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Harnessing Lean and FMEA techniques to eliminate waste and enhance performance in poultry processing

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ABSTRACT

This study integrates lean manufacturing and failure mode and effects analysis (FMEA) to identify and mitigate production waste and risk in a poultry processing facility. The study identifies dominant waste types, waiting, motion, and over-processing by applying value stream mapping (VSM), fishbone diagram, and FMEA. The highest risk priority number (RPN) of 210 was found in the chilling process, indicating a critical need for corrective action. Implementing proposed improvements such as layout redesign and chiller capacity expansion resulted in measurable gains: a 5.8% reduction in labor costs, a 2.3% drop in operational expenses, and a 1.2% decrease in raw material waste. Compared to prior studies that applied Lean or FMEA separately, this research offers a structured Lean–FMEA framework tailored for the poultry industry. This model enhances efficiency while ensuring food safety and serves as a replicable method for similar industries.

1. INTRODUCTION

Poultry processing is one of the fastest-growing segments in the food industry, particularly in developing countries like Indonesia. The demand for affordable animal protein, especially chicken meat, continues to increase in line with population growth and dietary changes. However, this industry faces significant operational challenges such as fluctuating production volumes, strict hygiene standards, and perishable raw materials that require rapid and precise handling. These constraints often lead to various forms of waste, ranging from excess motion and waiting time to equipment failures and product rework, which directly impact productivity, cost, and food safety compliance. Poultry processing companies must adopt systematic approaches to reduce non-value-added activities and improve process reliability to stay competitive. Lean Manufacturing has been widely recognized as an effective practice for eliminating waste and improving flow efficiency in production environments. Meanwhile, FMEA is a structured risk management tool to identify and prioritize potential process failures before they result in significant losses. However, in many cases, these two approaches are implemented separately, and few studies have explored their integration, especially in high-risk food sectors such as poultry processing [1], [2], [3].

Recent literature shows growing interest in combining Lean-FMEA as a hybrid framework to identify waste and evaluate the risks associated with each failure point. This integration is particularly relevant for industries like poultry processing, where failure at any point, whether due to delay, contamination, or equipment malfunction, can have cascading effects. However, most existing research focuses on general manufacturing or automotive industries, with limited application in the poultry context. Moreover, few studies offer a structured roadmap or framework for applying Lean–FMEA in a real-world poultry facility with measurable impact on performance. Lean Manufacturing is widely applied to streamline operations by reducing non-value-added activities and improving process efficiency. Its application in poultry processing remains limited and underexplored in integrated frameworks. Lean Manufacturing identifies seven primary types of waste: transportation, Inventory, motion, waiting, over-processing, overproduction, and defects. This study begins by mapping the overall production process using Big Picture Mapping and VSM to visualize both material and information flows. By categorizing each activity into these waste types, the root causes of inefficiencies can be explored further using Fishbone Diagram analysis [4], [5], [6]. The initial study will determine the direction of new policies to improve the efficiency of machines, labor, and raw materials and reduce production costs [7], [8].

One of the main issues in the production process is the presence of waste, which can appear in various forms such as defective products, overproduction, and unnecessary processing. These types of waste negatively affect productivity, increase costs, and lead to business losses. Lean Manufacturing helps companies address these inefficiencies by identifying and eliminating waste. Lean Manufacturing offers a systematic approach to eliminate non-value-added activities by identifying and minimizing the seven common types of waste: transportation, Inventory, motion, waiting, over-processing, over-production, and defects. Each flow and the flow of production process activities will be categorized according to the seven waste tables. By recognizing the production activities classified in the seven wastes, a fishbone diagram analysis can be used to identify three interrelated high-risk areas [9], [10]. Lean Manufacturing maximizes time efficiency in the production process while reducing or eliminating the possibility of waste. Based on the identified issues, this research seeks to identify types of waste in the poultry processing production flow, prioritize waste types based on risk level using FMEA, and map material and information flows to propose effective waste reduction strategies. While existing studies have explored the use of Lean tools such as SMED in the garment industry or Lean Six Sigma in food manufacturing, they focus on large-scale industries and rarely examine poultry processing.

Moreover, prior research typically applies Lean-FMEA separately, lacking a combined framework that integrates waste analysis with structured risk prioritization. Therefore, a clear gap exists in applying an integrated Lean-FMEA model to poultry processing, where high variability in raw materials and strict hygiene standards demand customized solutions [11]. In this case, the company must play an active role in continuously improving and controlling waste. Continuous improvement and control can be done by looking at data analysis, a systematic way to prevent equipment damage, defective products, and labor inefficiency. Improvement and control in this research use five methods: Big Picture, VSM, Lean Manufacturing, Fishbone Diagram, and FMEA, which explain the cause and effect of the risk of waste, risk control, and improvement [12].

This study addresses that gap by integrating Lean-FMEA into a unified framework for the poultry processing industry. The novelty of this study lies in the structured integration of Lean-FMEA within the poultry processing industry, a sector characterized by high variability, short production cycles, and limited automation. While prior studies have applied Lean or FMEA separately in large-scale manufacturing, this research combines both approaches into a unified framework that identifies waste and prioritizes risk in a practical, measurable way. The expected outcome is reduced production waste and risk, leading to higher efficiency, lower costs, and better product quality. Although recent research, such as Ugural *et al*. [13] and Adley [14], have applied Lean approaches in sustainable building operations and food safety analysis, respectively, none have specifically addressed Lean–FMEA integration in the poultry processing context. Their focus remains on either waste identification or food safety monitoring, without integrating structured risk prioritization. This study fills that gap by presenting a novel Lean-FMEA framework that detects waste and prioritizes critical failure modes in poultry operations, where hygiene and speed are essential. Theoretically and practically, it contributes by validating the approach in a real-world slaughterhouse with measurable efficiency gains.

The main contributions of this study are:

1) Introducing an integrated Lean-FMEA approach for waste reduction and risk mitigation in poultry processing
2) Identifying and categorizing waste through the seven waste analysis and fishbone diagrams
3) Prioritizing corrective actions based on RPN values from FMEA analysis.

The structure of this paper is as follows: Section 2 presents the literature review, Section 3 discusses the research methodology, Section 4 provides the results and discussion, and Section 5 concludes the paper with key findings and future research directions.

This research offers a novel contribution by integrating Lean-FMEA into a unified framework tailored to the poultry processing industry. While previous studies have applied these tools separately in large-scale manufacturing sectors, their combined application in poultry, especially with measurable efficiency gains, remains scarce. The structured methodology proposed here identifies waste and evaluates risk priority to guide targeted improvements.

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This study proposes an integrated Lean–FMEA approach, where Lean tools are used to map and reduce waste, and FMEA is applied to prioritize risks that significantly impact operational efficiency.

The novelty of this research lies in the structured integration of Lean Manufacturing and Failure Mode and Effects Analysis (FMEA) into a unified improvement framework specifically designed for the poultry processing industry. While Lean and FMEA have been widely applied as separate approaches in various industries, including automotive, healthcare, and food production, their combined application remains limited, particularly in high-risk and high-variability environments such as poultry slaughter-houses. This study goes beyond traditional implementations by mapping and categorizing waste using Lean tools (VSM and Fishbone Diagram) and prioritizing failure risks using FMEA's Risk Priority Number (RPN) methodology within the same system.

Compared to studies such as Ugural *et al*. [13], which applied Lean principles for sustainability in building management, and Adley [14], which focused on food safety risk assessment using statistical models, this research uniquely combines Lean and FMEA to address operational inefficiencies and critical process risks simultaneously. The resulting Lean-FMEA framework delivers quantifiable performance improvements, including cost savings, risk reduction, and increased process stability, and it offers a replicable model that can be adapted to other food processing sectors. This structured and integrated approach represents a novel contribution to both academic literature and industrial practice in lean-based quality and risk management.

2. RELATED WORK

In the global manufacturing landscape, industries must continuously optimize production efficiency to remain competitive. Several waste reduction methodologies have been widely applied in manufacturing, including Lean Six Sigma, Kaizen, and Total Productive Maintenance (TPM). These approaches to Lean–FMEA in terms of focus, complexity, data requirements, and suitability for the poultry processing environment.

Table 1 summarizes previous studies related to Lean, FMEA, and other production management approaches. The table highlights the methodologies used, their focus areas, key findings, limitations, and relevance to this research. It is evident that most prior studies applied either Lean or FMEA individually in various industries such as garments, manufacturing, and food processing. However, few studies integrated both methods simultaneously, and none specifically focused on the poultry processing sector. This reinforces the research gap this study aims to fill by combining Lean-FMEA to address waste and risk in poultry processing. The integration offers a more comprehensive and structured approach to enhancing operational efficiency.

This study aims to address the gap. Integrating Lean-FMEA has shown potential in a few studies. Ugural *et al*. [13] applied Lean principles to optimize energy use and workflow efficiency in sustainable building operations. Their work demonstrates how Lean tools can enhance resource efficiency and reduce environmental impact. However, their focus was on energy and environmental metrics in buildings, not operational risks in food production environments.

Meanwhile, Adley [14] used FMEA to identify and assess food safety hazards in dairy production. While they effectively mapped risk points using a risk matrix, their work does not integrate process waste analysis or production efficiency concerns. In contrast, this study bridges both approaches by integrating Lean waste mapping and FMEA risk prioritization into a unified model specifically tailored for poultry processing. This sector requires food safety, high production speed, hygiene compliance, and operational cost-efficiency.

Toki *et al*. [11] combined SMED and Lean tools to reduce setup time and waste in the garment industry. Yet, their analysis did not involve risk mitigation. Zhang *et al*. [15] proposed a hybrid Lean-FMEA model in meat processing, which helped identify quality risks and streamline packaging processes. Their study supports the relevance of combining process flow optimization with risk-based prioritization in food industries [8], [11]. Recent studies have explored the application of Lean in the food and poultry industries. Widiyati *et al*. [9] implemented Lean Six Sigma to reduce waste in food processing, highlighting improvements in cycle time and defect rate. However, their research did not integrate risk prioritization through FMEA [16]. FMEA, on the other hand, is commonly used to prevent system failures by calculating RPN based on Severity, occurrence, and detection. Ahmad *et al*. [12] applied FMEA in manufacturing to minimize quality defects, while Dyah Susanti [17] focused on defect control in plywood processing. Both studies, however, did not consider process waste or workflow analysis, making their application context-specific [12], [17]. Despite these advancements, there remains a lack of studies applying Lean-FMEA integration specifically in poultry processing. The unique characteristics of this industry, including perishable raw materials, fast cycle times, and strict hygiene standards, demand a tailored approach. This research seeks to address that gap by developing a comprehensive model that combines Lean tools for waste identification and FMEA for risk prioritization, with direct application in a live chicken processing facility. However, these studies primarily focused on general production environments rather than addressing the specific risks associated with

Table 1. Comparative review on lean and FMEA in manufacturing

Author	Year	Methodology	Focus area	Findings	Limitations	Relevance
Toki *et al*. [11]	2023	SMED, Laen Tools	Garment Industry	Reduced setup times and waste	Focused on the garment industry, no risk analysis	Demonstrates the effectiveness of Lean tools, relevant for identifying waste in poultry processing
Widiwati *et al*.[16]	2024	Lean Six Sigma	Food Manufacturing	Minimized waste in food processing	Did not combine Lean with risk management	Supports the application of Lean to reduce waste in poultry processing
Ahmad *et al*. [12]	2023	FMEA	Manufacturing	Enhanced quality control and defect reduction	Focused on defect minimization, no waste mapping	Validates the use of FMEA for prioritizing risks in poultry processing
Dyah Susanti [17]	2023	FMEA	Plywood Processing	Reduced product defects	Limited to quality control, no Lean integration	Highlights the role of FMEA in improving process quality
Felix Jacquez *et al*. [18]	2021	Lean Manufacturing	Railroad Company	Improved operational efficiency with Lean tools	Limited to new process introduction, no FMEA use	Demonstrates Lean tools on operational efficiency
Liao [19]	2015	EPQ	One stop	Improved efficiency in production and repair	No focus on waste or cost reduction	Provides insights into production efficiency improvements
This Research		Lean, FMEA	Poultry Processing	Reduced waste and costs, enhanced efficiency	Limited to the poultry industry	Combines lean and FMEA for integrated waste and risk management

poultry processing, such as contamination risks, process inefficiencies, and real-time quality assurance. This study builds upon previous research by integrating Lean-FMEA in the poultry processing industry, an approach that remains underexplored. While Lean principles focus on reducing the seven wastes, FMEA prioritizes risk mitigation by identifying failure modes with the highest RPN. The novelty of this study lies in its systematic approach to mapping waste and risks in poultry processing using VSM and fishbone analysis while simultaneously implementing targeted corrective actions based on FMEA findings. By bridging this research gap, this study contributes to the development of a more efficient and sustainable poultry processing model. The findings provide valuable insights for manufacturing companies looking to enhance operational efficiency, reduce waste, and improve overall production quality through a combined Lean-FMEA framework [20].

In the poultry industry, sources of waste often stem from inefficient layout, manual material handling, inconsistent quality control, and delays between processes. To identify and eliminate such inefficiencies, Lean Manufacturing offers several tools and techniques, including VSM to visualize the flow of materials and information, Fishbone Diagram (Ishikawa) to identify root causes of process inefficiencies, and 5S, standard work, and visual control to maintain discipline on the shop floor [21], [22], [23].

While various process improvement frameworks such as Lean Six Sigma, Kaizen, and Total Productive Maintenance (TPM) have been widely implemented across manufacturing sectors, each comes with different focuses and levels of complexity. Lean Six Sigma, for example, emphasizes rigorous statistical analysis through the DMAIC (Define, Measure, Analyze, Improve, Control) cycle, which requires significant data maturity and analytical capacity. On the other hand, Kaizen focuses on continuous incremental improvements through employee engagement, which can be more suitable for culture-driven environments.

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TPM concentrates on equipment maintenance to reduce downtime, a useful approach in highly automated systems. In contrast, the Lean–FMEA integration applied in this study was chosen for its balance between simplicity, practicality, and analytical depth. It allows organizations to identify production inefficiencies using visual tools such as VSM and Fishbone Diagrams, while also assessing the risk of failure modes using RPN scoring. This approach is particularly suitable for poultry processing environments, where automation levels are moderate, and real-time data may be limited. By combining process flow improvement with risk prioritization, Lean–FMEA offers a structured yet adaptable framework for operational enhancement [24], [25], [26], [27], [28], [29].

2.1. Lean manufacturing as a waste elimination practice

Lean Manufacturing, also referred to as Lean Production, is a business philosophy and operational strategy aimed at maximizing value by eliminating waste and improving efficiency. While the two terms are often used interchangeably, Lean Manufacturing emphasizes the holistic system of waste reduction across the organization, whereas Lean Production often refers to the practical implementation on the production floor [30], [31], [32]. Lean Manufacturing focuses on identifying and eliminating non-value-added activities throughout the value stream. The seven common types of waste in Lean are: Transportation – unnecessary movement of products, Inventory – excess raw materials or finished goods, Motion – inefficient movement by workers, Waiting – delays between processes, Over-processing – performing more work than necessary, Overproduction – producing more than needed, and Defects – errors that require rework or scrap [7]. Lean manufacturing fosters a culture of continuous improvement, known as Kaizen, and incorporates concepts like Just-In-Time (JIT), 5S, and Kanban. These are conceptual approaches rather than standalone tools. For poultry processing industries, applying Lean methods can result in reduced processing time, lower defect rates, improved worker productivity, and better resource utilization. Successful Lean implementation requires full organizational commitment and leadership support [33]. The success of Lean implementation relies heavily on the commitment of management. Ensuring that Lean principles are embedded in a company's culture is essential to reap long-term benefits. In chicken processing, this can involve regular training and the involvement of all employees in Lean initiatives. The study reported significant improvements in production efficiency and waste reduction. For chicken meat processing, similar implementations can lead to reduced processing time, lower defect rates, and better resource utilization, ultimately resulting in higher profitability and competitiveness [34]. However, while Lean effectively visualises and removes waste, it lacks a structured approach to assessing the risk of failure or breakdown in each process step.

2.2. Failure mode and effects analysis (FMEA) in risk evaluation

FMEA, on the other hand, is a specific analytical tool used within the broader risk management framework. FMEA systematically identifies possible failure modes in a process, assesses their impact (Severity), how often they occur (Occurrence), and the ability to detect them (Detection). These three criteria are multiplied to obtain an RPN, which helps prioritize the most critical issues for corrective action. FMEA has been widely applied in manufacturing, healthcare, and automotive sectors to ensure operational reliability and reduce costly process interruptions. In poultry processing, FMEA is useful for analyzing critical points such as chilling systems, inspection stations, or conveyor mechanisms that could fail and disrupt production. Nevertheless, when used in isolation, FMEA does not provide a comprehensive picture of value-added versus non-value-added activities across the production stream. It focuses on risks, not on flow efficiency or waste elimination.

Risk Management is a structured practice used to identify, analyze, evaluate, and control risks in business processes. It provides a framework for making informed decisions and taking preventive measures to reduce or eliminate potential disruptions. In manufacturing, effective risk management enhances process stability, ensures compliance with safety and quality standards, and supports operational continuity [35]. Risk management has a systematic flow that starts with risk identification. In the identification, a detailed process is carried out that can cause danger in the flow of activities. The process is carried out by conducting surveys, static data analysis, and interviews with parties related to the flow of an activity. Then, the process carried out after risk identification is the risk analysis process, recognizing every impact that may be caused in a flow of activities.

The next step is risk management, which determines the precautions that can be taken to reduce the impact of existing hazards. The last step is risk communication, which is the delivery of risk details and alternative solutions in the activity flow to management so that it is expected to contribute to reducing hazards in the activity flow. Effective risk management in poultry processing involves optimizing material flow to improve production efficiency, reduce delays, and ensure the availability of materials when needed. Implementing strategic layout design, lean optimization techniques, and robust inventory management practices are critical to mitigating risks associated with material flow disruptions. These measures improve operational efficiency and contribute to better resource utilization and increased profitability in poultry processing operations [15]. In poultry processing, integrating Lean-FMEA allows companies to eliminate waste and anticipate and mitigate risks that could affect quality, safety, and efficiency. For instance, FMEA can be used to identify risks in critical stages such as slaughtering, chilling, or packing, each of which has unique vulnerabilities that may lead to defects or delays if not properly managed [36].

2.3. Integration of lean manufacturing and FMEA

This study integrates Lean-FMEA To effectively reduce waste and enhance operational performance. While Lean Manufacturing focuses on identifying and eliminating non-value-added activities, FMEA complements this by prioritizing potential process failures based on their risk level. Integrating both approaches provides a structured methodology to reduce inefficiencies and anticipate and control failures that may affect quality, safety, or productivity. The combined framework begins with mapping production processes and identifying the seven categories of waste using Lean tools such as VSM and Fishbone Diagrams. Once the root causes of waste are determined, FMEA is applied to evaluate each process step by calculating the RPN, derived from the Severity, occurrence, and detection ratings. This helps prioritize which issues require immediate corrective action. This integration offers a more comprehensive approach than applying Lean or FMEA alone. Lean improves flow efficiency and eliminates visible inefficiencies, while FMEA captures hidden risks that could cause process breakdowns or product defects. In the poultry processing industry, where production involves high speed, strict hygiene standards, and fluctuating raw material quality, this dual approach ensures waste is minimized while process risks are proactively addressed. By combining Lean-FMEA, companies can develop targeted strategies to improve efficiency, reduce costs, and ensure consistent quality. This research provides a replicable framework for other manufacturing sectors facing similar waste and risk management challenges.

Various waste reduction techniques have been applied across different manufacturing sectors. Table 2 compares Lean–FMEA with other common approaches, such as Lean Six Sigma, Kaizen, and Total Productive Maintenance (TPM). The comparison includes their primary focus, complexity level, data requirements, and suitability for poultry processing environments. Based on this comparison, Lean–FMEA offers a practical balance between simplicity and analytical depth, making it highly applicable to poultry operations where waste is critical and statistical capabilities may be limited. This analysis highlights why Lean–FMEA was selected in this study, as it offers a balanced combination of simplicity, risk-based prioritization, and adaptability to mid-level automation systems commonly found in poultry facilities.

Recent advancements in Lean manufacturing emphasize the role of digital technologies in enhancing traditional process improvement frameworks. The emergence of Lean 4.0 or Smart Lean integrates Industry 4.0 tools such as IoT sensors, artificial intelligence (AI), and real-time analytics into Lean practices to improve responsiveness and accuracy in operational decision-making. For example, AI-based predictive maintenance can be used to detect early signs of equipment failure, while IoT-enabled systems allow continuous monitoring of production flow and resource consumption. Integrating these tools with FMEA enhances failure detection and prioritization by providing real-time risk data and reducing subjectivity in scoring [37]. Therefore, the potential synergy between digital tools and Lean–FMEA opens new avenues for smarter, faster, and more resilient waste reduction strategies. Lean-FMEA is associated with operational efficiency and contributes significantly to environmental sustainability. Prior studies have shown that Lean practices such as waste elimination, VSM, and standardization can lead to reductions in energy consumption, water usage, and material waste [38], [39]. Moreover, FMEA can support eco-efficiency by prioritizing risks that cause environmental harm, such as chemical leaks or overuse of utilities. Adopting Lean–FMEA can contribute to greener operations by aligning process improvement with environmental performance goals in the poultry processing industry, where water and energy are used intensively. Integrating such sustainability considerations into future Lean–FMEA models will enhance their relevance in circular economy and ESG-driven manufacturing [40].

Table 2. Comparative analysis of waste reduction methods

Method	Focus	Complexity	Data requirement	Suitable for poultry
Lean–FMEA	Waste reduction + Risk prioritization	Medium	Moderate	High
Lean Six Sigma	Statistical process control + DMAIC	High	High	Medium
Kaizen	Continuous small improvements	Low	Low	High
TPM	Equipment uptime & maintenance	Medium	Moderate	Medium

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2.4. Research gap and study justification

The gap in this study is lack of Lean–FMEA integration studies focused on poultry or other high-risk food processing sectors, absence of a structured and replicable framework for implementing Lean–FMEA in real-world poultry facilities, and limited discussion on the measurable impact of Lean–FMEA on process performance metrics such as lead time, cost, or risk reduction. This study addresses these gaps by developing and testing a Lean–FMEA improvement framework designed for the poultry processing context.

2.5. Conceptual framework

The proposed framework begins with identifying waste using Lean tools such as VSM and the Seven Wastes. Root causes are then analyzed using the Fishbone Diagram. These insights are used to conduct FMEA and calculate RPNs for each failure mode. The prioritized failure modes guide targeted improvement actions that aim to both reduce waste and mitigate process risks.

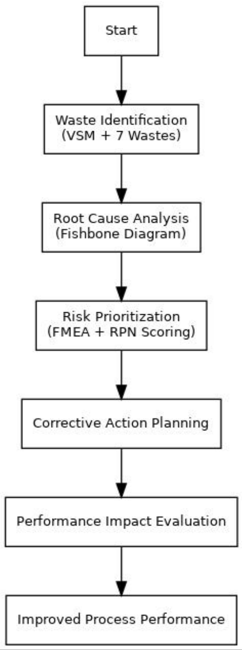

Fig. 1. Conceptual framework

The conceptual framework of this study integrates Lean Manufacturing tools with FMEA to address two key aspects of poultry processing: waste elimination and risk mitigation (Fig. 1). The framework is designed as a structured improvement cycle consisting of the following stages: Waste Identification, using Lean tools such as VSM and the Seven Waste classification, This stage aims to detect non-value-added activities across the production line. Root Cause Analysis, once waste categories are identified, a Fishbone Diagram (Ishikawa) is used to trace root causes, organized by categories such as man, method, machine, material, and environment. Risk Prioritization (FMEA), potential failure modes are analyzed using the FMEA method. Each is scored based on Severity (S), occurrence (O), and detection (D) to calculate the RPN. This prioritization helps determine which problems are most critical. Corrective Action Planning, high-priority failure modes are targeted with specific corrective actions aimed at process improvement and waste reduction. Performance Impact Evaluation, after implementation, changes in performance (such as reduced downtime, increased yield, or cost savings) are measured to validate the framework's effectiveness.

3. RESEARCH METHODS

This study is structured based on three main research objectives. Each objective is addressed with a specific method for data collection and analysis. Accordingly, the methodology and results in the following sections are organized based on these objectives to ensure clarity and coherence. The flowchart (Fig. 2) explains that planning each step in this research is essential to achieve coherent and maximum results. In addition, the flowchart also explains several planned steps that must be taken in the research, starting from literacy studies and problem formulation to detailed data analysis so that conclusions can be obtained that can be a reference in decision-making. Descriptive statistical analysis was used to compare production performance before and after implementing improvement actions, including mean, standard deviation, and variance. This supported the evaluation of Lean–FMEA effectiveness in quantitative terms. This study did not control for external variables such as supplier delays, shifts in demand, or labor availability, which may have indirectly influenced waste levels or process performance.

3.1. Research design

This study employed a case study approach to explore how Lean-FMEA can be integrated to eliminate waste and enhance performance in poultry processing. Both qualitative and quantitative methods were applied to obtain detailed insights into production activities, identify types of waste, and prioritize critical risks. The tools used include the Seven Waste Framework, VSM, Fishbone Diagram, and FMEA.

3.2. Data collection

This study conducted field observations and semi-structured interviews with production staff and managers. Data on production flow, work hours, material handling, and output were collected to classify waste using the seven waste. Each waste type was identified in relation to specific processes along the production chain. Interviews were structured and tiered, as they focused on gathering important information during data collection through interviews. The researcher also used a deliberate selection process to identify key informants who could provide more extensive information.

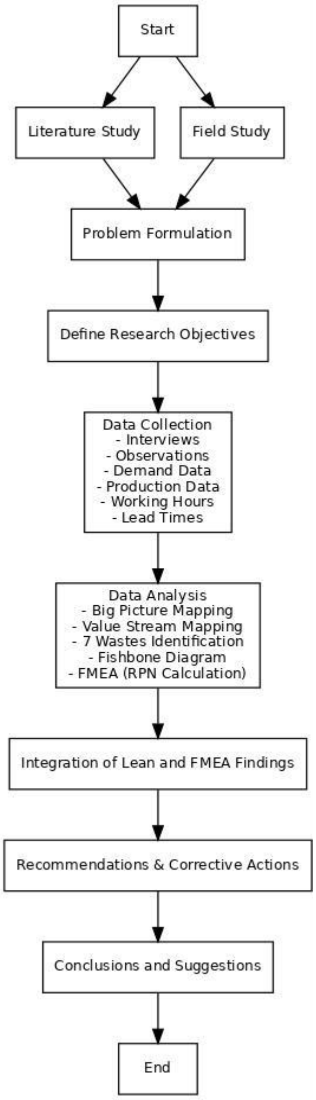

Fig. 2. Flow of research

This study's participants were selected using a purposeful sampling strategy, explicitly targeting individuals recognized as experts in their respective professions. Interviews were conducted with informants who met specific criteria to ensure the completeness of the research data. These criteria included being permanent employees with a minimum of five years of service, having a comprehensive understanding of the work process, and having a minimum position of section head directly related to the production process. Meetings were conducted face-to-face to collect information from all informants.To fulfill the above criteria, five informants were obtained as a reference for research conducted on the production process of the chicken slaughterhouse company, including the Head of Unit, who explained the overall workflow in the work unit and the connected workflow in each department. The National Head of PPIC explains the company's overall work planning and strategies to achieve the required production targets. The Head of the PPIC Unit explains the detailed planning needed in the production process. The Head of Production explains the workflow of initial production, sorting raw materials, and providing labor to package finished products ready to be sent to consumers. The Head of Quality Control explains the flow of product quality control that goes hand in hand with the production process so that the finished product can meet predetermined standards.

This data collection, conducted in interviews, is data related to the flow of activities in production. This process was carried out by verifying the validity and credibility of the data through field research. The initial stage of data collection was done by conducting interviews. Interviews were structured and tiered, as they focused on gathering important information during data collection through interviews. The researcher also used a deliberate selection process to identify key informants who could provide more extensive information. This study's participants were selected using a purposeful sampling strategy, explicitly targeting individuals recognized as experts in their respective professions. The observation process starts with consumer requests collected by the marketing department, which the PPIC department will then process to calculate the need for raw materials, labor, and other supporting materials needs. The calculation process in the PPIC department is also an initial reference to determine the quality and quantity of production that the production department will achieve. The pre-production process requires raw materials and supporting materials to be collected by the purchasing department.

3.3. Lean-FMEA analysis procedure

The Lean-FMEA analysis procedure are:

Step 1: Big Picture Mapping and VSM were used to visualize the production flow.

Step 2: Seven Wastes analysis categorized process inefficiencies.

Step 3: Fishbone diagrams identified root causes of major wastes.

Step 4: FMEA was applied to prioritize risk, scoring failure modes by Severity, Occurrence, and Detection to generate RPN.

Step 5: Corrective actions were developed based on RPN scores.

3.4. Mapping production flow and waste points

This objective was addressed using VSM and Fishbone Diagrams. VSM was employed to map the entire production process from material input to finished product. The process was analyzed to locate

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high-waste areas, especially those contributing to delays, bottlenecks, or resource overuse. A Fishbone Diagram was developed to identify possible causes of waste based on categories such as manpower, method, machine, material, and environment. Each activity flow is recorded in detail and then categorized based on the level of risk that can occur and classified based on the level of waste that exists. Data collection also uses the field observation method directly during the production process within one month. Field observations are conducted to determine the activities carried out in the pre-production to post-production process. Field observations are also used to see the match between interview data and the reality in the field. Example: If workers spent time looking for crates, it was classified under motion waste. If products waited in cold storage due to insufficient temperature, it was categorized as waiting waste.

3.5. Risk prioritization using FMEA

This objective FMEA was used to prioritize process risks that could affect productivity and quality. Data from the VSM and fishbone analysis were used to identify failure modes. Each failure was assessed using the RPN, which was calculated by multiplying the S × O × D. The scoring was performed independently by three assessors and finalized through consensus to ensure reliability.

3.6. Data analysis

The study focused specifically on internal production processes from live bird reception, slaughtering, chilling, cutting, and packaging excluding upstream (breeding, procurement) and downstream (distribution, customer service) activities. The Lean-FMEA integration was applied to analyze waste and operational risks over a one-month observation period. The model developed may require adjustments when implemented in other facilities due to differences in scale, technology, labor systems, or automation levels. Limitations of this study include the use of qualitative interviews may introduce subjectivity, though triangulation was applied, the scope is limited to one production line and does not reflect company-wide integration, and statistical data is descriptive; further inferential analysis could strengthen impact assessment. The initial stage in data analysis is to record production activities in detail and then categorize potential waste and potential risks. Set parameters to measure how much impact each waste has. Using Big Picture Mapping and VSM, the researchers mapped out the material flow, information flow, and production lead time. This allowed for a comprehensive view of the value stream [7]. Each production activity was categorized into one of the seven Lean wastes. To ensure consistency, the categorization used standardized Lean waste definitions from established literature [7]. The findings of the seven categories of waste reveal the factors that underlie the steps of making a fishbone diagram. The fishbone diagram will provide a clearer picture of the waste affecting production results [41]. Each data analysis stage will be calculated through RPN in the FMEA method, where systems and processes can experience failures or problems, including equipment damage and potential labor errors [42].

Table 3. Impact scale-frequency-detection

Impact (Severity)	
Score	**Description**
1-2	Very low probability of occurrence
3-4	Less likely to occur
5-6	Equal probability of occurrence or non-occurrence
7-8	It can likely happen.
9-10	Indeed, it will very likely occur.
Frequency (Occurrence)	
Score	Description
1-2	Never happened
3-4	Rare (with frequency of occurrence 10x in 1 month)
5-6	Frequent (with frequency of occurrence 15x in 1 month)
7-8	More frequent (with frequency occurring 20x in 1 month)
9-10	Very frequent (with frequency of occurrence 25x in 1 month)
Detection	
Score	**Description**
1-2	The probability of the controller detecting a failure is very high
3-4	The controller's probability of detecting a failure is somewhat high
5-6	The controller's likelihood of detecting a failure is low
7-8	Rarely is it likely that the controller will discover a potential failure
9-10	There is a very remote likelihood that the controller will discover a potential failure.

Table 3 presents the scales used to assess Severity, Occurrence, and Detection levels in the FMEA calculation. These values are multiplied to determine the RPN for each potential failure mode, which helps prioritize improvement actions [43]. Failure modes with the highest RPN will be the top priority for corrective action or performance improvement. Each critical failure mode (based on the identified waste) was evaluated using FMEA, scoring it on Savérity (S) – how serious the impact is, Occurrence (O) – how frequently it happens, and Detection (D) – how likely it is to be detected before occurring. The Risk Priority Number (RPN) is calculated as: RPN = Severity × Occurrence × Detection. Table 3 shows the scoring criteria used for Severity, Occurrence, and Detection. Failure modes with the highest RPN were prioritized for corrective action. The data processing results are then presented and interpreted; the final step is to provide conclusions and suggestions. Failure modes were selected based on historical maintenance records, frequency of occurrence, and input from production supervisors regarding their impact on throughput and product quality. Three experienced production and quality control staff assessed the RPN scores independently. Scoring was standardized using company SOP definitions for Severity, occurrence, and detection, and finalized through consensus to reduce subjectivity. This study did not account for external variables such as supply chain disruptions, labor shifts, or seasonal demand variations. These factors may indirectly influence the levels of waste and process stability.

4. RESULTS AND DISCUSSION

This section presents the findings from the identification of waste using Lean tools and the prioritization of failure modes using FMEA. The discussion elaborates on how these findings inform improvement strategies in the poultry processing industry.

4.1. Waste identification results

The analysis identified several dominant types of waste within the production process. Among the seven categories, the most frequently observed were motion (25%), waiting (22%), and defects (18%). Table 4 presents the detailed classification of waste types according to process stages, while Fig. 3 illustrates the distribution graphically. The high presence of motion and waiting waste indicates layout and workflow design inefficiencies. These findings align with the author, who reported similar issues in poultry production environments.

The entire production flow was visualized from live bird arrival to packaging u8sing Big Picture Mapping and VSM. Each process step was examined for inefficiencies based on the seven Lean waste categories. From this, seven types of waste were identified based on Lean principles. The three dominant wastes are waiting (Workers often waited for cooled raw materials due to limited chiller capacity, causing production delays), motion (workers walked back and forth to retrieve tools or materials not positioned near workstations), and overprocessing (excess handling during weighing and sorting stages added no value but consumed time and labor). These findings indicate inefficiencies that reduce productivity and increase labor cost. This step fulfils objective 1 by identifying waste types throughout production. These findings indicate inefficiencies that reduce productivity and increase labor cost. This step fulfills objective 1 by identifying waste types throughout production.

4.2. Process flow and waste mapping

The production process flow map using the VSM technique can identify waste and is divided into three main processes: information flow, material flow, and production lead time. The information flow includes communication and data exchange during the production process. An efficient information flow ensures that all data, instructions, and feedback are delivered quickly and accurately to the relevant stakeholders. Challenges include delays in communication between departments, inaccurate data entry that can lead to production errors, and a lack of real-time monitoring and reporting. Material flow involves moving raw materials, components, and finished products through production. Efficient material flow reduces delays and ensures materials are available at the right place and time. Challenges faced include inefficient layouts, which lead to excessive transportation, and poor inventory management, which can lead to overstocking or understocking.

Meanwhile, Production Lead Time is the total time required from the beginning to the end of the production process. One of the wastes occurs in Production Lead Time, where the time used in production process activities does not provide added value to the product, directly impacting efficiency and production costs. In the daily production process, the company uses two work shifts involving 300 workers and 15 machines, with a total cycle time of 72,000 seconds, while the available time is only 64,800 seconds. To reduce waste, the identification and management of non-value-added activities are essential. Other challenges include a high reliance on manual processes and obsolete machinery, which requires improving efficiency through implementing Lean Manufacturing and using automated technologies. Using VSM, the current state map revealed multiple process gaps and imbalances. The lead time for processing was 5.8 hours, with significant idle times in the cooling and sorting sections. The fishbone diagram (Fig. 4, Fig. 5, and Fig. 6) identified root causes such as manual inspection delays, overlapping tasks, and uneven material flow. These bottlenecks can be addressed through standardized work procedures and reallocation of manpower. The findings support the Lean principle of balancing workload to reduce waste.

4.3. Root cause and risk prioritization using FMEA

Each critical waste area was analyzed using Fishbone Diagrams to determine root causes. Subsequently, FMEA was applied to evaluate failure modes based on Severity (S), Occurrence (O), and Detection (D). The RPN was calculated using: RPN = Severity × Occurrence × Detection. The highest RPN identified was RPN = 210 (Chiller issue: waiting time due to insufficient capacity). Other high RPN values were related to motion waste from layout inefficiency (RPN = 168). Over-processing from unstandardized

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sorting steps (RPN = 144). FMEA results showed five critical failure modes, with RPN scores ranging from 160 to 280. Due to maintenance delays and part unavailability, the highest risk was associated with conveyor downtime during chilling. Table 5 lists all failure modes, effects, causes, and RPN scores. By targeting the top-ranked failure modes, the company implemented corrective actions that led to a 5.8% labor efficiency gain and 2.3% reduction in operational cost. This confirms that combining Lean-FMEA enhances process visibility and decision-making for risk mitigation. This analysis satisfies Objective 2 by prioritizing failure points contributing most to performance inefficiencies.

4.4. Statistical analysis of production data

The descriptive statistics indicate a notable shift in production characteristics after implementing the Lean–FMEA framework (Table 4). The average monthly output increased from 319,246 Kg to 338,505 Kg, accompanied by a rise in standard deviation and coefficient of variation, reflecting greater department fluctuations. Skewness values remained within an acceptable range, from –0.11 before implementation (slightly left-skewed) to 0.38 after (slightly right-skewed), suggesting that the data remained reasonably symmetrically distributed. The coefficient of variation rose from 86.02% to 98.26%, indicating that variability increased, likely due to the growth in high-output departments (e.g., cut up and whole chicken). These statistical insights support the validity of the data used and show that production improvements were quantitative and statistically significant in terms of performance dispersion and distribution behavior.

Table 4. Descriptive statistics of monthly production output before and after lean-FMEA implementation

Statistic	Before	After
Minimum	3.873 Kg	3.873 Kg
Maximum	588,493 Kg	811,270 Kg
Mean	319,246 Kg	338,504 Kg
Median	345,141 Kg	301,179 Kg
Standart Deviation	274,609 Kg	332,628 Kg
Coefficient of Variation (%)	86,02%	98,26%
Skewness	-0,11	0.38

4.5. Proposed improvements from lean–FMEA integration

Integrating Lean-FMEA in this study provided a systematic framework for waste elimination and risk prioritization. While Lean tools helped identify non-value-added activities, FMEA prioritized which failure points had the greatest impact. This synergy enhanced the company's ability to implement focused and impactful improvement strategies. The combined Lean-FMEA analysis proposed the following improvements: increase chiller capacity and optimize the cooling line to reduce waiting time. Layout redesign to reduce motion waste by bringing tools/materials closer. SOP standardization for weighing and sorting to reduce over-processing. After simulation and implementation of the corrective actions, the company achieved 5.8% reduction in labor costs, 2.3% reduction in operational costs, 1.2% reduction in raw material waste. These outcomes confirm the benefit of combining waste identification and risk analysis into one integrated improvement system. This fulfils the objective by demonstrating measurable performance improvement using Lean–FMEA techniques.

PPIC section has formulated the calculation of all components, the planning data will be sent to the purchasing section for the raw material ordering process (Fig. 3). The purchasing department is also tasked with ensuring that raw materials arrive according to the production process schedule, where the entire process is integrated with the accuracy of labor fulfillment in the production process. Material flow involves the movement of raw materials, components, and finished products through the production process. Efficient material flow reduces delays and ensures materials are available at the right place and time. Challenges include inefficient layouts, which lead to excessive transportation, bottlenecks at certain stages of production, and poor inventory management, which results in excess Inventory or stock-outs [44]. Suppliers will deliver raw materials according to the quantity and schedule ordered by the purchasing department. The dirty area production department will receive the raw materials, which will be processed from slaughtering, de-feathering, taking offal, cutting feet, and chicken heads. After that, the semi-finished raw materials will enter the clean area production section, where the raw materials will be sorted and cut according to consumer demand. Raw materials that have been grouped will be put into the packing area. In the packing area, all products will be labelled to be separated between fresh products that can be sent directly to consumers and products that must go through the freezing process in the cold storage section. Redesign the plant layout to minimize transportation distances, streamline material flow, and adopt lean inventory management practices to reduce excess Inventory and ensure timely replenishment. Live chicken procurement is obtained from in-house farms. Then, the chicken selection and transportation process is carefully conducted to ensure the quality and health of the chicken before slaughter. Each chicken arriving at the slaughterhouse goes through a health check by a team of veterinarians to ensure there are no diseases or conditions that could affect the quality of the meat. Chickens that pass the health check then enter the slaughter process, which is closely monitored by food

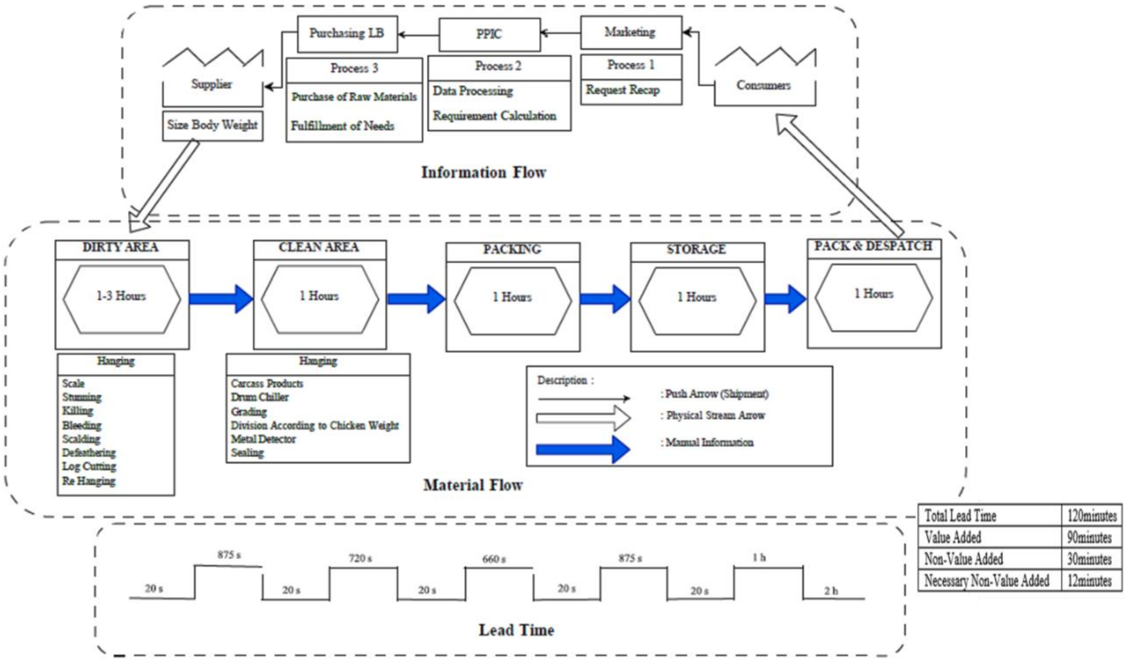

Fig. 3. Production process flow-VSM

safety and animal health standards; this process includes several stages, such as stunning, slaughtering, de-feathering, and cleaning. The slaughtered chicken meat is further processed according to market demand, including cutting (breast, thigh, and wing), marinating, and packaging. The processed products produced include ready-to-cook and ready-to-serve products that require further processing, such as seasoning. Processed chicken products are packaged with packaging technology that ensures freshness and hygiene. The products are then stored in cold storage under controlled conditions to maintain quality until distribution. The products are ready to be marketed to various consumer segments, namely traditional markets, supermarkets and hypermarkets, restaurants and the hooka industry (hotels, restaurants, catering), the food industry, direct sales and e-commerce, and exports to Malaysia and Timor Leste.

Waste treatment from the slaughtering and processing process is carried out by the Waste Water Treatment Plant (WWTP). Planning standards: Organic waste can be processed into other products such as animal feed or compost. A strict quality management system supervises the entire process from upstream to downstream to ensure the products meet international food safety standards [45]. Regular certifications and audits are conducted to maintain compliance with industry regulations and standards. Innovation and development of new products based on market trends and consumer needs are also carried out to improve process efficiency and reduce waste.

Table 5 describes the analysis of seven wastes in inefficient and value-added production in the transportation process, with no wastes identified; continuously monitor the transportation process to ensure it remains efficient and adapts to changing production needs. Analysis of excessive inventory There is a buildup of finished products due to raw materials that must conform to quality standards and consumer demand. Implement stricter quality control measures for raw materials to ensure they meet standards before production, improve demand forecasting accuracy to align raw material procurement with actual consumer demand, and implement lean inventory management practices such as just-in-time to minimize excess inventory. Unnecessary motion, such as searching for empty crates, adds no value to the production process. Redesign workstations to ensure all necessary tools and materials are within easy reach and implement standardized procedures to reduce unnecessary movement. Significant lead times are wasted, mainly when raw materials cannot be processed due to temperature standards that must be met. Optimize process flow to reduce lead times by ensuring that raw materials are processed as soon as they arrive and implement better environmental controls to maintain the required temperature standards for raw materials. The make-to-order system produced 7% more than the demand, exceeding the company's tolerance of 6.5% for overproduction. Improve production planning and scheduling to better align with actual demand and implement a flexible production system that can quickly adapt to changes in demand to prevent overproduction. In a redundant process, specific processes are considered waste and do not provide added value. Conduct a detailed analysis of each production step to identify and eliminate overprocessing, focus on activities that add value to the

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Table 5. Impact scale-frequency-detection

No.	Type of *waste*	Description
1	Transportation (Transporting)	There is no waste in the product delivery process, and procedures for every transportation step in the production process are efficient and value-added.
2	Excessive inventory (Inventory)	Waste occurs in the production process as finished products accumulate. This waste is related to raw materials that do not meet quality standards and raw materials that do not meet consumer demand.
3	Unnecessary movement (Motion)	Some movements in the production process should be avoided, such as looking for empty crates to place each product in.
4	Waiting time	Waiting time is spent relatively infrequently. This can be seen in the *value stream map,* where the most considerable waiting time occurs in 180 minutes to reduce the amount of production. Time is wasted on raw materials that cannot be processed immediately in the production room because the temperature (cold) needs to meet the specified standards.
5	Overproduction	The production process employs a make-to-order system; however, 7% of product outputs do not meet demand, exceeding the company's tolerance by 6.5%.
6	Overprocessing	In the existing production process, processes considered less critical or wasteful that do not produce added value are not repeated.
7	Defective products	Several types of defective products are produced in the production process, including bruised or broken bones, cuts, and products that are not on demand, bubbles on the feet, and bruised meat.

product, and eliminate or reduce activities that do not add value. Defective products are production processes that result in various faulty products, including bruises or fractures, cuts, unwanted products, bubbles on the feet, and bruised meat. Root cause analysis is conducted thoroughly using FMEA to identify the causes of defects, implement quality improvement initiatives such as lean thinking to reduce defect rates, and train employees in paper handling and processing techniques to minimize defects [12]. Implementing lean methodologies and continuous monitoring will help sustain these improvements and adapt to changing production needs. In the transportation waste category, no waste was found in the product delivery process. Shipping processes and procedures are considered efficient and provide added value because they already use a Transportation Management System (TMS), which is software designed to help companies plan, execute, and optimize freight shipments, with key features that include route planning and optimization, carrier management, tracking and visibility, cost management, and customer service. Inventory waste scored 25% because of the waste that occurs in the form of a buildup of finished products related to raw materials that do not meet quality standards or do not match consumer demand. Motion waste is 15%, and some movements in the production process must be avoided, such as looking for empty crates to place products and inefficient labor flow due to limited production space. Waiting of 30%, where waiting time is wasted relatively a lot. As seen from the map of raw material flow, it often occurs that is stopped for various reasons, with the most significant waiting time occurring for 180 minutes. Overproduction wastage is 7%, and the production process uses a make-to-order system. However, 7% of the product output did not match the demand, exceeding the company's tolerance of 6.5%, resulting in finished products that the market could not fully absorb. Overprocessing wastage, 5%, is an existing process considered less critical or a waste that does not add value and is not repeated. Defect wastage of 18%; several defective products are generated in the production process, including bruises or fractures, inappropriate cuts, leg bubbles, and bruised chicken meat. It can be concluded that three of the seven identified wastes have a considerable impact. The three wastes are waiting for defects and inventory vehicle spare parts.

To find out the causes of the three wastes, in addition to using the tools (Fig. 3), it is also necessary to analyze using a fishbone diagram to find out the root of the problem and provide recommenda-tions for improvements to the waste that occurs. The purpose of using these tools is to prevent product defects and increase product quality. Making a fishbone diagram refers to the results of the seven waste analyses in the previous method. From this method, the results with the most significant waste value will be known, which must be immediately corrected or eliminated. The fishbone diagram has a chart shape that resembles a fish, where the bones of the fish represent the potential causes of waste while the head of the fish shows the waste. Fig.

5 shows the fishbone diagram for wastage related to waiting. This diagram helps identify the root causes of delays in the production process. The leading causes of waste waiting identified are delayed receipt of raw materials from suppliers that disrupts the production schedule, the cooling process of raw materials that takes longer than expected, causing delays in the next stage of production, and insufficient cooling capacity to keep up with the production rate, leading to bottlenecks (i.e., buildup of raw materials). The causes are visually represented in a fishbone diagram, with each fishbone representing a different root cause category, such as machine problems, process inefficiencies, and external factors, such as supplier delays. Fishbone diagrams are helpful for systemati-cally analyzing the causes of wasteful waiting and developing strategies to address them, thereby improving overall production efficiency.

Fig. 4 shows a fishbone diagram, a visual tool to systematically identify and analyze the leading causes of defects in the production process. In this case, the diagram identifies the causes of defects in chicken meat processing. The fishbone diagram is also known as the Ishikawa diagram, which resembles the shape of a fish, with the head of the fish representing the problem (defects in the production process) and the bones of the fish representing different categories of potential causes.

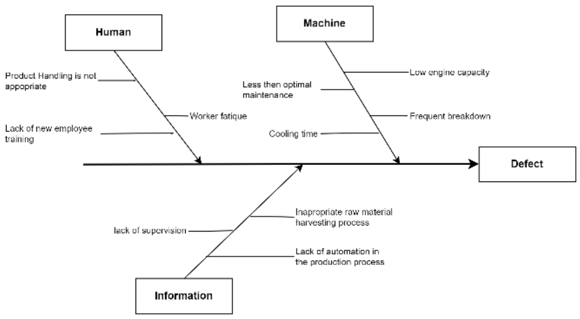

Fig. 4. Fishbone diagram for waste defect

Each prominent bone on this diagram represents a broad category that can cause defects. The causes of defects and effects on this diagram are human and labor-related factors such as lack of worker ability, inadequate training, and lack of supervision. Poor handling by workers during the production process can lead to defects, such as broken or bruised chicken parts. The method factor refers to inefficiencies or incorrect procedures in the production process, i.e., improper harvesting techniques can result in low-quality chicken and lead to increased waste. Material factors and issues related to the quality of raw materials, such as receiving chickens that do not meet standards, can contribute to defects. This also includes inefficient use or handling of materials. On the machinery factor, defects can be caused by equipment that is outdated or not functioning correctly. If machines are properly maintained and can handle the required capacity, this can lead to defective products. Environmental factors (external factors): The temperature in the production area also plays a role in maintaining product quality. Inappropriate ecological conditions can lead to contamination and spoilage. Management factors that lack supervision, scheduling, or operational planning can exacerbate defect rates. If management provides adequate support for preventive maintenance or staff training, defective products will likely occur.

The fishbone diagram used to analyze the leading causes of wasteful waiting time in production (Fig. 5). There are several leading causes, namely, delays in receiving raw materials from the farm; when raw materials do not arrive on time, this disrupts the planned production schedule and causes delays in starting the production process. The cooling process that takes longer than expected will directly delay the next production stage. Insufficient cooling capacity, i.e., an imbalance between cooling capacity and production rate, results in bottlenecks in the production flow, as raw materials cannot be further processed before being cooled to the correct temperature. Each bone on this diagram represents a different category of causes; this is very beneficial in systematically analyzing the causes of lead time wastage so that the company can develop strategies to address the problem and improve overall production efficiency.

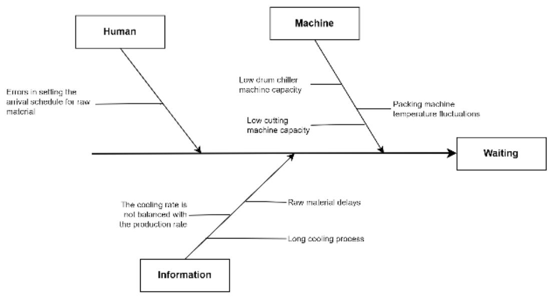

Fig. 5. Fishbone diagram for waste waiting

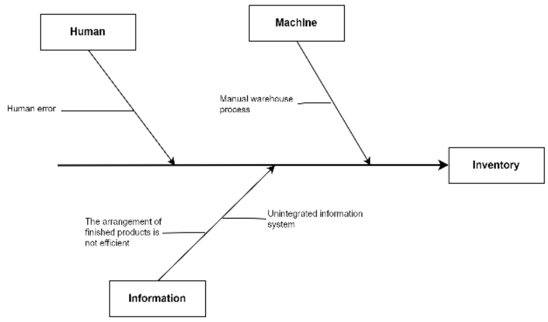

Fig. 6. Fishbone diagram for waste inventory

The fishbone diagram is used to identify the root causes of inventory wastage in production (Fig. 6). The causes of the waste include raw materials that do not match the demand, causing inventory buildup. The imbalance between ordering and demand often occurs

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due to supplier fulfilment errors. Inefficient inventory management leads to difficulties in managing stock. Finished products need to be correctly organized in the warehouse, resulting in accumulation and difficulties in timely delivery. Another cause is a marketing strategy that does not match the actual consumer demand, leading to overproduction and the eventual accumulation of finished goods stock in the warehouse. This shows a mismatch between production and actual market demand. Using this fishbone diagram, the company can more easily identify the root causes of inventory wastage, and corrective measures can be designed to reduce or eliminate the wastage. This identified inventory wastage can be reduced by creating more accurate marketing strategies, improving storage practices, and managing the supply chain more efficiently. The root causes of waste defects are the need for more automation in the production process, a lack of supervision, and the harvesting process of raw materials that are not in demand. The root causes of inventory waste are raw materials that are not in demand, inefficient arrangement of finished products, and inappropriate marketing strategies resulting in warehouse stock accumulation. Waste waiting occurs due to the late arrival of raw materials, the long-temperature cooling process, and the cooling rate that needs to be balanced with the production process rate. The fishbone diagram for inventory wastage, identifies the root causes of inventory wastage, which includes raw materials that are not in demand and refers to raw materials that are not needed or used efficiently, leading to excess inventory (Fig. 6). Poor organization and storage practices result in difficulties in managing inventory (inefficient structuring of finished products) and inappropriate marketing strategies that do not match actual demand, leading to overproduction and overstocking.

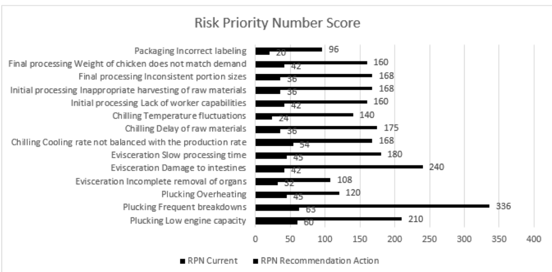

Fig. 7. Diagram of risk priority number (RPN) score

FMEA is necessary to analyze the risk factors that cause a production process to fail (Fig. 6). This method is used to obtain the RPN value, which is by multiplying the severity indicator value (which is the level of seriousness of the waste that occurs), occurrence (which is the level of how often the waste occurs), and detection (an indicator that warns of the ease with which the waste is detected). From the multiplication of these variables, the highest angle scale will be obtained, which will then be used as the basis for recommendations for actions that can be taken to reduce the occurrence of waste in the production process. Low machine capacity in picking has a high initial RPN of 210, indicating a significant problem due to outdated or less prominent equipment that needs to be upgraded to higher-capacity equipment. Frequent breakdowns in picking with the highest RPN of 336 are critical, caused by inadequate preventive maintenance, requiring the implementation of a preventive maintenance schedule. Unbalanced cooling rate in refrigeration; it has an RPN of 168, which is caused by insufficient capacity of the chiller drum, and suggests increasing the chiller's capacity or adding units to balance the cooling rate. RPN value [35].

The category of waiting time waste has several causes, including improper product handling, worker fatigue, and less than optimal machine maintenance, which causes the low quality of the products produced. The highest RPN value indicates the most critical area needing improvement. For example, frequent breakdowns in the picking process have an initial RPN of 336, which means a high priority for the preventive maintenance schedule. Severity, occurrence, and detection values help understand the most impactful and frequent problems and how well they can be controlled. Suggested actions often involve equipment upgrades, better maintenance schedules, and better worker training to address the root cause of the problem and reduce the likelihood and impact of failures.

Implementing the suggested actions significantly decreases the RPN score, indicating the effectiveness of the targeted improvements. Continuous process monitoring and adjustment based on FMEA analysis can improve production efficiency and product quality. This approach ensures systematic risk reduction and continuous improvement in production workflows. Previous research related to this study was conducted by Mishra *et al*. [46], focusing on reducing waste in manufacturing production by providing training at the operator level to improve the quality of production results, using the VSM method to identify and reduce waste. Meanwhile, research by Félix Jácquez *et al*. [18] focused on applying Lean Manufacturing to the introduction of new processes in a railroad company by using various Lean tools such as 5S, Kanban, and Just-In-Time (JIT) to improve operational efficiency. The result was increased production efficiency, decreased defect rates, and better resource utilization. Ulfah *et al*. [47] focused on minimizing waste in production by performing routine maintenance on production machines using the Lean Manufacturing method and using FMEA to identify and analyze the leading causes of waste. The results of routine maintenance on production machines increase production output and reduce frequent machine breakdowns. There is also

Table 6. Summary of failure modes, effects, and risk priorities

No.	Process step	Potential failure mode	Potential effect of failure	S	Potential cause of failure	O	Current controls	D	RPN	Recommended actions	Action taken	S	O	D	RPN
Waiting															
1	Plucking	Low engine capacity	Slow processing, bottlenecks	7	Outdated or undersized equipment	6	Scheduled maintenance	5	210	Upgrade to higher capacity equipment	Upgrade equipment	5	4	3	60
2	Plucking	Frequent breakdowns	Production delay, increased downtime	8	Inadequate preventive maintenance	7	Reactive maintenance	6	336	Implement a preventive maintenance schedule	Preventive maintenance plant	7	3	3	63
3	Plucking	Overheating	Equipment damage, increased repair costs	6	Continuous operation without cooldown	5	Manual monitoring	4	120	Install an automated cooling system	Automated cooling systems	5	3	3	45
4	Evisceration	Incomplete removal of organs	Contamination of meat, health risk	9	Equipment malfunction	4	Regular equipment maintenance	3	108	Upgrade maintenance schedule	Implemented new schedule	8	2	2	32
5	Evisceration	Damage to the intestines	Fecal contamination, spoilage	8	Improper handling	5	Worker training programs	6	240	Enhance worker training programs	Enhanced training	7	3	2	42
6	Evisceration	Slow processing time	Bottlenecks reduced throughput	6	Manual process	5	None	6	180	Introduce automation or process improvement	Process improvement	5	3	3	45
7	Chilling	The cooling rate is not balanced with the production rate	Insufficient cooling, spoilage risk	7	Inadequate drum chiller capacity	6	Periodic capacity checks	4	168	Increase chiller capacity or add units	Added chiller units	6	3	3	54
8	Chilling	Delay of raw materials	Production delays, workflow disruption	7	Late arrival of chickens from the farm	5	Coordination with suppliers	5	175	Improve logistics coordination	Enhanced coordination	6	3	2	36
9	Chilling	Temperature fluctuations	Product spoilage, safety issues	7	Inadequate temperature control system	5	Manual temperature monitoring	4	140	Install an automated temperature control system	Automated control system	6	2	2	24
Defect															
10	Initial processing	Lack of worker capabilities	High error rate, inconsistent quality	8	Insufficient training and experience	5	Basic training programs	4	160	Enhance training programs and regular assessments	Enhanced training programs	7	3	2	42
11	Initial processing	Inappropriate harvesting of raw materials	Poor quality chickens, increased waste	7	Improper handling during harvesting	6	Supplier quality checks	4	168	Train suppliers on proper harvesting techniques	Supplier training program	6	3	2	36
12	Final processing	Inconsistent portion sizes	Waste, increased costs	7	Manual cutting processes	6	Visual inspection	4	168	Standardize portion sizes using automated cutting machines	Automated cutting machines	6	3	2	36
Inventory															
13	Final processing	The weight of the chicken does not match the demand	Customer dissatisfaction, repurchase of finished materials	8	Variability in chicken sizes	5	Weight checks and adjustments	4	160	Implement a precise weighing system and adjust the sourcing	Improved weighing systems	7	3	2	42
14	Packaging	Incorrect labelling	Regulatory non-compliance	6	Human error during labelling	4	Double-checking labels	4	96	Implement automated labelling systems	Automated labelling systems	5	2	2	20

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production machines increase production output and reduce frequent machine breakdowns. From several previous studies, researchers conducted this research with a novelty that combines Lean-FMEA methods to provide a precise, effective, and comprehensive approach to identifying and eliminating waste and managing risks in the production process. This results in a study that can help develop a more efficient and safer workflow.

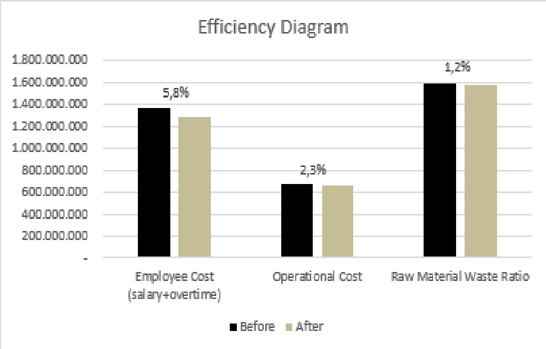

Fig. 8. Efficiency diagram

The Lean-FMEA methods use Big Picture Mapping, VSM, seven waste analysis, and fishbone diagrams to identify and analyze the causes of waste in detail. The primary root cause is the need for a robust preventive maintenance schedule. This results in equipment needing serviced regularly, leading to frequent breakdowns. Reactive maintenance practices further exacerbate this problem, as they only address issues after they occur, causing unplanned downtime and disruptions in production. Equipment used in the picking process may need to be updated, or its size may need to be adjusted to meet current production demands. This can lead to overloading and stress on machinery, increasing the likelihood of damage. Manual monitoring and the need for automated systems to detect early signs of wear contribute to the difficulty of predicting and preventing equipment breakdowns. Fig. 8 shows the efficiency diagram, which compares the cost and waste ratios before and after implementing Lean-FMEA.

The findings of this study demonstrate that integrating Lean-FMEA significantly reduces waste and improves efficiency in poultry processing. Compared to previous studies, the combination of these two methods has been underexplored in the poultry industry, making this study a valuable contribution to the existing literature. Toki *et al.* [11] demonstrated the effectiveness of Single Minute Exchange of Dies (SMED) in reducing setup times and waste in the garment industry. This aligns with our study, which similarly focuses on waste reduction but extends the scope by integrating risk management through FMEA. Widiwati *et al.* [16] applied Lean Six Sigma in food manufacturing to improve efficiency. However, our research is distinct in its focus on poultry processing, where variability in raw materials and food safety standards pose unique challenges. Ahmad *et al.* [17] and Dyah Susanti [23] utilized FMEA to enhance quality control and reduce defects in manufacturing,. Unlike their studies, which primarily addressed defect minimization, our research integrates Lean-FMEA to systematically address various types of waste and risks. Our study expands this approach to production flow analysis, identifying critical waste areas in poultry processing. This diagram includes three main categories monitored to assess the impact of improvements. The cost comparison that arises is the impact of improving the schedule for regular repair of production machinery so that the frequency of damage to production machinery can be reduced and directly impact existing cost efficiency.

The efficiency is the efficiency of employee costs,

Table 7. Comparison of production costs before and after lean-FMEA

Cost reduction in production process				
No	**Type of cost**	**January cost**	**February cost**	**Difference (%)**
1	Salary	1,219,057,920	1,148,962,090	
2	Overtime	150,670,080	142,006,550	
		1,369,728,000	**1,290,968,640**	**5.8%**
3	Electricity	627,346,280	612,786,300	
4	Water	33,728,300	32,945,500	
5	Solar	13,491,320	13,178,200	
		674,565,900	**658,910,000**	**2.3%**
Production process waste reduction				
No	**Type of waste**	**January cost**	**February cost**	**Difference (%)**
1	Raw Material	47,752,767	47,179,733	
2	Finished Products	1,544,006,119	1,525,478,056	
		1,591,758,886	**1,572,657,789**	**1.2%**

which amounted to Rp. 1,369,728,000 to Rp. 1,290,968,640 (Table 7). Implementing Lean-FMEA helps reduce employee costs, including overtime expenses, by increasing labor efficiency. Operating costs before implementation amounted to Rp. 674,566,000 and after Rp. 658,910,000 there was a slight reduction in operating costs, indicating that improvements to processes and work scheduling also affected overall operating costs. This raw material wastage ratio was before the application of Rp. 1,591,758,886 became Rp. 1,572,657,779 the raw material wastage ratio decreased after applying the Lean method and FMEA, indicating an improvement in raw material utilization, which means less waste was generated.

The reduction in labor cost by 5.8% after Lean–FMEA implementation indicates a significant increase in manpower efficiency. This change suggests that non-value-adding tasks, such as unnecessary motion and waiting were successfully minimized. Furthermore, the reduced standard deviation in daily labor hours reflects more excellent stability and predictability in the production schedule. While the raw material waste only declined by 1.2%, this change is meaningful in the context of high-volume poultry production, where even a 1% reduction can result in substantial savings over time. Moreover, the variance in waste quantity also decreased, indicating greater process consistency. These results support the study's first objective, which aimed to identify and reduce waste. Additionally, the prioritization of risks through FMEA aligns with the second objective by enabling targeted corrective action based on critical failure points.

Using FMEA, the study identified the highest RPN for key failure modes, Frequent breakdowns in the picking process RPN: 336, and the solution is to implement a preventive maintenance schedule. Low machine capacity in picking RPN: 210, solution upgrade equipment to higher-capacity machine. Unbalanced cooling rate in refrigeration RPN: 168, solution increase chiller drum capacity.

4.6. Research implication

This research provides some important alternative considerations for planning and managing the production process in the future.

1. Theoretical Contribution: This research bridges the gap in Lean-FMEA integration in poultry processing, which has been largely unexplored in previous studies. It extends the application of VSM and Fishbone Diagrams in identifying and prioritizing waste.
2. Practical Contribution: Companies can adopt this Lean-FMEA model to improve waste identification, process optimization, and risk management, preventive maintenance strategies should be prioritized to minimize machine downtime and enhance production flow, and the results highlight the cost-effectiveness of Lean-FMEA implementation, encouraging broader adoption in the poultry processing industry.

4.7. Implementation challenges

Implementing Lean-FMEA in poultry processing is not without challenges. One of the primary barriers is employee resistance to change, particularly when new procedures alter long-established work routines. Effective Lean implementation requires cultural readiness, and in many facilities, frontline workers may lack exposure to continuous improvement principles. In this study, change management efforts were initiated through internal training and direct supervision, yet some inconsistencies in execution were observed during the early stages. Another challenge is related to infrastructure limitations, particularly space constraints that hinder layout reconfiguration to reduce motion and waiting waste. The limited availability of automation tools and digital monitoring systems also affected the consistency of data collection for FMEA scoring. For example, detection ratings were subjectively determined due to the absence of real-time defect tracking systems. Furthermore, management support and cross-departmental coordination play a critical role. Delays in decision-making and inconsistent follow-up on improvement actions were noted as organizational constraints that affected implementation speed. These findings highlight the need for strong leadership, structured communication channels, and phased implementation strategies to overcome common Lean-FMEA adoption barriers in poultry processing environments.

The success of Lean–FMEA implementation is not solely dependent on technical tools, but also on the readiness of the workforce and the support of organizational culture. In this study, several operational improvements required changes in work procedures, equipment usage, and real-time responsiveness, which depend heavily on employee involvement. Interviews with key personnel revealed that frontline worker engagement, structured training, and management supervision played critical roles in ensuring consistent implementation. However, challenges such as habitual resistance to change, lack of standard operating procedures (SOP) awareness, and inconsistent communication between departments occasionally hindered the pace of adoption. These findings underscore the importance of fostering a continuous improvement culture supported by leadership commitment, clear communication, and team-based problem-solving. Future studies are encouraged to assess change management strategies and cultural factors as enablers or barriers in Lean–FMEA adoption across different organizational settings. Successful Lean-FMEA implementation requires management commitment and employee engagement. In this study, structured interviews highlighted that team training and

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clear SOP communication were key enablers of change. While standard RPN scoring was used in this study, future research is encouraged to conduct sensitivity analysis using alternative weighting or fuzzy logic models to assess the robustness of risk prioritization.

No adverse impact on product quality or production flexibility was observed during the implementation of Lean–FMEA. Based on internal quality control reports and daily production monitoring, product consistency remained within specification, and customer complaints did not increase. In addition, production scheduling flexibility was maintained, indicating that waste reduction did not compromise the plant's ability to respond to operational changes. This suggests that the implemented improvements enhanced efficiency without sacrificing quality or responsiveness.

Although the integrated Lean-FMEA methodology developed in this study has shown measurable improvements in operational efficiency, its applicability may not be universal across all industries or processing environments. This framework is well-suited for mid-scale poultry processing plants with moderate automation, high raw material variability, and strict hygiene standards. The methodology relies on direct observation, qualitative interviews, and expert assessments for FMEA scoring, which may limit its generalizability in fully automated or highly digitized production systems. Furthermore, industries with different production dynamics, such as continuous-flow manufacturing (e.g., chemical processing), may require adjustments in data collection methods, risk categorization, and Lean tool selection. Therefore, the Lean–FMEA approach proposed in this paper is best classified as context-specific, particularly applicable to food processing sectors where waste elimination and risk prioritization are crucial but real-time data systems are limited. Future studies are encouraged to adapt and test this framework in various operational contexts to validate its scalability and flexibility.

5. CONCLUSION

This study successfully developed and validated an integrated Lean–FMEA framework specifically designed for waste elimination and risk prioritization in poultry processing. By combining Lean tools such as Value Stream Mapping and Fishbone Diagrams with FMEA scoring techniques, the study identified three dominant types of waste waiting, motion, and over-processing, across the production line. The FMEA analysis revealed that the most critical failure mode was frequent machine breakdowns in the plucking stage, with the highest RPN score of 336, followed by inadequate cooling capacity and manual sorting inefficiencies. Implementation of targeted corrective actions led to measurable improvements, including a 5.8% reduction in labor costs, 2.3% reduction in operational expenses, and 1.2% decrease in raw material waste. These outcomes confirm that the Lean–FMEA integration is effective in identifying inefficiencies and prioritizing and addressing process risks based on their impact.

Theoretically, this study contributes a replicable model for combining waste mapping and risk prioritization in food manufacturing an area previously underexplored in Lean literature. Practically, the findings provide poultry processing companies with a structured improvement methodology that is adaptable to similar environments characterized by moderate automation and high hygiene demands. However, applying this framework may face limitations in highly automated or continuous-flow industries, and relying on expert judgment for risk scoring may introduce subjectivity. Future studies are encouraged to expand the model's applicability through digital integration (e.g., real-time monitoring, AI-based FMEA), cross-industry validation, and long-term impact assessment through longitudinal case studies.

Despite its contributions, this study has several limitations. The study primarily focuses on manual process improvements; future research should explore the role of automation and digital monitoring systems. The findings are based on a single poultry processing plant, limiting generalizability. Expanding the study to multiple facilities could enhance the robustness of results. Real-time data monitoring was not fully implemented; a more continuous data tracking system would provide deeper insights into process improvements. Future research can expand on this study by exploring automation and Industry 4.0 technologies, such as real-time data analytics, Internet of Things (IoT), and Artificial Intelligence (AI) to enhance waste reduction and process efficiency further, conducting multi-site studies across different poultry processing plants to validate the applicability of Lean-FMEA in various operational environments, deve-loping predictive maintenance models using machine learning to optimize equipment uptime and reduce unplanned breakdowns, and integrating sustainability practices, such as waste recycling and energy efficiency strategies, to create a more environmentally friendly poultry processing framework. This study demonstrates that Lean Manufacturing and FMEA can be effectively integrated to reduce waste, enhance productivity, and improve overall efficiency in poultry processing. By systematically identifying and addressing inefficiencies and risks, this approach provides a practical and scalable model for similar industries looking to streamline operations and improve sustainability. For practitioners, companies are encouraged to adopt Lean-FMEA integration to improve process flow and anticipate risks continuously. Periodic reassessment of RPN scores should be conducted to ensure sustained performance. For future researchers, further studies could explore quantitative simulations (e.g., using Arena or AnyLogic) to model the impact of Lean-FMEA interventions. In addition, applying this method across multiple poultry processing plants would enhance generalizability and validate the framework across broader industrial contexts. Lean–FMEA integration should be considered as a strategic tool for continuous improvement, particularly in process-critical environments like poultry processing. Periodic RPN reassessment is recommended to monitor effectiveness. Future studies may incorporate simulation modeling or multicase validation to enhance generalizability. A longitudinal study would also help assess long-term sustainability of the proposed improvements. To ensure the long-term effectiveness of Lean–FMEA implementation, companies are advised to establish a dedicated cross-functional Lean–FMEA team responsible for monitoring daily operations, reassessing failure modes quarterly, and training staff on process improvement tools. It is also recommended that digital dashboards be adopted that display real-time KPIs such as cycle time, defect rate, and downtime. These actions can institutionalize continuous improvement efforts and embed Lean thinking into daily operational culture. The integration of Lean and FMEA effectively reduced operational waste and improved process reliability in the poultry industry.

Although the current study demonstrates measurable short-term improvements following the implementation of Lean–FMEA techniques, it does not evaluate whether these gains are sustained over time. The assessment was conducted over a one-month observation period, which may not capture long-term variability in production patterns, workforce behavior, or equipment performance. Therefore, future research is recommended to conduct longitudinal studies over several months or production cycles. This would allow for a more comprehensive understanding of the sustainability and consistency of the improvement outcomes and the organizational learning curve associated with Lean-FMEA integration. Such studies could also assess whether risk levels (RPN) remain stable or re-emerge, thereby supporting continuous monitoring and process maturity evaluation.

While this study primarily focused on reducing operational waste and improving process efficiency, environmental sustainability remains an important dimension, especially in poultry processing industries where water usage, energy consumption, and waste by-products are significant. Future implementations of Lean–FMEA should consider integrating environmental performance indicators, such as energy efficiency during chilling operations, water usage during scalding and cleaning, and solid waste management from off-cuts and by-products. By aligning process improvement efforts with Environmental, Social, and Governance (ESG) goals, poultry processors can enhance operational performance, environmental responsibility, and regulatory compliance. Further research could expand the Lean–FMEA framework to include Green Lean metrics, contributing to productivity and sustainability objectives. One limitation encountered during this study was the limited use of digital tools in monitoring real-time production data and risk indicators. Many assessments, including detection ratings in FMEA, relied on manual observations and staff input due to the absence of automated systems. In modern manufacturing environments, integrating digital technologies such as Internet of Things (IoT) sensors, machine learning algorithms, and AI-based quality control could significantly enhance the accuracy, consistency, and speed of Lean–FMEA implementation. For instance, IoT-enabled devices could automatically detect deviations, record lead times, and track defect occurrences, reducing subjectivity and improving data reliability. Therefore, future studies are encouraged to explore digital Lean-FMEA frameworks, enabling companies to achieve smarter, more responsive process optimization, especially in industries like poultry processing where real-time decisions are critical. Future implementations of Lean–FMEA should include structured monitoring systems to support long-term sustainability. This could involve the use of digital dashboards, weekly KPI reviews, and periodic re-evaluation of RPN scores to ensure continued process stability. Companies can prevent performance regression by institutionalizing this feedback loop and build a continuous improvement culture. Future work should explore the integration of Industry 4.0 tools such as AI-assisted predictive maintenance and IoT sensors to automate data capture, reduce subjectivity, and enhance the efficiency of Lean–FMEA application in real time.

This study applied the standard RPN calculation by multiplying severity, occurrence, and detection scores with equal weight. However, it is acknowledged that the prioritization of failure modes may vary if the scoring system or weighting factors are adjusted. Future research is recommended to conduct a sensitivity analysis or apply fuzzy FMEA approaches to evaluate the robustness and consistency of risk rankings under different assessment models.

Although the primary focus of this study was on operational waste and process efficiency, the Lean–FMEA framework also holds potential to improve environmental sustainability. By reducing waiting time, motion waste, and equipment inefficiencies, there is an indirect reduction in energy consumption, particularly in energy-intensive stages such as chilling and scalding. Additionally, improved process flow can reduce water usage and solid waste generation. Future research is encouraged to integrate specific environmental performance indicators such as electricity usage, water consumption, and carbon

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footprint to enhance the relevance of Lean–FMEA in supporting ESG and circular economy goals. The Lean–FMEA approach used in this study may be adapted to other food processing sectors facing similar waste control challenges, hygiene standards, and production variability. Industries such as seafood processing, dairy production, and frozen food manufacturing often deal with high perishability and operational bottlenecks. Applying this integrated framework in those settings could offer comparable efficiency, risk mitigation, and resource optimization benefits. This study also opens future research avenues by suggesting integrating digital tools like IoT sensors and machine learning-based predictive maintenance to enhance real-time monitoring and scoring accuracy in Lean-FMEA applications. Moreover, the framework can be adapted to other high-risk food industries to improve efficiency and ensure food safety compliance simultaneously.

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