Proceedings of the 3rd GCC International Conference on Industrial Engineering and Operations Management
Tabuk, Saudi Arabia, February 2-4, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/GC03.20260095
Published: February 2, 2026

Waste Management and Operational Efficiency Improvement in Cake and Pastry Factory Through Adapting DMAIC Methodology

Kaouther Ghacham, Shoug Ghanem Alshawi, Raghad Muhammed Aljaloud, Malath Abdulkarim Alrawdhan, Munerah Saleh Alrudhyan and Lial Hamad Almari
Industrial and Systems Engineering Department
Princess Nourah bint Abdulrahman University
Riyadh, Saudi Arabia
KGMaatki@pnu.edu.sa

Abstract

The food industry is a key pillar of the global economy, where sustainability and resource management are essential for minimizing waste and maximizing efficiency. In food production, particularly in bakeries, sustainability focuses on minimizing food, time, and energy waste, reducing emissions, and enhancing economic performance. Company X, a leading Saudi food manufacturer, operates a cake and pastry factory facing high waste in its bun production line. This project aims to reduce waste to 1% through process analysis, identification of waste sources, and implementation of targeted solutions. Integrating sustainable practices into bakery operations promotes both environmental responsibility and operational excellence. To achieve these goals, the DMAIC methodology was applied. In the Define phase, SIPOC mapped processes and identified plant-level waste. The Measure phase used Pareto charts and statistical tools (Excel, Minitab) to quantify losses. In the Analyze phase, fishbone diagrams, failure data, and reliability calculations identified root causes, including breakdowns and process variation. During the Improve phase, several solutions were implemented, while the remaining ones were tested using Arena simulation. The Control phase introduced monitoring activities to sustain results. Food waste decreased from 1.5% to 0.88%, OEE rose from 45% to 58.5%, and time loss dropped 31.6%, surpassing factory targets.

Keywords
DMAIC Methodology, Waste Reduction, Productivity Improvement, OEE, Operational Efficiency.

1. Introduction
The food industry plays a vital role in achieving sustainability; however, food waste remains a significant barrier to this goal. More than 13% of food is wasted before reaching retail shelves due to inefficiencies in production and supply chains (UNEP, 2024). Food waste not only represents lost products but also wasted resources, including labor, energy, time, and materials. These inefficiencies increase operational costs and environmental impact through resource depletion and higher emissions. Reducing food waste is therefore crucial for enhancing sustainability and improving production efficiency. By optimizing processes and utilizing resources more efficiently, factories can reduce waste generation and improve overall performance. This study focuses on reducing waste and enhancing operations in a bun production line within a leading bakery manufacturer that has over 40 years of experience in the fast-food and baking industry and is ranked among the top 50 most valuable brands in Saudi Arabia. The bun line, one of the most demanded production lines, faces challenges related to dough and bun waste caused by production errors, quality control rejections, and maintenance interruptions.

1.1 Objectives
The main objectives of this study are to reduce waste by 33% (from 1.5% to below 1%), increase Overall Equipment Effectiveness (OEE) to 55%, propose cost-effective sustainability solutions, and implement a real-time waste monitoring system within four months.

2. Literature Review
2.1 Sustainability
Sustainability focuses on the responsible management of resources to preserve ecological balance and support future generations. As environmental challenges intensify, industries, particularly those in food production, are expected to implement sustainable practices that align with global environmental goals (Corigliano & Algieri, 2024). Sustainability in food production is built on three pillars: environmental, social, and economic (Corigliano & Algieri, 2024). As industry significantly impacts water and energy use, achieving true sustainability requires an integrated approach that extends beyond improving energy efficiency (Sarker et al., 2024). The environmental pillar of sustainability seeks to reduce the ecological footprint through energy efficiency, lower emissions, and waste reduction, which also bring economic benefits (Sarker et al., 2024; Nwokediegwu et al., 2024). Social sustainability emphasizes a supportive workplace, community engagement, and customer loyalty (Patel et al., 2020; Goncharuk et al., 2023). Economic sustainability focuses on long-term stability by adopting renewable energy and improving efficiency to maintain consistent food production despite external challenges (Corigliano & Algieri, 2024).

2.2 Waste Management
Waste management in the food industry involves minimizing and controlling waste throughout all stages of production (Sarker et al., 2023). With the sector's rapid growth, effective waste management has become crucial for enhancing sustainability, resource efficiency, economic performance, and reducing energy use. Food waste and loss (FWL) are significant challenges in the food industry, accounting for approximately 8% of global greenhouse gas emissions (Goodwin, 2023). While 13% of food is lost before reaching retail and 19% is wasted at the retail and household levels, high-income countries, such as Saudi Arabia, face particularly severe impacts (United Nations Environment Program [UNEP], 2024; Skaf et al., 2021). Saudi Arabia ranks among the highest generators of food waste, discarding around 33% of its food production, about 4 million tons worth 40 billion SAR annually, with flour and bread being the top contributors. The Saudi government recognized the environmental and economic consequences and aimed to cut food waste by 50% by 2030 through targeted policies and initiatives (Ministry of Environment, Water, and Agriculture, 2020; Sobaih, 2023). Waste disposal in the food industry involves strategies to minimize environmental impact and maximize resource recovery. According to the U.S. Environmental Protection Agency (2022), food waste management practices are prioritized, with a focus on prevention first. The industry focuses on waste prevention through efficient processes. When prevention is not possible, waste can be upcycled into valuable products containing bioactive compounds (Liu et al., 2023), donated to reduce food insecurity, or converted into animal feed to lessen environmental impact (Nath et al., 2023). Less sustainable methods, such as landfilling and incineration, should be avoided (Siddiqua et al., 2022).

2.3 Lean and DMAIC Approaches for Operational Improvement
The Fourth Industrial Revolution has transformed industrial sectors, including food manufacturing, by integrating digital technologies that enhance efficiency, reduce waste, and improve product quality. According to Dora et al. (2020), focusing on operational improvements in the food sector plays a vital role in minimizing food loss, particularly during the processing stage, which remains a major hotspot for inefficiencies. Lean Production, rooted in the Toyota Production System, aims to maximize customer value by minimizing resource use and eliminating non-value-added activities. These wastes fall into eight categories: Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects, and Skills. (Lakshmanan et al., 2023; Čiarnienė and Vienažindienė, 2012; Maalouf and Zaduminska, 2019). Lean Manufacturing streamlines, stabilizes, and standardizes production processes to enhance performance by minimizing waste across essential resources, including food and energy. (Dora et al., 2016; Sacadura and Tenera, 2011; Buer et al., 2020). Recommended lean tools in food production include DMAIC (Define, Measure, Analyze, Improve, Control), Root Cause Analysis, and performance measures such as Key Performance Indicators and Overall Equipment Effectiveness (OEE) (Kholil et al., 2021; Leksic et al., 2020). The DMAIC methodology, originating from Six Sigma, provides a structured, data-driven framework for systematic problem-solving. Widiwati et al. (2024) integrated Lean Manufacturing with DMAIC to create a comprehensive framework for process improvement, structured around five phases: Define, Measure, Analyze, Improve, and Control, each supported by targeted Lean tools to enhance accuracy and ensure measurable results. Pramono and Utami (2024) emphasized that

combining Lean and DMAIC provides a systematic approach that improves problem identification, analysis, and solution implementation, thereby enhancing operational control and sustaining process improvements.

2.4 Applications and Validation in Food Manufacturing Processes

Studies demonstrate the effectiveness of combining Lean, Six Sigma, and DMAIC methodologies in improving food production operations. Tannady et al. (2019) applied Lean Six Sigma to enhance manufacturing efficiency and reduce waste using multiple data collection methods, including direct observation and process documentation. SIPOC diagrams defined the process scope and stakeholders, Control Charts and Sigma Levels validated measurements, Pareto and Fishbone analyses identified inefficiencies, and Risk Priority Numbers guided improvements, while Control phase monitoring ensured sustainability. However, post-implementation sigma levels were not reported. The effectiveness of Lean Six Sigma in the food industry has been validated in multiple contexts. Widiwati et al. (2024) implemented LSS with DMAIC in a bread factory, resulting in significant reductions in production waste, improvements in process flow, minimized downtime, and reduced costs by targeting five key wastes: transportation, waiting, overprocessing, defects, and inventory. Similarly, Garcia-Garcia et al. (2022) applied Lean tools like SMED and Line Hopping in meal production, cutting changeover time by 30% and boosting OEE, while simulation techniques validated performance within Lean Six Sigma frameworks.

Simulation techniques have also been integrated into Lean and Six Sigma frameworks for validation and performance analysis. Wang et al. (2023) used a three-stage simulation approach to optimize operations in a furniture manufacturing company. Value Stream Mapping identified waste, while Lean tools, such as Kanban, addressed inefficiencies. Arena simulation validated the improvements, confirming reduced lead time and improved process flow efficiency. Similarly, Moshayedi et al. (2024) developed a simulation-based approach for supply chain optimization using Arena, modeling existing operations, testing alternative scenarios, and validating proposed improvements that demonstrated enhanced efficiency and reduced operational costs. Other studies support these findings using similar methodologies. Azra and Dwijayanti (2022) improved bakery production OEE through cause-and-effect analysis, preventive maintenance, and operator training.

Tannady et al. (2019) utilized DMAIC tools, including SIPOC, VSM, and FMEA, in noodle manufacturing, identifying defective labeling machines as the primary source of waste. Targeted equipment redesign and adjustments to cutting speed significantly reduced waste. Chetna Chauhan et al. (2021) integrated Green Lean Six Sigma and redesigned food supply chains to minimize waste and implement sustainable production and inventory policies.

Quantitative tools such as Pareto analysis and Control Charts validated improvements, highlighting frequent defect sources and ensuring process stability (Pramono & Utami, 2024; Tannady et al., 2019). Despite demonstrated effectiveness, few studies integrate real-time waste monitoring with targeted OEE improvements in high-demand bakery lines, indicating a need for research combining DMAIC, Lean practices, and quantitative metrics to optimize efficiency and sustainability in food manufacturing. The literature emphasizes sustainability in the food industry, stressing responsible resource management to balance environmental, social, and economic goals.

Food waste not only represents lost products but also represents an inefficient use of resources, driving environmental impact and increased costs. Lean and DMAIC offer structured frameworks for optimizing processes, eliminating non-value-added activities, and enhancing production efficiency through systematic analysis and targeted interventions. Empirical studies show these methodologies can reduce waste, enhance process flow, improve equipment effectiveness, and lower operational costs. Tools like Pareto and Control Charts validate improvements, while simulations enable scenario testing before implementation. Overall, combining structured process improvement with data-driven validation effectively boosts sustainability, efficiency, and cost-effectiveness in food production.

3. Methods

3.1 Research Methodology

Based on a comprehensive review of previous studies, the DMAIC framework has proven effective in reducing waste and enhancing operational efficiency, particularly within manufacturing environments (Widiwati et al., 2024; Pramono & Utami, 2024; Tannady et al., 2019; Hung & Sung, 2011). This project focuses on applying DMAIC methodology to the Bun Production Line of a Cake and Pastry Factory, by proposing targeted solutions that aim to minimize waste and improve overall operational performance.

3.2 Approach, Tools, and Techniques

The DMAIC methodology consists of five distinct phases: Define, Measure, Analyze, Improve, and Control. A comprehensive set of Lean Six Sigma tools and techniques was employed across these phases. The tools applied in each phase are outlined below. Although extensive analyses and improvements were conducted, this paper highlights the most impactful outcomes that best demonstrate the achieved process enhancements.

1. Define phase, the concept, and types of waste, as defined by the company, and waste targeted levels were identified through a series of interviews. Scope and limitations were clarified. For a comprehensive understanding of the Bun production process, a SIPOC chart was developed. This method focused on identifying areas of waste, thereby paving the way for significant enhancements in operational efficiency within these identified segments. Additionally, critical control points in the production process were identified.
2. Measure phase, the waste ratios in bun production were quantified by machine and waste category (e.g., production, downtime) using Excel and Minitab to calculate current rates, historical trends, correlations, and performance metrics. Pareto charts identified machines with the highest breakdown frequency.
3. Analyze phase, waste causes in the most waste-intensive processes were identified using a Fishbone diagram and prioritized via Pareto analysis based on their impact on overall performance. Maintenance metrics: MTBF, MTTR, reliability, and availability were also calculated to support targeted interventions.
4. Improve phase, targeted solutions were developed for the most significant waste causes to enhance efficiency. Solutions were evaluated via a Decision Matrix, assessed using Arena simulation, and clearly communicated to operators, with all necessary resources provided for effective implementation.
5. Control phase: A control plan was established to sustain improvements, with defined measurement methods, responsible personnel, and monitoring frequency for each enhancement. Refined procedures were integrated into the bun production line to ensure consistent, long-term performance.

A structured, data-driven methodology applied to the bun production line is expected to reduce waste, improve process efficiency, and strengthen sustainable operational practices, thereby contributing to the company's competitive performance and environmental commitments.

4. Data Collection

4.1 Define Phase

The define phase aims to clarify the scope of the study, outline current challenges, and establish a framework for improvement. Waste management was identified as a critical area for improvement in the factory, especially at its bun production line, which generates the highest amount of waste. Though the factory's waste rate stands at 1.5% within the company's limits of 5%, the goal is to reduce it below 1%. Similarly, improving Overall Equipment Effectiveness from its current level of 48% to more than 55% is crucial for enhancing productivity and achieving sustainability. To systematically address waste reduction, the factory classifies waste under two primary types.

First, food waste encompasses production waste generated due to products failing to meet quality standards, breakdown waste resulting from unexpected machine failures, and R&D waste resulting from research and development trials for new products.

Second, time waste includes breakdown time lost due to sudden machine failure and changeover time required to switch from one production batch to another, often resulting in downtime and loss of efficiency. The bun production line has been identified as the most significant contributor to waste within the factory. Data from 2022 to 2024 reveal several inefficiencies in waste management, operational effectiveness, and changeover processes, resulting in significant losses of food, time, and resources. Three objectives were established to achieve sustainable practices in the bun production line. First, reduce food waste from 1.5% to 1% within 4 months by minimizing breakdowns and reducing regular production waste. Second, increase OEE from 48% to above 55% within 4 months by reducing changeover time, enhancing performance, and improving availability.

Third, propose sustainable and cost-effective solutions to include real-time waste monitoring systems. The study categorizes the major causes that contribute to generating inefficiencies and waste. High waste generation includes rejected buns, excess dough, and inefficient scheduling. Downtime inefficiencies are caused by mechanical failures, machine stoppages, and inefficient changeover processes, aiming to reduce the monthly duration from 26 to 10 hours. Changeover losses contribute to wasted materials and excessive idle machine time, with a targeted reduction from 70 to 24 hours monthly. Real-time waste monitoring is not available at the factory; therefore, predefined metrics are used instead of automatic tracking systems.

The SIPOC diagram showed a high-level overview of the bun production line. The leading suppliers are raw material suppliers, providing flour, yeast, sugar, dairy products, and water, as well as packaging material suppliers. The critical inputs to the process are raw ingredients, production equipment, including a sponge mixer, dough mixer, divider, panner, proofer, oven, depanner, cooler, and packaging machines, consisting of ingredient preparers, machine operators, quality inspectors, and packaging materials, and process control parameters for temperature, humidity, and time settings. The production process involves eleven key steps: receiving the order, preparing and mixing the ingredients, kneading the dough, dividing and panning, proofing, baking, depanning, cooling, inspecting and sorting, cutting, and packaging. The outputs are the finished packaged buns, waste byproducts such as deformed buns and packaging material waste, and production data logs. Customers include the restaurant chain, retailers, and end consumers. The production flow indicates the points in the bun production process where critical control points occur. Control points during production are sponge mixing time and temperature, dough mixing time and temperature, dough cut weight in the divider, proofing time and temperature, baking time and temperature, cooling time and temperature, and packaging codes. Control points after production include product weight, dimension, moisture percentage, pH, and water activity. If there is no proper management of critical control points, production specifications will not be met, and, as a result, quality decreases, leading to the wastage of products and resources.

4.2 Measure Phase

The measure phase assessed the problem of food and time waste during bun production by evaluating the current performance of the factory. The data collection process included two approaches: the first approach involved factory measurements using sensors to monitor production lines, while waste baskets equipped with digital scales were used at workstations (mixing, proofing, baking, and packaging). Additionally, production and maintenance records were broken down by shifts, recorded by operators and technicians. Second approach: project team measurements, including site visits with stopwatch timing, photo and video documentation, meetings with production and maintenance managers, analysis of historical waste records (2022-2024) using Excel, maintenance logs, and overall equipment efficiency (OEE) metrics. The factory operates three production lines, running 24/7 across three shifts, with approximately 45 employees per shift.

Based on January 2025 performance, 86.5% of planned production time was used effectively, while 13.5% was lost to non-productive activities, including setup, changeover, machine downtime, and maintenance. Historical data show a worrying upward trend: total waste increased from 85,252 kg (0.42%) in 2022 to 286,723.99 kg (1.48%) in 2024, representing a 236% increase, while downtime increased from 106.26 hours to 244.17 hours, despite production levels remaining relatively stable at around 20 million units. Correlation analysis confirmed a strong relationship between downtime and waste percentage ($r \approx +0.997$) and between units produced and waste percentage ($r \approx -0.961$), demonstrating that downtime is the primary factor contributing to waste. The 2024 performance yielded a 98.55% yield with an 82% automation level, but moderate technology utilization was observed, indicating untapped potential and weak process control that require further investigation.

Total food waste in the bun production line was 286,723.99 kg in 2024, representing approximately 1.5% of total production. It is categorized into three primary sources: production waste at 37.7%, breakdown waste at 61.7%, and R&D waste at 0.6%. Over the course of ten months in 2024, the total food waste amounted to 182,539 kg. Analysis revealed that breakdown waste had a significantly higher mean of 11,258.3 kg compared to production waste at 6,995.69 kg, with breakdown waste exhibiting a standard deviation of 3,737.1 kg compared to 1,381.52 kg for production waste, making it more unpredictable and challenging to manage. Reducing breakdown waste by 10% would result in a 6.2% reduction in total food waste, compared to a 3.8% reduction in production waste. Pareto analysis (Figure 1) identified the imprinter machine as having the most significant contribution at 59,692 kg and requiring the highest level of priority for corrective action. R&D waste, though minor at 1,158.98 kg in January 2024, represented 6.55% of experimental activity waste in the month.

Time waste results from two primary sources: breakdown time and changeover time. Over the course of ten months in 2024, 187 breakdowns resulted in 204.75 hours of downtime (3.032% of production time), an acceptable rate that requires ongoing monitoring, particularly for trends that persist. Analysis of breakdown sources in Figure 2 showed that the proofer was the most critical contributor with 55 hours lost across 28 incidents, followed by power interruption during the Eid al-Fitr season. The remaining downtime was caused by other sources, including the packaging machine, divider, conveyor, silo minor, and dough mixer. The factory produces 16 types of buns, with five main products accounting for the majority of production volume and requiring frequent changeovers. Changeover activities during January 2025 consumed 66.63 hours, which accounted for 9.77% of total production time, a relatively high percentage attributed to the product variety. The waste of breakdown time and changeover time together accounted for 12.8% of production time.

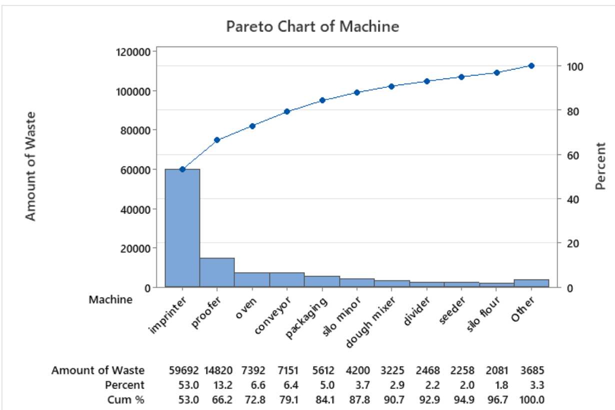

Figure 1. Amount of Waste Pareto Chart

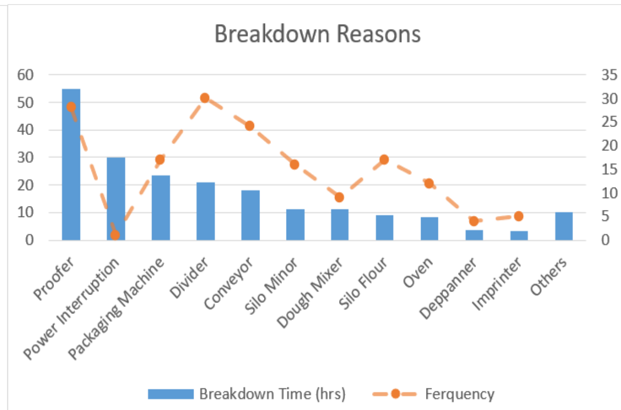

Figure 2. Breakdown Sources and Downtime

5. Results and Discussion

5.1 Analysis Phase

Following the Measure Phase, this phase focused on analyzing factors that contribute to high food and time waste.

5.1.1 Food Waste

Among the three categories of food waste, breakdown waste accounted for the most significant proportion. The earlier Pareto chart shown in Figure 1 identified the imprinter machine as the most critical source, contributing 53% of breakdown waste and 32.7% of total food waste. The imprinter's design requires precise physical contact with each bun, making it extremely sensitive to minor variations in bun height and texture. A root cause investigation identified multiple issues, including misalignment with the conveyor, mechanical wear, and dough adhesion due to surface deterioration. These factors led to frequent stoppages and bun deformation. The proof was identified as the second-largest contributor to breakdown waste, generating 14,820 kg of waste due to repeated failures in its endless drive system. These failures were caused by worn bearings, misaligned grids, and the absence of a predictive maintenance program. Next, the oven, with 7,392 kg of waste, experienced frequent jamming and gas supply fluctuations, resulting in uneven baking and temperature deviations. Its enclosed design also made early detection of faults difficult, extending recovery times. The conveyor system contributed 7,151 kg of waste due to ageing equipment and

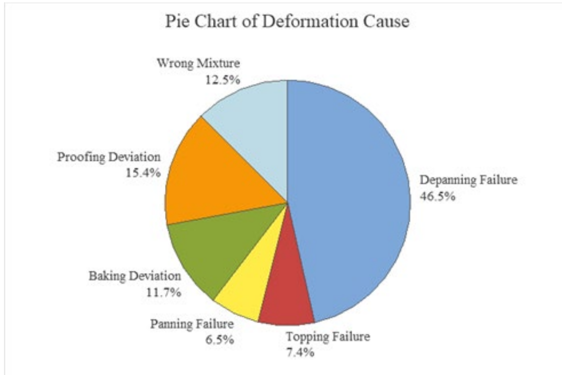

Figure 3. Pie Chart of Production Waste Causes

insufficient lubrication. Finally, packaging machines generated waste through wear of stopper cylinders, sprockets, and sealing heads, resulting in defective seals and unplanned downtimes. Collectively, these breakdown sources reveal that equipment deterioration, poor synchronization, and reactive maintenance practices are the key drivers of food waste on the line. Production waste accounted for 37.7% of total food waste in 2024. This category primarily resulted from process deviations and handling inefficiencies along the bun-making stages. Through direct observation and data review, six leading causes of production waste were identified: depanning failures, proofing deviations, baking deviations, ingredient mixing errors, panning failures, and topping application failures. The relative contributions of each cause are presented in Figure 3.

The depanning failures, representing approximately 46.5% of production waste, were identified as the most significant contribution. Inspection revealed that most issues stemmed from the excessive use of baking pans, which had been in use for well beyond their recommended lifespan of 3,000 production cycles. Pans currently in use exceeded 4,000 cycles, leading to the deterioration of the non-stick coating. As a result, buns adhered to the pan surfaces, tearing or deforming during removal. Regular pan replacement and coating restoration were identified as critical improvement actions. Proofing and baking deviations, together accounting for 27% of production waste, were primarily linked to equipment malfunctions in the proofer and oven discussed earlier. Interruptions in these stages can cause over-proofed or under-baked buns, resulting in texture, size, and coloration issues. Ingredient mixing errors (12.5%) were another source of loss, due to manual weighing and human variability. Inaccurate flour-to-water ratios resulted in inconsistent dough, affecting the texture and rise of the buns during proofing. Similarly, topping and panning failures (13.9% combined) occurred when dough balls were misaligned in pans or when glazing and sesame seeds were applied unsuccessfully.

5.1.2 Time Waste

Time wasted is one of the most critical losses in factory operations, directly affecting productivity. In this analysis, by focusing on two leading causes: machine breakdowns and changeovers, both of which interrupt workflow and reduce

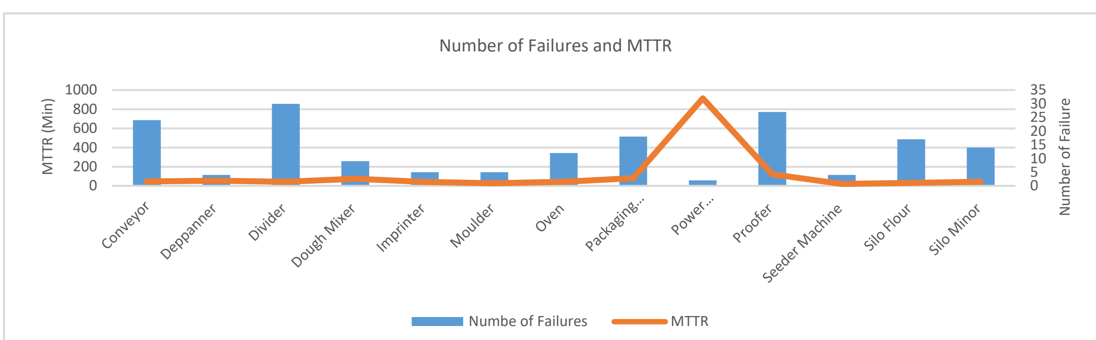

Figure 4. The Number of failures and MTTR

efficiency. First, machine breakdowns affect the machine's availability and reliability. Focusing on the machine that has the most significant impact in the factory, as indicated by the Pareto chart in the Measure phase.

Divider exhibits the highest probability of failure in the upcoming month, indicated by the most significant number of recorded breakdowns (30 incidents). The high failure frequency combined with moderate repair time (MTTR = 42.1 minutes). The most notable problem is the repeated failure of the feed screw, which has been broken or damaged multiple times. Proofer, with a recorded 27 failures, has the longest average MTTR (121.22) and reliability at only 4.25%, underscoring its substantial impact on unplanned downtime. The most common issue is tray jamming, which has been reported multiple times and directly disrupts production by causing trays to get stuck inside the proofer. Moderate risk machines such as Conveyer, Packaging machine, and Silo system demonstrate moderate reliability,

while their availability is above 99%. However, their MTTR exceeds the preferred threshold of 25 minutes, indicating that repair times are longer than ideal. Low-risk machines such as the Imprinter, Moulder, Depanner, and Seeder Machine displayed both high availability (>99.93%) and relatively high reliability (above 56%). The Power Interruption category only happened twice; it had a high MTTR of 913.5 minutes, which brought the reliability down to 79.22%. This demonstrates that even rare issues, if they persist long enough, can significantly impact the system's stability. However, the analysis identified a significant increase in machine downtime during April. This anomaly can be attributed to two primary factors: increased post-Eid production demand and external power disturbances from nearby factory closures, which caused voltage fluctuations and led to higher operational stress and unplanned downtime at the factory. Analysis of 200 breakdown events by shift (Day: 6 AM - 6 PM, Night: 6 PM - 6 AM), Figure 5 showed a higher concentration of incidents during the night shift, particularly in the late evening and early morning hours.

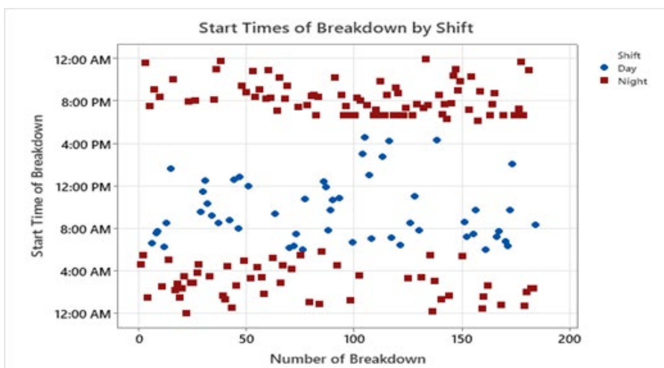

Figure 5. The Timing of the Machine Breakdown

This trend indicates that equipment failures are more frequent during nighttime operations, due to reduced staffing and delayed detection of early stress signs, as well as the cumulative mechanical strain carried over from daytime usage. Changeovers significantly contribute to time loss. The Ishikawa diagram (Figure 6) analyzed root causes of increased changeover time under the 6Ms: Man, Machine, Method, Material, Measurement, and Environment.

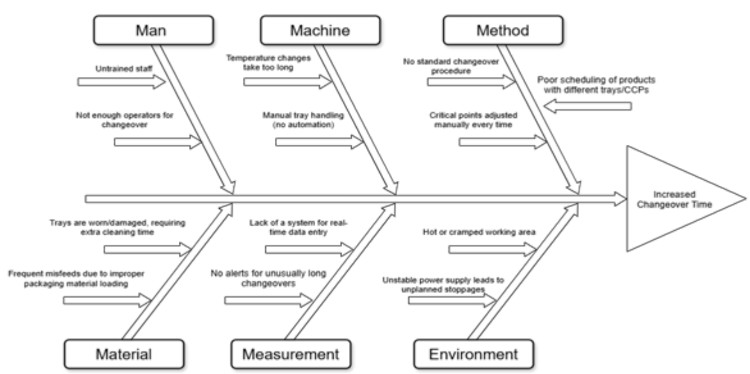

Figure 6. Increased Changeover Time Reasons

5.1.3 Study the Relationship Between Time Waste and Food Waste

This study focuses on two main types of waste in the production process: maintenance waste, caused by machine breakdowns, downtime, and production waste, resulting from quality issues or operational inefficiencies. These forms of waste impact overall performance. Descriptive statistics are presented to summarize key variables related to machine breakdown time and food waste. Table 1 describes the difference in variances. To investigate further, we conducted a normality check for both samples. The results indicated that neither sample follows a normal distribution. Therefore, we used a non-parametric approach.

Table 1**.** Descriptive statistics

Variable	N	N*	Mean	SE Mean	StDev	Variance	CoefVar	Minimum	Q1	Median	Q3	Maximum
Maintenance Waste	267	0	422.2	24.0	392.1	153705.6	92.86	0.0	200.0	321.0	480.0	3180.0
Production Waste	267	0	252.8	11.4	186.9	34916.9	73.91	15.1	173.2	213.4	265.8	1949.1

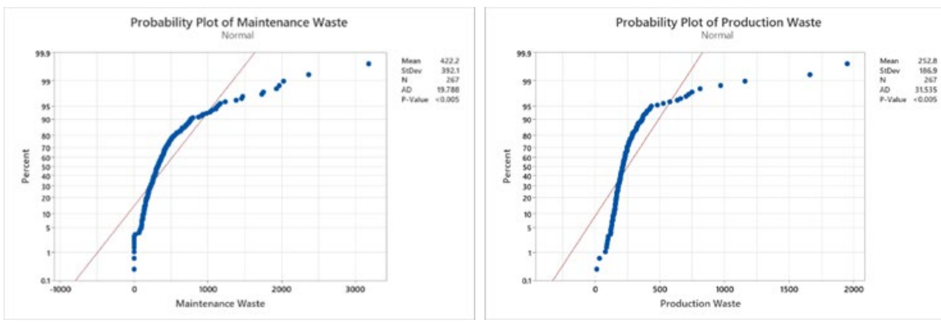

Figure 7. Normality Test

Due to the lack of normality in the data distributions, a Mann-Whitney U test was conducted, as shown in Figure 7, to compare maintenance waste and production waste. The hypotheses were as follows:

- Null hypothesis (H_0): There is no difference in the medians of the two groups ($\eta_1 - \eta_2 = 0$).
- Alternative hypothesis (H_1): There is a difference in the medians ($\eta_1 - \eta_2 \neq 0$).

The results showed a statistically significant difference between the two groups ($W = 84483.50$, $p < 0.001$). The median maintenance waste was 231.00, while the median production waste was 213.45. The estimated difference in medians was 96.79, with a 95.01% confidence interval ranging from 70.74 to 123.67. Since the p-value is less than 0.05, we reject the null hypothesis and conclude that there is a statistically significant difference in waste levels between the two departments, with maintenance waste being significantly higher. To explore the potential impact of time-related inefficiencies on waste generation, a simple linear regression analysis was performed, as detailed in Appendix D, using 267 daily observations that incorporated both normal operating and downtime periods. The analysis assessed the relationship between Total Minutes (representing downtime) and each type of waste (Production and Maintenance). For Production Waste, the regression equation was:

Production Waste = 257.9 – 0.1108 × Total Minutes

The negative coefficient suggests a decrease in waste as downtime increases, though this relationship was not statistically significant ($p = 0.163$). Despite this, the model showed a high R-squared value of 73%, indicating a strong fit and substantial variance explained. For Maintenance Waste, the regression equation was:

Maintenance Waste = 394.6 + 0.605 × Total Minutes

This model revealed a positive and statistically significant relationship ($p < 0.001$), indicating that more extended downtime is associated with increased maintenance waste. The model's R-squared was only 4.97%, suggesting limited explanatory power. This contrast highlights a key insight that the predictor can be statistically significant without being impactful, and vice versa. While Total Minutes showed a strong fit for predicting Production Waste, its relationship was not statistically reliable. Conversely, it was statistically significant for Maintenance Waste but explained only a small portion of the variance. These findings suggest that additional variables or more complex models may be necessary to understand better and manage production inefficiencies.

5.1.4 Operation Efficiency (OEE)

Operational efficiency was evaluated using Overall Equipment Effectiveness (OEE), to assess performance and identify losses. Results showed an Availability of 82.41%, a Performance of 87%, and a Quality rate of 68.18%, leading to an overall OEE of 48.64% and indicating potential for improvement, as world-class OEE values typically exceed 85%.

5.2 Improve Phase

In the Improve phase, solutions and an action plan addressed production, breakdown, and time wastes, prioritized by impact in a three-phase plan. Analysis showed that the Imprinter caused 53% of breakdown-related waste (32.7% of total), followed by the Depanner at 17.4% and Ingredient Mixing at 12.9%.

5.2.1 Proposed Solutions for Individual Waste Sources

First, eliminating the stamping process required no investment, could be completed in one shift, and was expected to reduce breakdown-related waste by 53% (32.7% of total waste), with acceptable risks confirmed through consultation with stakeholders, which would impact visual branding. Second, the Depanner failures should be addressed by the immediate replacement of all baking pans that have exceeded 4,000 production cycles, since the manufacturer recommends a maximum of 3,000 cycles. Overuse resulted in deterioration of the non-stick coating, leading to buns sticking or being damaged during Depanning. A pan replacement policy was implemented to retire pans at 3,000 cycles or earlier if coating wear affects quality, which has been integrated into the preventive maintenance program without incurring additional costs. Third, ingredient mixing errors will be minimized by standardized, color-coded measuring tools precisely sized for recipe quantities that were placed next to ingredients, eliminating weighing, reducing errors.

5.2.2 Proposed Solutions for Multiple Waste Sources

First, ensure backup generators are available year-round or during peak seasons like Eid, along with an Automatic Voltage Regulator when the electrical load exceeds limits. Second, improve night shift performance by allowing longer machine rest periods, adding shifts with shorter hours, conducting inspections during rest, providing maintenance support at the start of shifts, and offering training to operators. Third, revise preventive maintenance for high-breakdown machines (divider, proofer, conveyor, packaging), replacing expired parts to reduce repair costs and waste. Fourth, implement a jam detection system using proximity, vibration, camera, load, and thermal sensors. Fifth, efficient scheduling for types of buns based on production specifications, including size, proofer temperature, humidity, and oven temperature. A Similarity matrix (Figure 8) grouped similar products for consecutive scheduling to minimize changeover adjustments, sequencing from lower to higher oven temperatures, since heating is faster than cooling.

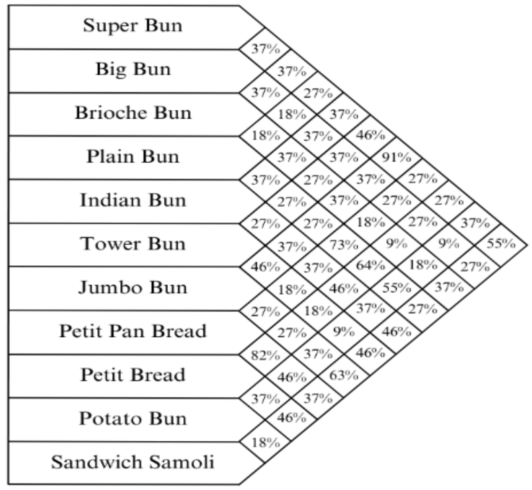

Figure 8. Similarity Matrix of Bun Types

5.2.3 Solutions Execution

Based on effectiveness, ease of implementation, and affordability, proposed solutions were ranked, as shown in Table 2, then developed into an action plan in three phases.

Table 2. Solution Decision Matrix

Phase	Solution	Effectiveness	Ease of Implementation	Affordability	Total Score
Phase 1	Elimination of Stamping Process	10	10	8	28
	Pan Replacement Policy	8	9	7	24
Phase 2	Similar Product Scheduling	9	8	6	23
	Preventive Maintenance	9	7	6	22
	Standardized Color-Coded Measuring Tools	6	8	7	21
Phase 3	Jam Detection System	10	5	5	20
	Night Shifts Improvements	7	5	8	20
	Backup Generators	8	6	4	18

Phase 1, from February to March 2025, implemented the elimination of the stamping process, the policy of immediately replacing worn pans, and the pan replacement policy. Implementation resulted in a reduction of 24.8% in food waste, from 1.5% to 1.13%, and a 7.11% increase in OEE, from 48% to 52.6%. The time wasted was not impacted, as the implemented solutions were only designed to reduce food waste. In Phase 2, from April to May 2025, similar product scheduling was implemented, along with preventive maintenance and the standardization of color-coded measuring tools. Implementation led to a 13% reduction in food waste, from 1.13% to 0.983%, 5% increase in OEE, from 52.6% to 55.4%, and a 31.6% reduction in time waste, dropping from 12.8% to 8.76%, successfully meeting the project objectives. Phase 3 continues beyond the project timeline and will include the jam detection system, night shift improvements, and backup generators. Since these solutions extend beyond the project timeline, a discrete-event simulation model was developed using Arena software to evaluate the potential improvements without incurring real-life costs. Simulation results showed a 10.5% reduction in food waste, from 0.983% to 0.88%, a 5.4% increase in OEE, from 55.4% to 58.5%, and a 20.1% reduction in time waste, from 8.76% to 7%.

5.3 Control Phase

The Control phase will ensure the sustainability of the improvements implemented over time. The following control plan, outlined in Table 3, details the measures implemented to monitor critical variables and maintain process stability. To ensure the long-term success of the improvements and support the targeted goals of reducing both food and time waste (Table 3).

Table 3. Control Plan for Sustaining Improvement Actions

Goal	Recommended Improvement	Measurement Method	Responsible Party	Monitoring Frequency
Reducing breakdowns and regular production waste	Trays timely replacement	No. cycles per tray	Production manager/ Procurement department	Daily
	Implementing jam detection system	No. jam incidents	Line staff/ production manager	Monthly
	Implementing Preventive maintenance schedule	No. Breakdown/Avg. downtime /Machine Reliability	Engineering and maintenance manager	Weekly/ Monthly
	Ingredient measurement standardization using custom tools	Frequency of wrong mix occurrence	Production manager/ Quality assurance team	Monthly
Reduce changeover time	Standardized changeover procedure (SOP)	Avg. changeover time per shift or per product	Production manager	Daily
	SMED	Number of steps /Total changeover time	Production manager	Daily

*No. = Number of, Avg. = Average, SOP: Standardized Operating Procedure, SMED: Single-Minute Exchange of Dies

Stamping machines will remain removed until a better alternative is available. The jam detection system will be validated by comparing jam incident rates and resolving time before and after installation. Any detected jam will be logged with its cause, duration, and amount of waste, allowing for faster intervention and analysis. Tray replacement will be controlled by tracking the usage cycle of each tray, while keeping a spare batch of trays in inventory. Preventive maintenance schedules will be tracked through maintenance logs, and key indicators such as breakdowns, duration, and repair frequency will be monitored to ensure the system reduces the need for reactive maintenance. Additionally, daily pre-operation checklists will be completed at each shift to ensure the readiness of critical systems, such as water and packaging machines. Staff will be trained on these checklists, and compliance will be audited regularly. The effectiveness of ingredient measurement standardization using calibrated tools will be validated by comparing the occurrence of incorrect mixes before and after implementation. The production waste log will track waste sources to enable root-cause analysis and timely corrective actions. To monitor the improvements in OEE from 48% to 55%, SMED will be applied to sustain the improvements made, reducing changeover time and eliminating time waste. By standardizing the optimized changeover steps, SMED helps ensure that operators follow a consistent and efficient process every time the bun type is changed. Regular audits and operator training are also integrated to reinforce the procedure and prevent regression.

These control efforts will ensure that the implemented solutions are sustained, measurable, and continuously improved. By closely monitoring key performance indicators and reinforcing operator compliance through training and audits, the factory can maintain the gains achieved, reduce variability, and stay aligned with its quality and productivity goals.

6. Conclusion

The bun production line is among the most in-demand lines in the factory, as it supplies to restaurants and retailers. The line has an OEE of 48% and a food waste rate of 1.5%, holding the highest waste rate across the factory. This is primarily due to inefficiencies, operational disruptions, and recurring product defects. The main objective of this study was to reduce the waste rate to 1% and increase Overall Equipment Effectiveness (OEE) to 55%. To achieve these objectives, the DMAIC methodology was applied as a structured problem-solving framework. In the Define phase, the project's goals were clearly established. A SIPOC diagram and a flowchart were used to map out the production process for buns. Food waste was categorized into regular production and machine breakdown waste. To help achieve the OEE goal, the time waste sources were identified to be breakdown and changeover time waste. In the Measure phase, data was collected and analyzed using Excel and Minitab, revealing that breakdown food waste was the primary contributor to overall waste and low OEE. Pareto charts highlighted key problematic equipment: the imprinter, proofer, and oven for food waste; the proofer, power interruptions, and packaging machine for time waste. The Analyze phase further investigated these sources, identifying tray jamming and buns sticking to trays as significant issues. Machine reliability was assessed to determine where preventive maintenance was necessary, and a regression model was used to study the relationship between time and food waste. During the Improve phase, several solutions were proposed, such as removing the imprinter, replacing trays, color-coding parts, installing a jam detection system, and adjusting production and shift schedules. These were prioritized and implemented through a three-stage action plan. Solutions that had not yet been applied were evaluated via simulation. Finally, in the Control phase, a monitoring plan was introduced to sustain improvements. The project successfully reduced food waste from 1.5% to 0.88% and increased OEE from 48% to 58.5%, exceeding the initial targets. Future work should investigate and address the issue of excessive ambient heat in the factory, as it may adversely affect equipment performance and reliability. Additionally, reducing normal variations in machine output is recommended to improve process stability.

References

Azra, M.A. and Dwijayanti, K., "Total productive maintenance analysis of the oven machine using overall equipment effectiveness method (Case study at CV. Halalan Thoyiban Bakery)," *Journal of Industrial Engineering and Halal Industries*, vol. 3, no. 1, pp. 49–56, 2022.

Buer, S.V., Semini, M., Strandhagen, J.O. and Sgarbossa, F., "The complementary effect of lean manufacturing and digitalisation on operational performance," *International Journal of Production Research*, vol. 59, no. 7, pp. 1976–1992, 2021.

Chauhan, C., Dhir, A., Akram, M.U. and Salo, J., "Food loss and waste in food supply chains: A systematic literature review and framework development approach," *Journal of Cleaner Production*, vol. 295, p. 126438, 2021.

Čiarnienė, R. and Vienažindienė, M., "Lean manufacturing: Theory and practice," *Economics and Management*, vol. 17, no. 2, pp. 726–732, 2012.

Corigliano, O. and Algieri, A., "A comprehensive investigation on energy consumptions, impacts, and challenges of the food industry," *Energy Conversion and Management: X*, vol. 23, p. 100661, 2024.

Dora, M., Kumar, M. and Gellynck, X., "Determinants and barriers to lean implementation in food-processing SMEs: A multiple case analysis," *Production Planning & Control*, vol. 27, no. 1, pp. 1–23, 2016.

Dora, M., Wesana, J., Gellynck, X., Seth, N., Dey, B. and De Steur, H., "Importance of sustainable operations in food loss: Evidence from the Belgian food processing industry," *Annals of Operations Research*, vol. 290, no. 1, pp. 47–72, 2020.

Garcia-Garcia, G., Singh, Y. and Jagtap, S., "Optimising changeover through lean-manufacturing principles: A case study in a food factory," *Sustainability*, vol. 14, no. 14, p. 8279, 2022.

Goncharuk, A.G., et al., "Baking business sustainability through life cycle management," 2023.

Goodwin, L., "The global benefits of reducing food loss and waste, and how to do it," World Resources Institute, 2023.

Hung, H.C. and Sung, M.H., "Applying Six Sigma to manufacturing processes in the food industry to reduce quality cost," *Scientific Research and Essays*, vol. 6, no. 3, pp. 580–591, 2011.

Kholil, M., Haekal, J., Suparno, A., Savira, D. and Widodo, T., "Lean Six Sigma integration to reduce waste in tablet coating production with DMAIC and VSM approach," *International Journal of Scientific Advances*, vol. 2, no. 5, 2021.

Lakshmanan, R., Nyamekye, P., Virolainen, V.M. and Piili, H., "The convergence of lean management and additive manufacturing: Case of manufacturing industries," *Cleaner Engineering and Technology*, vol. 13, p. 100620, 2023.

Leksic, I., Stefanic, N. and Veza, I., "The impact of using different lean manufacturing tools on waste reduction," *Advances in Production Engineering & Management*, vol. 15, no. 1, pp. 71–84, 2020.

Liu, Z., De Souza, T.S.P., Holland, B., Dunshea, F., Barrow, C. and Suleria, H.A.R., "Valorization of food waste to produce value-added products based on its bioactive compounds," *Processes*, vol. 11, no. 3, p. 840, 2023.

Maalouf, M. and Zaduminska, M., "A case study of VSM and SMED in the food processing industry," *Management and Production Engineering Review*, vol. 10, no. 2, pp. 60–68, 2019.

Ministry of Environment, Water and Agriculture, "Minister of Environment: Saudi Arabia is working to reduce food waste by 50% by 2030," 2020.

Moshayedi, A.J., Roy, A.S., Liao, L., Khan, A.S., Kolahdooz, A. and Eftekhari, A., "Design and development of FOODIEBOT robot: From simulation to design," *IEEE Access*, vol. 12, pp. 36148–36172, 2024.

Nath, P.C., Ojha, A., Debnath, S., Sharma, M., Nayak, P.K., Sridhar, K. and Inbaraj, B.S., "Valorization of food waste as animal feed: A step towards sustainable food waste management and circular bioeconomy," *Animals*, vol. 13, no. 8, p. 1366, 2023.

Nwokediegwu, Z.Q., et al., "AI-driven waste management systems: A comparative review of innovations in the USA and Africa," *Engineering Science & Technology Journal*, vol. 5, no. 2, pp. 150–157, 2024.

Pramono, Y.B. and Utami, A.R., "Optimizing the production process of biscuit industry using DMAIC method," *IOP Conference Series: Earth and Environmental Science*, vol. 1364, no. 1, p. 012080, 2024.

Sacadura, L.M.F.C. and Tenera, A.M.B.R., "Integrating value and lean management in manufacturing processes," *2011 International Conference on Management and Service Science*, pp. 1–5, 2011.

Sarker, A., Ahmmed, R., Ahsan, S.M., Rana, J., Ghosh, M.K. and Nandi, R., "A comprehensive review of food waste valorization for the sustainable management of global food waste," *Sustainable Food Technology*, vol. 2, no. 1, pp. 48–69, 2023.

Siddiqua, A., Hahladakis, J.N. and Al-Attiya, W.A.K.A., "An overview of the environmental pollution and health effects associated with waste landfilling and open dumping," *Environmental Science and Pollution Research*, vol. 29, no. 39, pp. 58514–58536, 2022.

Skaf, L., Franzese, P.P., Capone, R. and Buonocore, E., "Unfolding hidden environmental impacts of food waste: An assessment for fifteen countries," *Journal of Cleaner Production*, vol. 310, p. 127523, 2021.

Sobaih, A.E.E., "Saudi Zero Food Waste Certification: A novel approach for food waste management in Saudi Arabia," *Agronomy*, vol. 13, no. 6, p. 1654, 2023.

Tannady, H., Gunawan, E., Nurprihatin, F. and Rahayu, F., "Process improvement to reduce waste in instant noodle manufacturing," *Journal of Applied Engineering Science*, vol. 17, pp. 203–212, 2019.

U.S. Environmental Protection Agency, "Wasted food: A scale," 2022.

United Nations Environment Programme, *Food Waste Index Report 2021*, 2021.

United Nations Environment Programme, *Food Waste Index Report 2024: Think Eat Save—Tracking Progress to Halve Global Food Waste*, 2024.

Wang, C.N., Vo, T.T.B.C., Chung, Y.C., Amer, Y. and Truc Doan, L.T., "Improvement of manufacturing process based on value stream mapping: A case study," *Engineering Management Journal*, vol. 36, no. 3, pp. 300–318, 2023.

Widiwati, I.T.B., Liman, S.D. and Nurprihatin, F., "The implementation of Lean Six Sigma approach to minimize waste at a food manufacturing industry," *Journal of Engineering Research*, 2024.

.

Biographies

Dr. Kaouther Ghacham is an Associate Professor in the Department of Industrial and Systems Engineering at the College of Engineering, Princess Nourah bint Abdulrahman University (PNU), Riyadh, Saudi Arabia. She earned her PhD in Industrial Engineering from the College of Engineering of Tunis. Dr. Ghacham has more than 18 years of academic experience across Tunisia and Saudi Arabia, teaching courses in operations research, simulation, design of experiments, quality, and project management. Her research focuses on optimization techniques, energy systems, computational fluid dynamics (CFD), simulation modeling, and process improvement. She has authored over 100 peer-reviewed publications and presented more than 18 international conferences.

Shoug Ghanem Alshawi is an Industrial and Systems Engineer based in Saudi Arabia. She holds a Bachelor's degree in Industrial and Systems Engineering from Princess Nourah bint Abdulrahman University (PNU). With two years of experience in management consulting as an Associate Consultant, she is currently serving as a Strategy Oversight GDP trainee at Qiddiya Investment Company. She also has a strong background in sustainability, contributed to the development of multiple sustainability strategies. She has created guidelines for selecting appropriate sustainability reporting frameworks and collaborated with various sustainability experts.

Raghad Mohammed Aljaloud is an Industrial and Systems Engineering graduate from Princess Nourah bint Abdulrahman University, Saudi Arabia. She gained professional experience at Riyadh Airports Company in logistics and inventory management, and served on quality and reporting committees at the Engineering Club and IEOM Club. She has earned recognition in multiple competitions, including first place in the department graduation project competition, with interests in supply chain, quality improvement, and process optimization.

Malath Abdulkarim Alrawdhan is an Industrial and Systems Engineer based in Saudi Arabia. She holds a Bachelor's degree in Industrial and Systems Engineering from Princess Nourah bint Abdulrahman University (PNU). She gained training experience at Elm Company in the Business Excellence Department as part of the Quality Assurance team, where she contributed to various projects across the organization. She was recognized by the Education and Training Evaluation Commission for achieving the highest score in the Industrial Engineering readiness exam among PNU graduates. She is particularly interested in quality assurance and process optimization, with a focus on driving continuous improvement and organizational excellence.

Munerah Saleh Alrudhyan is an Industrial and Systems Engineer based in Saudi Arabia. She holds a Bachelor's degree in Industrial and Systemsخ Engineering from Princess Nourah bint Abdulrahman University (PNU) and has a strong interest in process optimization and operational efficiency. She has project management experience with the National Industrial Development and Logistics Program (NIDLP), a Vision 2030 initiative, and supply chain experience with Riyadh Airports. These experiences have enhanced her analytical and problem-solving skills, preparing her to contribute effectively to the field of industrial engineering.

Lial Hamad Almari is an Industrial and Systems Engineer based in Saudi Arabia. She holds a Bachelor's degree in Industrial and Systems Engineering from Princess Nourah bint Abdulrahman University (PNU) and currently works as a Market Research Associate. She has experience applying the DMAIC methodology to improve operational efficiency and sustainability in industrial settings, particularly in the food production sector. Her expertise includes process improvement, data analysis, and AI applications, and she is passionate about using technology to enhance productivity and operational excellence.