a structured approach to identify, prioritize, and reduce critical waste in flexible packaging printing operations.

Based on this problem, this study focuses on reducing critical waste in the printing process of a flexible packaging company using the Lean-DMAIC approach. In this study, DMAIC is used as a systematic framework to map process conditions, measure waste, determine improvement priorities, identify root causes, and formulate corrective actions. This study offers two main contributions. First, from a methodological perspective, this research integrates VSM, seven waste measurements, Pareto analysis, RCA, and FMEA within the Lean-DMAIC framework to systematically identify and prioritize critical waste. Second, from a practical perspective, this study provides empirical evidence on how targeted improvement actions based on root cause and risk prioritization can reduce defects, inventory, and waiting in flexible packaging printing operations.

MATERIALS AND METHODS

This study uses a case study approach with a quantitative descriptive design to examine critical waste in the printing process in flexible packaging companies. The

research framework was prepared using the Lean-DMAIC approach, which consists of the stages of define, measure, analyze, improve, and control [1], [6]. In this study, DMAIC is used as a systematic framework to map process conditions, measure waste, determine repair priorities, trace the root causes, formulate corrective actions, and evaluate the sustainability of repair results.

The objective of the research is to increase the efficiency of the printing process in the flexible packaging production system. The data used includes process flow data, cycle time, lead time, production data, historical waste data, and other supporting operational information related to the production process. The observation period ran from January to December 2025. Data collection is conducted through direct observation in the production area, interviews with relevant personnel, and the review of internal company documents, such as production reports and waste records.

The overall research procedure is presented in Figure 1. The flowchart illustrates the study sequence, starting with data collection, process condition mapping, waste measurement, priority waste determination, root cause and risk analysis, improvement formulation, and control evaluation. This flowchart was developed to clarify how each stage of the Lean-DMAIC framework is connected to the research tools used in this study.

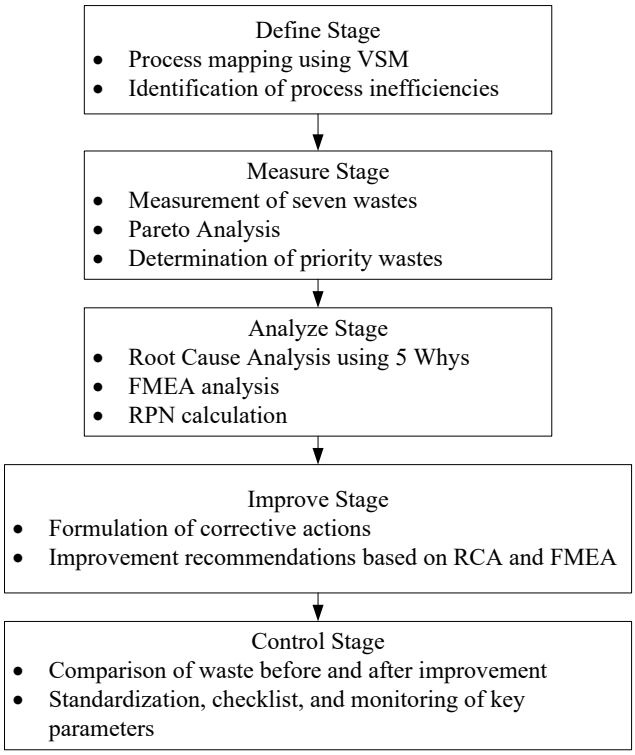


Figure 1. Research methodology flowchart

In the define stage, the research is focused on identifying actual process conditions and determining the scope of the problem in the printing process. Process mapping is carried out using Value Stream Mapping (VSM) to describe material and information flows between workstations and to identify lead time and cycle time at each process stage[7]. This stage aims to provide a comprehensive overview of existing conditions and identify process points that could lead to inefficiencies.

In the measure stage, the research measures all types of waste generated during the production process. Waste identification is a concept in lean manufacturing: overproduction, waiting, transportation, overprocessing, inventory, motion, and defects

[8]. Each waste category was measured using operational data during the observation period to determine its contribution to process inefficiency. The waste value obtained is then analyzed using a Pareto chart to sort waste from most dominant to least dominant, so that the priority waste can be determined and the focus of the next stage [9].

In the analysis stage, the selected priority waste is further analyzed to determine the main cause and risk level. Root Cause Analysis (RCA) is used to trace the root causes of problems in a structured manner, thereby identifying the main triggers of waste[10], [11]. Furthermore, Failure Mode and Effects Analysis (FMEA) is used to assess the risk level of each failure mode based on three parameters, namely severity, occurrence, and detection [12]. These three parameters are then multiplied to obtain a Risk Priority Number (RPN), which is used to determine the priority order of handling [13]. Thus, the analysis stage not only explains why waste occurs, but also indicates which problems are more urgent to fix.

During the improve stage, corrective actions are compiled based on the RCA results and prioritized according to the RPN values from the FMEA. Proposed improvements aim to reduce the likelihood of failure recurrence, minimize non-value-added activities, and improve process consistency in printing operations. Because the focus of this article is on practical operational improvements, the actions outlined are presented as specific responses to critical waste rather than general recommendations.

At the control stage, the study evaluated whether the proposed improvements could support more sustainable process performance. Evaluation is carried out by comparing waste conditions before and after repair, with process control through work standardization, the use of checklists, and monitoring of key parameters in the printing process [14]. This stage aims to ensure that corrective actions do not stop at a momentary correction but become part of the ongoing process control.

Overall, the study integrates VSM, seven waste measurements, Pareto, RCA, and FMEA diagrams into the Lean-DMAIC framework to provide a structured analysis basis for identifying, prioritizing, and reducing critical waste in the printing process in the flexible packaging industry. Thus, the methodology of this research is designed to support the article's main focus, namely the reduction of critical waste in the printing process, rather than solely the application of DMAIC as a method.

RESULTS AND DISCUSSIONS

At the define stage, the process mapping using Value Stream Mapping (VSM) shows that the flexible packaging production flow starts at the material warehouse and continues through printing, rewinding, laminating, aging room, slitting, final inspection, and packing before the product is stored in the finished goods warehouse. These results confirm that the printing process is part of an interconnected system, so that the inefficiencies that arise are influenced not only by the activity on the printing machine but also by the stages before and after.

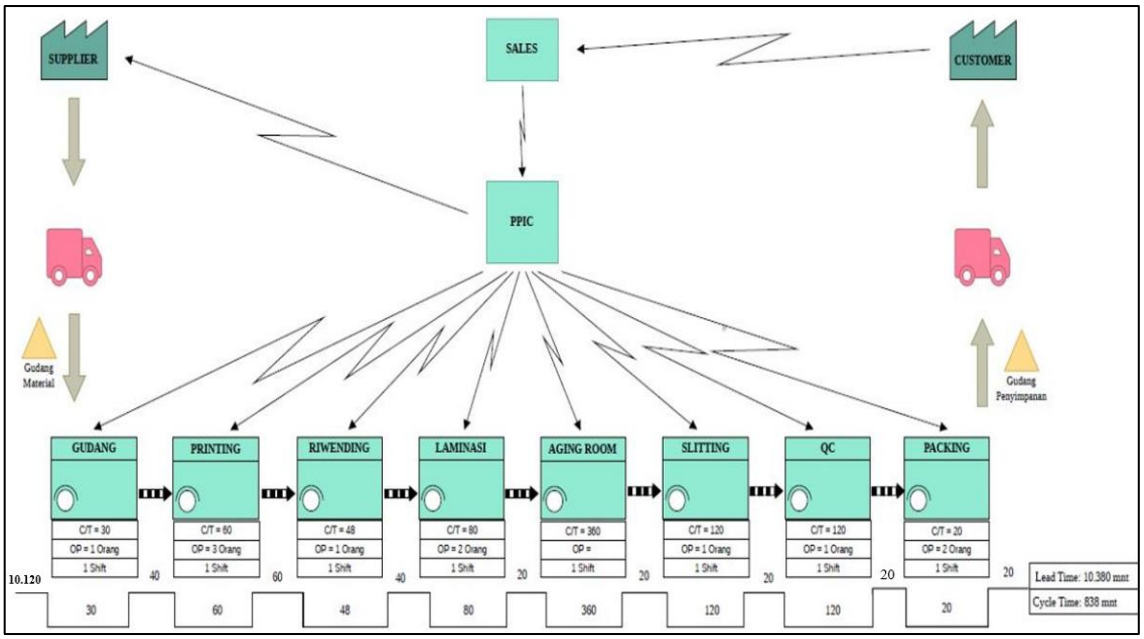


Figure 2. Value Stream Mapping (VSM) in the flexible packaging production process

Based on Table 1, the total cycle time of the production process is 838 minutes. The longest processing time is in the aging room at 360 minutes, followed by slitting and final inspection at 120 minutes each, and lamination at 80 minutes. Meanwhile, the printing process has a cycle time of 60 minutes and involves three operators, the highest number among the stages. These findings suggest that although printing is not the longest-running process, it remains a critical point because it involves more intensive operational interactions.

Table 1. Workforce and Processing Time at each stage

No	Stages	Description	Cycle Time (C/T) (Minutes)	Number of Operators (workforce)
1	Material Storage	Materials from raw warehouses are sent to production	30	1
2	Printing	Printing machine with a speed of 200 meters/minute	60	3
3	Rewinding	Rewinding process with a speed of 250 meters/minute	48	1
4	Laminating	Printing material lamination process with a speed of 150 meters/min	80	2
6	Aging Room	Aging room laminated	360	-
7	Slitting	Slitting process with a speed of 100 meters/min	120	1
8	Final Inspection	Check the results before sending them to the customer	120	1
9	Packing	The process of packing the finished materials before sending them to the customer	20	2
		Cycle Time	**838**	

Furthermore, Table 2 shows that completing a single order of 12,000 meters requires a much longer lead time than the cycle time. The largest lead time component

comes from the delivery of raw materials from suppliers for 8,640 minutes, followed by the flow of order information from sales/customers to PPIC for 1,440 minutes. It shows that the system inefficiencies are not only caused by the production process on the factory floor, but also by supply delays and the length of information flow before production begins. Thus, the opportunity for improvement lies not only in operational activities but also in reducing waiting times and strengthening coordination between parts.

Table 2. Lead time for the flexible packaging process with an order of 12,000 meters

No	Process Stages	Description	Lead Time (Minutes)
1	Sales/Customer to PPIC	Order info from sales/customer to job order drop	1440
2	Supplier	PPIC orders raw materials from suppliers	40
3	Delivery of Raw Materials from suppliers	The maximum delivery of raw materials from suppliers is 6 working days	8640
4	Printing	Delivery of raw materials to the printing process	40
5	Rewinding	After the printing process, the rewinding process continues	60
6	Dry/Extrusion	Wait for the dry lamination process	40
7	Aging Room	The results of the lamination are left alone and placed in the aging room	20
8	Slitting	After the aging room process is ventilated, it proceeds to the slitting process	20
9	Final Inspection	Final Inspection/QC checking	20
10	Packing	Packaging of products in cartons	20
11	Finished goods warehouse	The packing results are stored in the warehouse, so waiting for the delivery schedule	20
		Total Waktu	**10080**

In the measure stage, measurements were taken of seven types of waste in the printing process: overproduction, waiting, transportation, overprocessing, inventory, motion, and defects. The results of the measurement, summarized in Table 3, show that waste levels are not evenly distributed. The percentages for each waste are 5.10% for overproduction, 9.03% for waiting, 0.28% for transportation, 2.05% for overprocessing, 10.97% for inventory, 1.44% for motion, and 15.34% for defects.

Table 3. Summary of the results of seven waste measurements in the printing process

No	Waste	Occurrences
1	Defect	15,34%
2	Inventory	10,97%
3	Waiting	9,03%
4	Overproduction	5,10%
5	Overprocessing	2,05%
6	Motion	1,44%
7	Transportation	0,28%

These results show that the largest waste in the printing process is due to production defects, the buildup of work in process, and waiting time along the process flow. In contrast, transportation and motion still appear, but their contributions are relatively small. Thus, the main problem of the printing process concerns not only the quality of the output, but also the continuity of the process flow and the efficiency of work coordination.

To determine the focus of repair, the waste measurement results were then analyzed using a Pareto diagram. Based on Figure 3, the three main wastes are defects, inventory, and waiting, with contributions of 35%, 25%, and 20%, respectively. Cumulatively, these three represent 80% of the total waste identified.

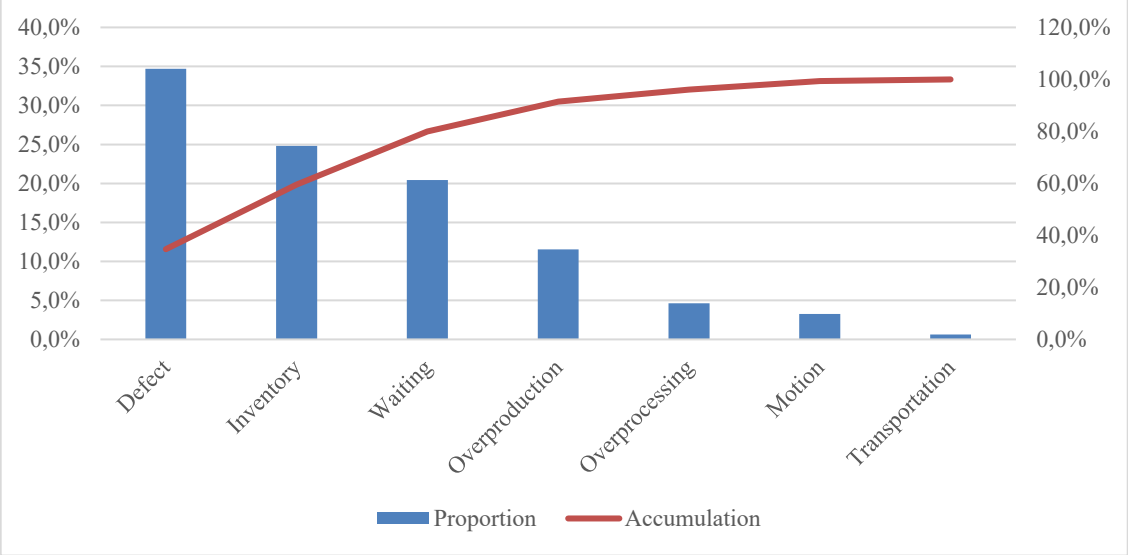


Figure 3. Pareto Diagram of the Waste Occurrences

These findings show that not all waste needs to be treated with the same intensity. In the printing process, defects are the main problem because they directly affect print quality, while inventory and waiting cause disruptions in the process flow and weak synchronization between parts. Therefore, further analysis focuses on the three dominant waste streams.

The analysis stage was carried out using Root Cause Analysis (RCA) and Failure Mode and Effects Analysis (FMEA). The RCA results in Table 4 show that waste defects, especially misprints and colors outside the standard, are mainly caused by operators still performing initial settings by feel, leading to inconsistent control of machine parameters. In the waste inventory, the main cause is the accumulation of work in process due to delays in follow-up processes, especially due to partial deliveries and the lack of formal commitments regarding delivery schedules. Meanwhile, waste waiting is mainly caused by operators waiting for confirmation of process standards, as there is no clear flow or SOP for the General Packaging Standard (GPS).

Table 4. Root Cause Analysis (RCA) results using 5 Whys

Waste	Defect		Inventory	Waiting
Sub Waste	Misprint	out-of-range colors	WIP stacking of the printing process	Machine downtime
Illustration				-
Why 1	The operator at the initial setting of the road uses a feeling		Printing is pending due to a partial send request.	The operator is awaiting

Waste	Defect	Inventory	Waiting
			confirmation of the standard process for the product.
Why 2	The parameters of the printing machine and the production process are not yet under control.	There are changes in customer needs or customer-side obstacles.	The General Packaging Standard (GPS) is still unclear, so it needs to be confirmed first.
Why 3	There is no clear standard operating procedure (SOP) in the initial process of the road.	There is no definite delivery schedule confirmation system	There is no standard / SOP regarding the specification of the product's GPS flow
Why 4	-	No formal commitment regarding the delivery schedule.	-
Why 5	-	-	-

Furthermore, Table 5 shows that the highest RPN value is found in waste defects at 567, followed by inventory at 216 and waiting at 72. This value shows that defects are the most critical problems because they have the highest impact and the least control. However, inventory and waiting still need improvement, as they directly affect the smooth flow of the process. These findings show that the main problems in the printing process are not only technical issues with machines but also related to work standardization, information certainty, and coordination between parts.

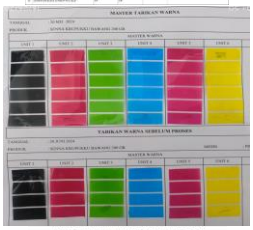
Table 5. Results of Failure Mode and Effects Analysis (FMEA)

Waste	Sub Waste	Effect	S	Cause	O	Control	D	RPN
Defect	Misprint and out-of-range colors	Discarded products	9	There is no clear standard operating procedure (SOP) in the initial process of the road.	9	Checking misprint results and colors outside the range manually, and at the end of the printing process	7	567
Inventory	WIP stacking of the printing process.	Raw material buildup	6	No formal commitment regarding the delivery schedule.	6	Checking manually means the WIP results that have not been processed further.	6	216
Waiting	Machine downtime	Operator and waiting machine	1	There is no standard / SOP regarding the specification of the product's GPS flow	8	Manual proof results check per customer request.	9	72

In the improvement stage, actions focus on three prioritized critical wastes. For waste defects, improvements focus on adding an initial process checklist and color pull

reference parameters to reduce setting variations. For waste inventory, actions focus on adding a formal statement on the maximum delivery schedule limit with customers to prevent WIP from being held up for too long. Meanwhile, for waste waiting, improvement proposals focus on adding guidelines to set maximum approval deadlines from the R&D department and customers.

Table 7. Summary of improvement recommendations

No	Waste	Sub Waste	Recommendation	Illustration
1	Defect	Misprint and out-of-range colors	Addition of a checklist at the beginning of the printing process setting.	
			Addition of color pull reference parameters at the beginning of the printing process setting.	
2	Inventory	WIP stacking of printing processes.	Addition of a statement of the maximum limit of delivery schedules with customers.	
3	Waiting	Machine downtime	Addition of maximum time limit guidance for ACC from RND and the customer	-

In the control stage, the repair results were evaluated by comparing pre- and post-implementation conditions. Based on Table 8, waste defects decreased from 13.20% to 6.15%, waste inventory decreased from 11.25% to 4.30%, and waste waiting decreased from 6.49% to 3.95%. This decrease shows that the formulated corrective actions are aligned with the identified root cause and have a real impact on the printing process.

Table 8. Comparison of waste before and after improvement

No	Waste	Sub Waste	Before Improvement	After Improvement	Efficiency
1	Defect	Misprint and out-of-range colors	13,20%	6,15%	7,05%
2	Inventory	WIP stacking of the printing process.	11,25%	4,30%	6,95%
3	Waiting	Machine downtime	6,49%	3,95%	2,54%

The results show that defects, inventory, and waiting are the dominant wastes in the flexible packaging printing process. This finding indicates that the main inefficiencies in the printing process are not only related to product quality, but also to process flow and coordination between departments. The dominance of defects is closely related to unstable machine settings, manual color checking, and the absence of a clear standard at the beginning of the printing process. Meanwhile, inventory and waiting are related to uncertainty in delivery schedules, WIP accumulation, and delays in product standard approval. These findings align with those of Habib et al. [1], who found that lean manufacturing can improve operational performance in a labeling and packaging plant by identifying waste and improving production flow. The similarity lies in the use of lean principles to reduce non-value-added activities in packaging-related operations. However, the present study differs in that it focuses specifically on the printing process in flexible packaging and combines seven waste measurement methods, Pareto analysis, RCA, and FMEA within the Lean-DMAIC framework. Therefore, this study provides a more focused process-level analysis rather than only evaluating general operational performance.

The results also support the study by Jadhav and Ekbote [2], which showed that lean techniques can be applied to packaging machines to optimize cycle time and improve process efficiency. Both studies emphasize the importance of improving operational activities at the machine and process level. However, while their study focused mainly on cycle time optimization, the present study identifies critical waste more broadly by considering defects, inventory, and waiting. This difference shows that efficiency improvement in flexible packaging printing should not be measured solely by processing time, but also by quality losses, WIP accumulation, and approval delays. Regarding flexible packaging, the findings are consistent with those of Farrukh et al. [3], who highlighted that managerial practices, coordination, and operational control strongly influence green-lean-six sigma adoption in the flexible packaging industry. Both studies recognize the importance of structured improvement practices in flexible packaging operations. However, Farrukh et al. [3] discussed the adoption of green-lean-six sigma from a broader managerial perspective. At the same time, this study provides empirical evidence at the printing process level. Thus, this research complements previous flexible packaging studies by showing how Lean-DMAIC can be translated into specific improvement actions, such as initial-setting checklists, color-pull reference parameters, delivery-schedule commitment, and approval-deadline guidelines.

The use of RCA and FMEA in this study also strengthens previous research on risk-based waste reduction. Sutrisno et al. [12] emphasized that FMEA can be used to prioritize lean waste risks, while Ince et al. [13] showed that FMEA-supported improvement can help identify and prioritize sustainability and performance problems in manufacturing. The similarity lies in the use of risk prioritization to determine which problems should be handled first. However, the present study applies FMEA directly to critical waste in the flexible packaging printing process. It identifies defects as the most critical waste, with an RPN of 567. It provides a clearer basis for selecting improvement priorities. After the improvement actions were formulated and evaluated, defect waste decreased from 13.20% to 6.15%, inventory waste decreased from 11.25% to 4.30%, and waiting waste decreased from 6.49% to 3.95%. These results support previous Lean-DMAIC studies that show the effectiveness of structured improvement stages in reducing process inefficiencies [6], [14]. However, the contribution of this study lies in its specific application to flexible packaging printing operations, where defects, WIP accumulation, and approval waiting are connected to operator dependency, process standardization, and

interdepartmental coordination. Therefore, this study extends previous research by demonstrating that Lean-DMAIC can be used not only as a general improvement framework but also as an integrated tool to identify, prioritize, and reduce critical waste in a specific printing process.

CONCLUSION

This study shows that waste in the printing process of flexible packaging manufacturing is not only related to print quality, but also to process flow, work-in-process accumulation, and coordination between departments. Based on the Lean-DMAIC approach, seven waste measurements and Pareto analysis identified defects, inventory, and waiting as the dominant critical wastes, contributing to approximately 80% of the total waste. RCA and FMEA further showed that these wastes were mainly caused by weak initial process standardization, uncertainty in delivery-schedule commitments, and unclear approval flows for product standards.

The improvement actions derived from the root cause and risk priority analysis reduced defect waste from 13.20% to 6.15%, inventory waste from 11.25% to 4.30%, and waiting waste from 6.49% to 3.95%. These results indicate that checklist implementation, color parameter references, delivery schedule commitment, and approval deadline guidelines can improve the consistency and flow of the printing process.

The findings of this study support previous research showing that lean-based improvement and Lean-DMAIC can reduce process inefficiencies in manufacturing and packaging operations. However, this study differs from previous research by focusing specifically on the printing process in flexible packaging, where defects, inventory, and waiting are strongly influenced by operator dependency, process parameter control, and interdepartmental coordination. The main contribution of this study lies in integrating VSM, seven waste measurement, Pareto analysis, RCA, and FMEA within the Lean-DMAIC framework to identify, prioritize, and reduce critical waste in a more structured, process-specific manner. Therefore, the proposed approach can serve as a practical reference for flexible packaging companies facing similar waste problems in printing operations.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI tools were used to create research ideas, research design, data, analysis, results, discussion, or conclusions in this manuscript. The authors only used Grammarly as a language-checking tool to support grammar checking, spelling correction, punctuation improvement, and sentence clarity. All language suggestions were carefully reviewed and validated by the authors. The authors take full responsibility for the content, accuracy, originality, and scientific integrity of the manuscript.

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