Arab Academy for Science, Technology and Maritime Transport

College of Engineering and Technology

Industrial And Management Engineering Department

B.Sc. Final Year Project

Implementing Digital Kaizen in the Confectionery Industry

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Implementing Digital Kaizen in the Confectionery Industry

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7	Recommendations and Conclusions	Jana Amr Seif El Yassin

We dedicate this research paper to our dearest families and friends, who have been our supporters until our research is fully complete, and our professors who, for months, have motivated us attentively to accomplish our work with confidence.

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Finally, we would like to thank our families for encouraging us to begin and complete this project. We improved this report because of their feedback and suggestions.

ABSTRACT

This project examines the implementation of Digital Kaizen in a gum and candy manufacturing facility in Egypt, aiming to reduce waste, enhance packaging line efficiency, and enable real-time quality monitoring. Through a detailed case study at Company X, major challenges were identified, including frequent machine stoppages, inconsistent packaging material quality, and the lack of reliable performance data. Root cause analysis tools such as Fishbone diagrams, Pareto charts, and 5 Whys were applied to uncover and address the underlying issues.

A customized Power BI dashboard and reports were developed to monitor rework and defect rates in real time, providing visual insights that supported ongoing improvement efforts. Additional interventions included experiments on packaging material quality and the implementation of a dynamic sampling system to improve defect classification accuracy. As a result, the project achieved measurable improvements in operational performance, reduced rework levels, and established a sustainable framework for continuous improvement.

This study demonstrates how integrating traditional Kaizen principles with advanced digital tools like Power BI can transform operations in the confectionery industry

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Chapter One

1 INTRODUCTION

1.1 CONFECTIONERY INDUSTRY

The confectionery sector is a lively and rapidly evolving field that satisfies the common human desire for sweet treats, including chocolates, candies, chewing gum, toffees, and sugar-free options. On a global scale, this industry has a considerable economic impact, producing an estimated revenue of around $221.6 billion in 2024. In Egypt, the confectionery market is projected to reach a volume of about $3.5 billion in 2024, accounting for 7.78% of the overall food industry.

The confectionery sector is continually changing, marked by shifting customer preferences and intense competition. Companies are increasingly focused on enhancing efficiency, sustainability, and reducing waste. A latest trend worldwide involves adopting digital transformation strategies to streamline operations, improve quality, and boost productivity. A recently embraced strategy is Digital Kaizen, which integrates the concept of ongoing improvement with the digital technologies available today.

1.2 INTRODUCTION TO KAIZEN

Kaizen, a term from Japan translating to "continuous improvement," represents a management philosophy based on the understanding that small, incremental changes can result in substantial long-term advancement. Originating from the Japanese words "kai" (change) and "zen" (better), Kaizen highlights the importance of gradual improvements in processes, productivity, efficiency, and quality. This philosophy relies on the active participation of all employees, from top executives to frontline workers, cultivating a culture of teamwork, collaboration, and problem solving. The fundamental principles of traditional “Kaizen” focus on continuous improvements through collaborative efforts and systematic problem solving. Kaizen is vital in comprehending and applying digital transformation by highlighting ongoing improvement through its essential principles. It promotes engagement from all levels of the organization, valuing the unique perspectives and experiences of team members, ranging from senior management to frontline personnel. Kaizen encourages continuous, incremental enhancements, where small changes made over time can lead to significant breakthroughs and critical transformations. In contrast to one off innovations, Kaizen emphasizes ongoing, gradual improvements that guarantee sustainability and flexibility in a consistently evolving business landscape. This approach is not confined to the manufacturing sector; it extends across various fields, including services, public sector work, and nonprofit organizations. The central concept is to identify and eliminate waste, optimize workflows, and standardize processes, which results in enhanced efficiency and improved resource utilization to maximize return on investment (ROI).

1.2.1 Kaizen Methodologies

The Kaizen approach is founded on several core principles, such as valuing individuals, reducing waste (Muda), and promoting collaboration. It is based on the belief that ongoing improvement is a continuous journey, rather than a singular occurrence. To successfully apply Kaizen, organizations frequently adopt different methodologies adjusted to their unique requirements and situations. Here are the four primary methodologies of Kaizen:

1.3 DIGITALIZATON AND KAIZEN

Digital transformation (DX) represents a major change across industries, propelled by the incorporation of digital technologies into every aspect of business operations. This change redefines conventional practices, such as methodologies like Kaizen, which emphasize continuous improvement via small, incremental adjustments. The transition from traditional Kaizen to Digital Kaizen illustrates this evolution, integrating digital tools and data analytics to improve efficiency and foster innovation.

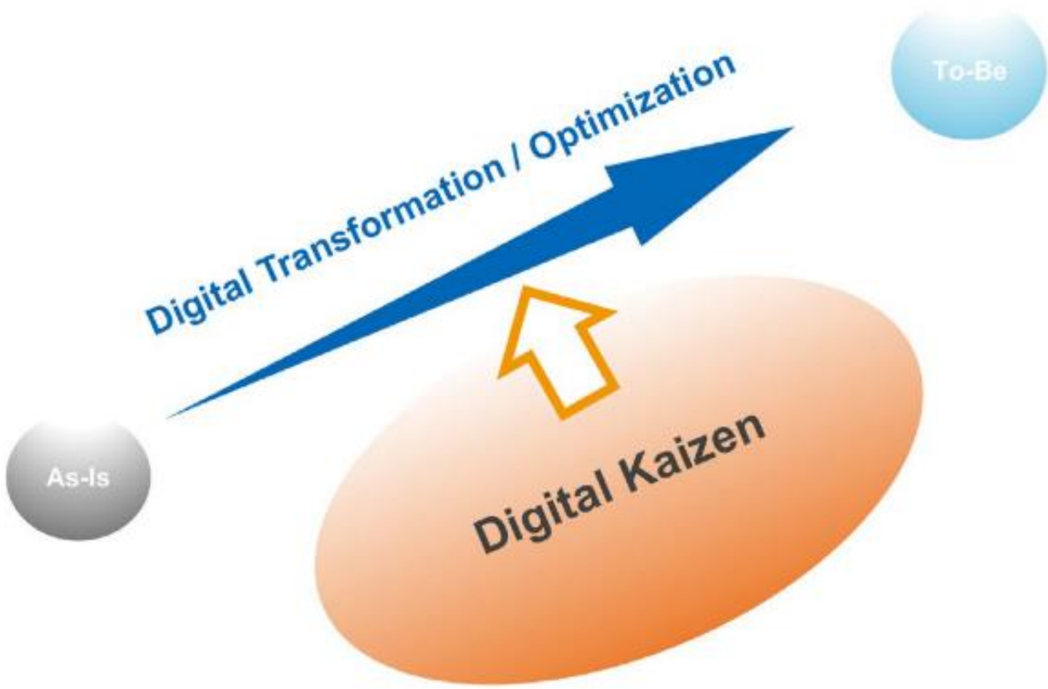


Figure 1-1-DX

1.3.1 Digital Kaizen

Digital Kaizen effectively integrates rapidly advancing digital technologies into kaizen initiatives, maximizing their potential to drive digital transformation and optimization. Achieving successful digital transformation through kaizen cannot be confined to the limits of traditional analog kaizen. Furthermore, it necessitates a thorough comprehension of digital technology and the capability to implement it effectively.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

Enabling real-time quality monitoring and continuous improvement, to reduce rework, increase global efficiency, and minimize production stoppages.

1.4.2 Objectives

To achieve our main aim, several objectives needed to be executed:

- Enable real time tracking of Rework% and PPM by June 2025
- Improve the Global Efficiency of the system to 90% by the end of June 2025
- Reduce the rework percentage in the packaging line to 1.60% by the end of June 2025
- Identify and reduce the average number of stoppages on the packaging line by the end of June 2025

The SMART criteria can be applied to the following objectives:

Specific: Define measurable goals to reduce errors and improve system efficiency

Measurable: Set targets for error reduction, system efficiency, rework, and downtime improvements

Achievable: Ensure objectives are practical by leveraging resources and team expertise

Relevant: Align goals with system capabilities and achievable timelines

Time Bound: Establish a timeline of 2 to 6 months to achieve each objective effectively.

1.5 OUTLINE

This document consists of seven chapters, including the present one. The structure of the rest of this document is organized as follows:

Chapter Two presents a literature review encompassing all the collected articles and papers related to the proposed solution.

Chapter Three briefly covers the industrial process of Company X and its problems, which were identified.

Chapter Four outlines the methodology we will follow to implement our proposed solution.

Chapter Five focuses on implementing a Power BI Dashboard for real-time monitoring.

Chapter Six covers the recommendations and conclusions for our project.

Chapter Seven: References

1.6 PROJECT IMPACT

This project had a significant impact on the packaging line's performance, visibility, and overall operational efficiency. By identifying material related stoppages and quantifying their effects through structured experiments, the team was able to uncover the direct relationship between packaging material quality and production losses. As a result, data driven decisions could be made regarding material selection, supplier specifications, and handling practices, leading to a clear reduction in rework and unplanned downtime.

The integration of digital tools, particularly the Power BI dashboard, introduced a new level of transparency across production, quality, and maintenance functions. Teams gained the ability to monitor real time KPIs such as Rework Percentage, PPM, MTBF, and Availability, and to compare performance by shift, machine, and SKU. This significantly improved response time, decision making accuracy, and cross functional alignment.

In addition, the project reinforced the adoption of standard operating procedures, OEM guidelines, and structured maintenance routines, supporting long term equipment reliability. While the defect detection sensor system posed technical challenges, the project provided a realistic roadmap for future implementation through phased recommendations. The deployment of digital weighing systems and structured sampling methods also enabled more accurate and consistent quality control.

Overall, the project advanced the organization's digital kaizen initiative, bridging the gap between manual operations and smart manufacturing practices. It not only delivered immediate performance improvements but also laid the foundation for sustainable, data driven continuous improvement on the packaging line.

Chapter Two

2 LITERATURE REVIEW

This chapter presents the methodology and tools used to conduct a structured literature review on Digital Kaizen in the confectionery industry. It begins by describing the review methodology, including the databases searched, the keywords applied, and the inclusion and exclusion criteria used to select relevant literature. The chapter then explains the use of VOS viewer for bibliometric mapping, demonstrating how key research themes and keyword relationships were visualized to ensure thematic consistency.

Next, the chapter outlines the fundamental waste types in traditional Kaizen Muri, Mura, and Muda which form the foundation for continuous improvement. It further explores the digital tools and technologies that advance Kaizen practices, such as big data analytics, smart autonomous systems, and the Internet of Things, enhancing the identification and elimination of waste. Finally, the chapter highlights the benefits of implementing Digital Kaizen, emphasizing real-time monitoring, improved collaboration, employee involvement, and alignment with Industry 4.0 technologies, leading to sustainable and scalable operational improvements.

2.1 REVIEW METHODOLOGY

The purpose of this review is to identify documents that provide a clear explanation of methods for implementing digital kaizen in industry. The Egyptian Knowledge Bank database was used, with English sources selected and related documents obtained from Elsevier's Scopus Database and Clarivate Web of Science. To narrow down our documents into specific and related searches for our problem, we used keywords such as Kaizen, Digital Kaizen, Lean, Food Packaging, and Rework. Furthermore, we included some criteria for filtering the found documents, focusing on publication dates, subject area, language, and document type as shown in the following Table 2-1 Summary of Inclusions and Exclusions Criteria.

Table 2-1 - Summary of Inclusions and Exclusions Criteria

Criteria	Inclusions	Exclusions
Publishing Date	2015 -2024	Before 2015
Subject Area	Kaizen, Digital Kaizen, Lean, Food Packaging, Rework	Studies that are focused on unrelated industries like pharmaceuticals, automotive, or non-food sectors
Language	English	
Document Type	Conference paper, Book, Book Chapter, Journals, Articles	Note, Letter

2.2 BIBLIOMETRIC MAPPING WITH VOS VIEWER

To ensure that the selected keywords are cohesive and pertain to the same research field or thematic area, VOS-viewer is utilized. VOS viewer is a software application designed for building and visualizing bibliometric networks. These networks may include elements such as journals, researchers, or individual publications, and can be created based on citation, bibliographic coupling, co-citation, or co-authorship relationships. Additionally, VOS viewer provides text mining capabilities that enable the construction and visualization of co-occurrence networks of significant terms derived from a collection of scientific literature.

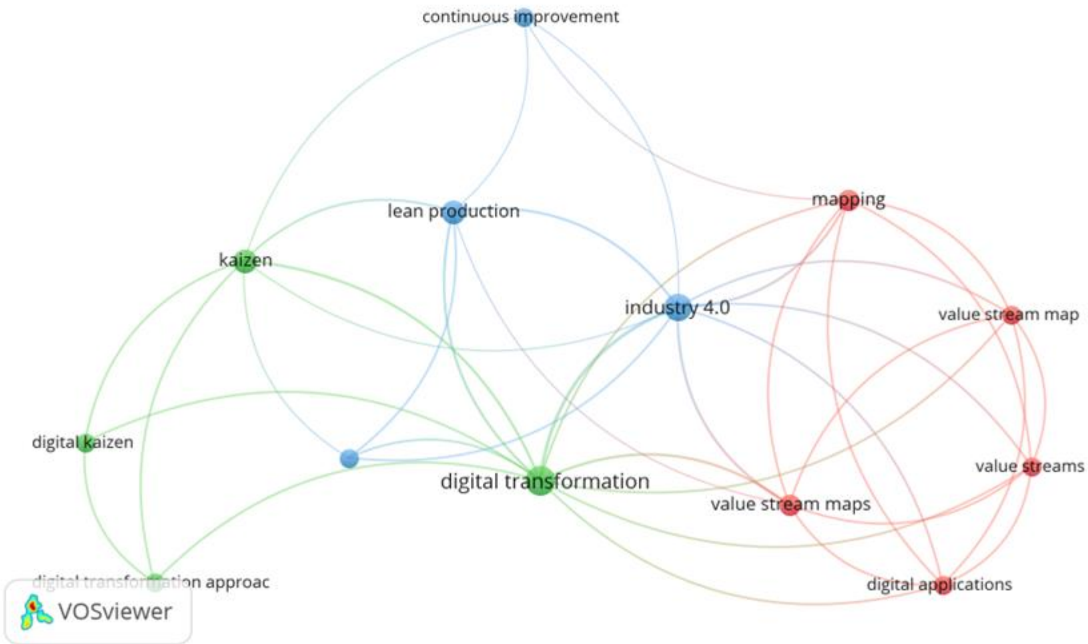


Figure 2-1-Vos viewer

The VOS viewer visualization presented above illustrates the connections among keywords such as "digital transformation," "Kaizen," "Industry 4.0," and other related terms. The network is categorized into clusters indicated by various colours, with each cluster representing interconnected topics. For instance, the green cluster emphasizes the relationships between "digital transformation," "Kaizen," and "digital Kaizen," highlighting their importance in continuous improvement initiatives.

This visualization is important because it offers a straightforward, data-oriented depiction of the relationships among these subjects. By recognizing these connections, researchers can align their studies with current literature and pinpoint areas for additional investigation. It also aids in the choice of coherent topics, promoting consistency and concentration in research efforts.

2.3 TRADITIONAL KAIZEN TYPE OF WASTE

In traditional Kaizen, a foundational philosophy for continuous improvement, three primary types of waste are identified: **Muri**, **Mura**, and **Muda**. [1][2][3].

Muri (Overburden): This refers to putting excessive strain on individuals or machinery beyond their limits. This may result in stress, exhaustion, and equipment breakdowns, which can adversely affect productivity and quality. To address Muri, organizations should make sure that workloads are realistic and that machinery is not overextended. [1].

Mura (Unevenness): Refers to variability or inconsistency in processes. This inconsistency can present itself as uneven workloads, fluctuating production rates, or varying quality. Mura creates inefficiencies because it requires additional resources to manage these fluctuations. To reduce Mura, it's essential to standardize processes and balance workloads to ensure a smoother flow of operations. Mura leads to inefficiencies as additional resources are required to manage the fluctuations. Reducing Mura involves standardizing processes and balancing workloads to ensure a smoother flow of operations.[3].

Muda (Waste): Refers to any activity that uses resources but does not enhance the product or service. The objective is to identify and eliminate these non-value-adding activities. This includes waste and activities that do not add value, which can be classified into seven specific types known as **T.I.M.W.O.O.D**, which stands for:

- **T**ransport
- **I**nventory
- **M**otion
- **W**aiting
- **O**ver-processing
- **O**ver-production
- **D**efects

Identifying and addressing waste is essential in the Kaizen philosophy to streamline processes and enhance overall productivity in any industry, including confectionery. [2].

2.4 DIGITAL TOOLS AND TECHNOLOGIES IN DIGITAL KAIZEN INITIATIVES

Digital Kaizen enhances traditional Kaizen principles by incorporating advanced digital technologies, which improve the identification and elimination of non-value-added activities. In traditional Kaizen, waste is minimized through incremental improvements facilitated by employee collaboration and manual observation. [4]. As industries evolve, the increasing complexity of processes and the vast amount of data require more advanced tools. Digital Kaizen utilizes technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to identify inefficiencies in real time, optimize workflows, and ensure continuous improvement. [5]. These digital tools not only speed up the elimination of non-value-added activities but also offer predictive and prescriptive insights, allowing organizations to achieve sustainable and data-driven operational excellence.

2.4.1 Big Data Analytics

Big data analytics empower organizations to make informed, data-driven decisions by collecting, analyzing, and visualizing large volumes of information. In the context of

Digital Kaizen, this tool is instrumental in identifying inefficiencies, optimizing workflows, and predicting potential bottlenecks. By utilizing analytics, companies can continuously improve their processes, reduce waste, and enhance overall productivity.[5][3].

2.4.2 Smart Autonomous Systems

Smart autonomous systems, powered by artificial intelligence (AI), operate independently to perform tasks with minimal human intervention. They are crucial for automating repetitive tasks, ensuring consistency, and enhancing efficiency. [3]. In the context of Digital Kaizen, these systems facilitate real-time monitoring and adaptive responses, such as adjusting production lines based on quality feedback.[5].

2.4.3 Cloud Computing

Cloud computing provides real-time data storage, sharing, and collaboration capabilities. This technology allows for seamless communication and cooperation among different departments and locations. Within the framework of Digital Kaizen, cloud platforms enable teams to access up-to-date data, exchange insights, and work together to effectively implement improvements. [5][3].

2.4.4 Industrial Internet of Things (IoT)

The Internet of Things (IoT) connects machines, sensors, and devices to collect, share, and analyze data in real-time. This connectivity is essential for Digital Kaizen, as it allows for real-time monitoring of production processes, predictive maintenance, and improved operational transparency. IoT helps identify and address inefficiencies quickly and effectively. [5][3].

2.4.5 Customized Digital Platforms

Digital platforms customized to meet an organization's needs enhance collaboration and provide ongoing feedback loops. These platforms act as a centralized hub for data analysis, process improvement, and team communication, supporting the Kaizen philosophy of involving employees in continuous improvement. [5][3][6].

2.4.6 Industrial Artificial Intelligence (IAI)

Industrial AI (IAI) analyzes complex datasets to predict outcomes and make autonomous decisions. In the context of Digital Kaizen, IAI is essential for optimizing production schedules, enhancing quality control, and predicting machine failures. This proactive approach leads to smoother operations and increased productivity.

These tools and technologies collectively shift traditional Kaizen to a digital-first approach, improving the speed, accuracy, and effectiveness of continuous improvement efforts. By integrating advanced systems, organizations can quickly adapt to market demands, reduce waste, and promote a culture of innovation.[5][3].

2.5 BENEFITS OF IMPLEMENTING DIGITAL KAIZEN

The integration of advanced digital tools and technologies into Digital Kaizen initiatives provides the foundation for achieving its transformative benefits. Tools such as IoT, AI, big data analytics, and cloud computing enable real-time monitoring, data-driven decision-making, and enhanced collaboration, making it possible to implement continuous improvement on a scale. These technologies empower organizations to not only identify and eliminate non-value-added activities but also create interconnected systems that align with Industry 4.0 principles.[7].

2.5.1 Leverages Data Analytics and Real-Time Monitoring

Digital Kaizen relies on tools like big data analytics and IoT to collect, process, and analyse data in real time. This capability enables organizations to monitor operations continuously, identify inefficiencies, and take immediate corrective actions. [7] For instance, real-time data analytics can highlight bottlenecks in production or detect anomalies in processes, ensuring that improvements are both timely and precise. By integrating data-driven insights into the decision-making process, organizations achieve a higher level of operational efficiency and accuracy. [5][3].

2.5.2 Promotes Collaboration Across Different Departments

One of the core tenets of Kaizen is teamwork, and Digital Kaizen enhances this principle through advanced platforms and technologies. Cloud computing and customized digital platforms facilitate the seamless sharing of information and insights across departments, breaking down silos and fostering a culture of collaboration. Teams can work together in real time to address inefficiencies, brainstorm improvements, and implement solutions, ensuring a unified approach to continuous improvement. This collaborative environment aligns teams toward shared goals and accelerates the implementation of Digital Kaizen initiatives.[8][9].

2.5.3 Involves Employees at All Levels

Digital Kaizen highlights the significance of involving employees at all levels, from front-line workers to management, in continuous improvement efforts. Utilizing digital tools like feedback platforms and data visualization dashboards empowers employees by offering actionable insights and opportunities to propose enhancements. By maintaining transparency around data and progress, employees are more engaged and motivated to support the organization's objectives. This involvement not only fosters improvement initiatives but also cultivates a culture of ownership and accountability.[10].

2.5.4 Aligns with Industry 4.0

Digital Kaizen is closely aligned with Industry 4.0 technologies, including the Internet of Things (IoT), artificial intelligence (AI), and cloud computing. These technologies create interconnected and adaptive smart systems that enable predictive maintenance, automation, and enhanced decision-making. Such capabilities are essential for improving efficiency and competitiveness in today's dynamic markets. By utilizing Industry 4.0 tools, Digital Kaizen helps organizations stay at the forefront of technological advancements, integrating continuous improvement into their smart manufacturing and operational processes. [2][3][11].

2.5.5 Supports Sustainable and Scalable Transformation

One of the most important outcomes of Digital Kaizen is its capacity to foster sustainable and scalable change. By leveraging technologies that minimize waste, optimize resource utilization, and enhance productivity, organizations can ensure that improvements are enduring and environmentally friendly. Furthermore, digital tools enable these enhancements to be scaled across various facilities, departments, or regions without sacrificing efficiency or consistency. This capability ensures that continuous improvement efforts can evolve alongside the organization, maintaining their effectiveness over time. [5][3][12].

2.6 POWER BI IN CONTINUOUS IMPROVEMENT

Power BI, a business intelligence tool developed by Microsoft, has gained widespread adoption across various industries as a means of enhancing operational visibility, data-driven decision-making, and continuous improvement. As industries embrace digital transformation, the ability to monitor performance indicators in real time has become essential. Power BI supports continuous improvement by enabling organizations to collect, analyze, and visualize large volumes of data through customizable dashboards and interactive reports. Studies have demonstrated its effectiveness in streamlining operations, particularly in production and supply chain environments, where key performance indicators (KPIs) such as efficiency, defect rates, and cycle times need to be continuously monitored.[13].

For example, in a supply chain application, Power BI enables real-time tracking of inventory levels, lead times, and supplier performance, leading to better responsiveness and reduced operational bottlenecks. In the healthcare sector, dashboards built with Power BI have been used to monitor service quality metrics and drive improvements based on visual feedback loops. Moreover, Power BI is often favored for its low-cost deployment, seamless integration with Microsoft Excel and SQL Server, and support for advanced data modeling making it accessible even for small to medium enterprises. These attributes Power BI as a practical enabler of continuous improvement in both digital and lean operational strategies. [13].

2.7 REVIEW OUTCOME

The literature reveals a clear progression from traditional Kaizen methodologies toward digitally enhanced continuous improvement systems. Digital Kaizen integrates technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to enable real-time performance monitoring, predictive insights, and faster, more informed decision-making. Tools like Power BI have proven effective in visualizing operational data, identifying inefficiencies, and supporting collaboration across departments. These technologies align with Industry 4.0 principles, offering scalable and sustainable solutions for quality improvement, waste reduction, and productivity enhancement. The reviewed research emphasizes the strategic value of digital tools in enabling continuous improvement efforts across various sectors.

Chapter Three

3 CASE STUDY

3.1 ETHICS CONSIDERATION

3.1.1 Canons of Ethics

During our project, we gained access to Company X's operations and resources; consequently, we were obligated to adhere to stringent ethical standards to manage all project aspects responsibly and professionally. The following ethical principles were essential to our work.

Confidentiality

Given our direct involvement with Company X, it was vital to safeguard their confidential information. We ensured that we did not disclose any specifics about their procedures, data, or operations to anyone outside our project team to honor their trust and protect their privacy.

Public Welfare

Throughout our engagement with Company X, we consistently prioritized the safety and well-being of all employees and products. We were diligent in ensuring that our solutions had a beneficial impact on everyone involved.

Conflict of Interest

During our time at the plant, we were careful to avoid any conflicts of interest that could affect our decisions or the trust between us and the company. We maintained transparency and focused solely on the project's objectives to ensure fair and unbiased results.

Honesty and Impartiality

Being directly involved in the plant demanded that we assess processes and results accurately. We were committed to presenting all evaluations, data, and reports with integrity and without bias, ensuring the company received trustworthy results.

Professional Reputation

Representing ourselves and our university while working at Company X's plant was an important responsibility. We always maintained professionalism, showing respect for the company’s staff, property, and intellectual property to uphold a positive reputation for everyone involved.

By adhering to these ethical principles, which are in alignment with the standards set by the Institute of Industrial and Systems Engineers (IISE), we conducted our project in a responsible and professional manner while adding value to Company X’s operations.

3.2 COMPANY PROFILE

This study was conducted at Company X, a leading global firm in the chocolate industry that began operations in 2012. The company has established itself as a market leader, ranking first in biscuit production, second in chocolate creation, and second in gum production, with a market share of 16.3%. Operating in 80 markets, Company X employs over 91,000 people and distributes its products in more than 150 countries. Renowned for its continuous innovation, the company utilizes the latest manufacturing technologies to maintain its competitive edge in the confectionery sector. In Egypt, Company X operates several key facilities, including a biscuits plant and a chocolate plant in the 10th of Ramadan, Cairo, a business unit in the 5th Settlement, Cairo, and a gum and candy plant in Borg El Arab City, Alexandria. These strategically located facilities support the company's commitment to high-quality production and global market expansion.

3.3 PLANT OVERVIEW

The gum and candy plant of Company X is an innovative establishment committed to creating premium confections. The plant, which is outfitted with advanced equipment and a well-organized workflow, specializes in producing a wide variety of gum and candy items to satisfy demand worldwide. Among its diverse portfolio, the primary products of interest are the one-pack gum and two-pack gum, which are produced at high volumes to meet both local and export needs. The facility is equipped with multiple unit packaging machines tailored for these formats, ensuring production efficiency and operational flexibility. To uphold the highest quality standards, the plant integrates thorough manual inspections throughout the manufacturing process as part of its strong commitment to quality control. This study focuses specifically on the company's packaging line, which is divided into two main stages: primary packaging and secondary packaging. The objective is to assess and enhance the performance of this line by analyzing its current challenges and exploring digital solutions to enhance its performance.

3.4 PRIMARY PACKAGING

"Operation Process Chart"

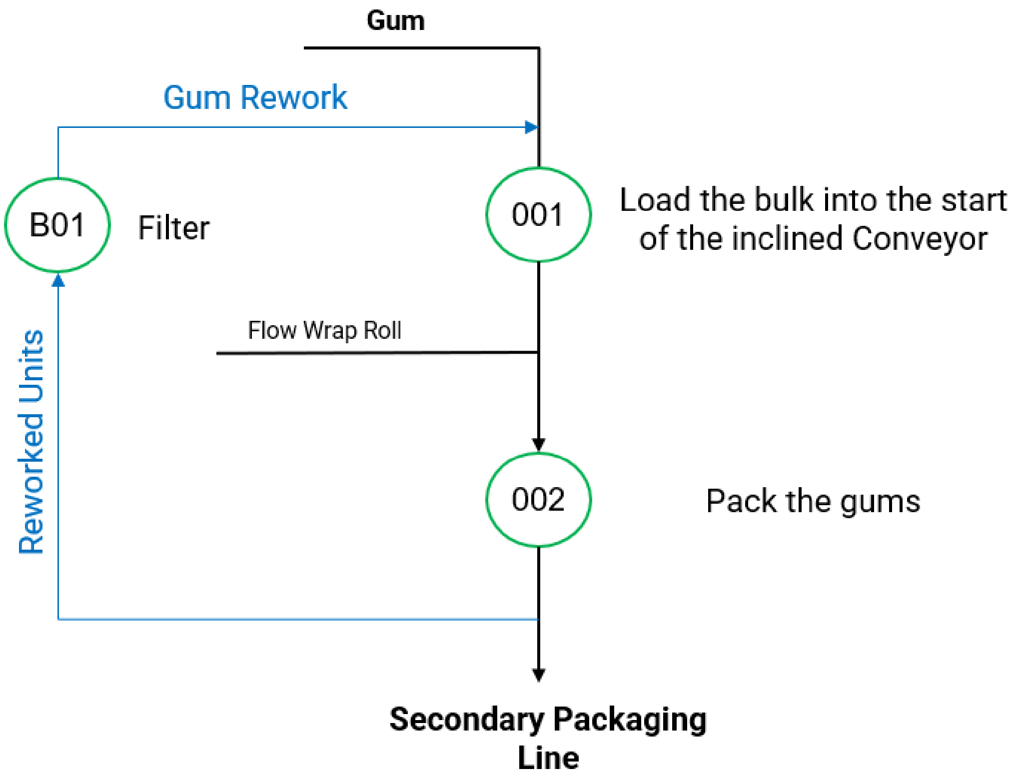


Figure 3-1-Primary Packaging

The primary packaging process begins by loading the raw material bulk gum units onto an inclined conveyor, which feeds the product continuously to the next stage. The gum is then fed into the Unit Packaging Machine to be packaged using the flow wrap packaging material, which is fed into the machine to wrap each gum unit. This material envelops each gum unit to form sealed, individual packages. Then, a filtration process takes place; if any defective or miswrapped units are detected, they are reworked by being redirected to the start of the line to undergo the packaging process again. This closed-loop rework approach ensures that only properly sealed and conforming gum units move forward in the process. Added to that, at the end of each shift, operators collect and weigh rework bags, which contain any defective or rejected gum units produced during the shift. This data is recorded per machine, and a total rework value for the entire line is calculated at the end of each day to monitor and control waste levels. Lastly, once the gum units are successfully packaged and pass the filtration stage, they proceed to the secondary packaging process

3.5 SECONDARY PACKAGING

"Operation Process Chart"

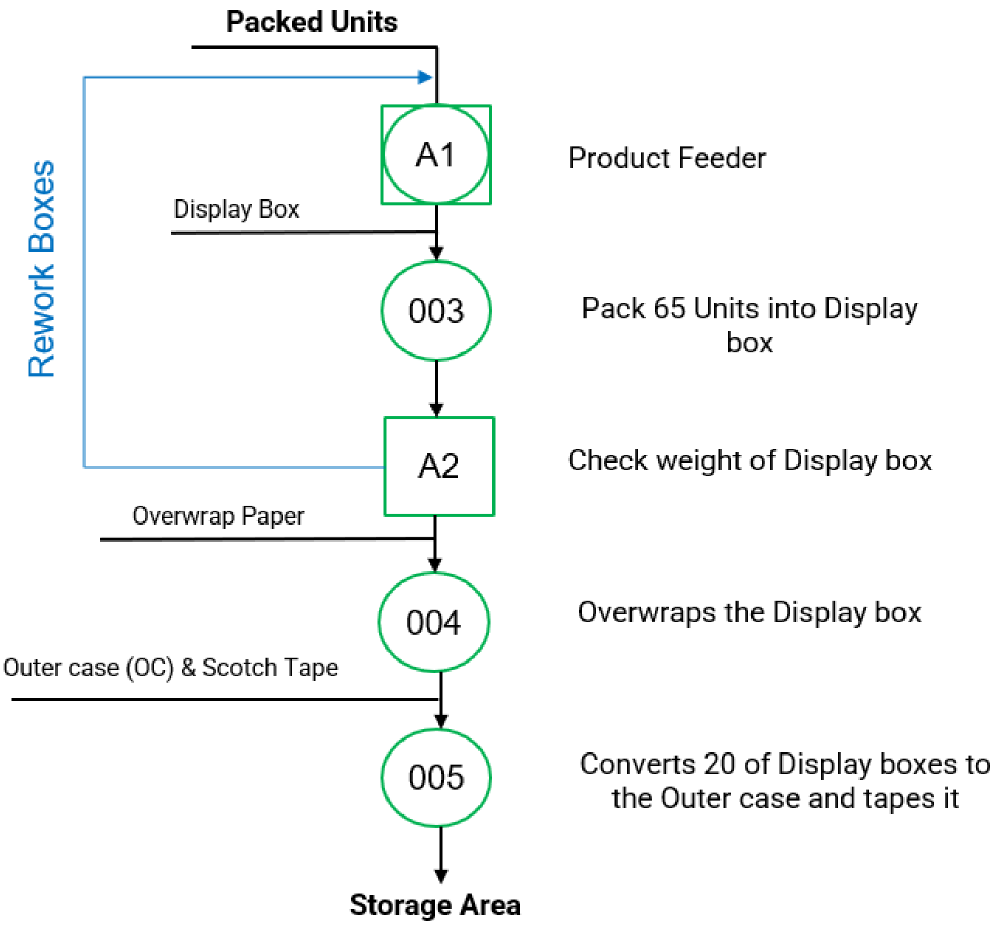


Figure 3-2- Secondary Packaging

The secondary packaging process begins as the packed gum units from the primary packaging stage enter this phase. Firstly, the products pass through Vacuum Machines, which remove any empty or improperly sealed packs to ensure only quality units continue downstream. Then, parts will pass through the Product feeder which plays a dual role: it acts as a manual inspection checkpoint where operators verify the integrity of the packed units, and serves an operational function, as the inspected gum packets are loaded into the feeder and transferred to an inclined conveyor for the next stage. The product then moves to the Display Box Packaging Machine, which automatically groups 65 gum packets into a single display box. This machine must be continuously supplied with empty display boxes to perform the grouping and packing function efficiently. Following this, the packed display boxes are transferred to the Check Weight Station, where each box is weighed to ensure it meets the target weight. If any display box fails the weight check, it is removed from the line and sent back to the Product Feeder to re-enter the secondary packaging cycle after appropriate adjustment. Only the boxes that pass the weight check proceed to the next stage.

The accepted boxes are then transferred to the Overwrap Packaging Machine, which wraps each display box using overwrap paper. This machine must be supplied with a steady feed of overwrapped paper rolls to ensure smooth and continuous operation. After overwrapping, the display boxes move to a manual packaging station, where operators manually pack 20 display boxes into an outer case. This process depends on the availability of empty outer cases, which are loaded by the operator.

Finally, the fully packed outer case is conveyed to the Taping Machine, where it is sealed using scotch tape. This marks the end of the secondary packaging process. The taped outer case is then classified as Finished Goods, ready for storage or shipment. Each step in this process is designed to ensure consistency, quality, and readiness for market distribution.

3.6 FACILITY FLOW DIAGRAM

The flow diagram provides a comprehensive overview of the packaging process for one-pack and two-pack gum products, divided into primary and secondary packaging stages. In the primary stage, Unit Packaging Machines (M/C 1 to M/C 6) handle the production of 1 pack gum, while M/C 7 and M/C 8 are dedicated to 2 pack gum. Then, the packaging process is executed through the structured steps previously described in detail. In addition, rework bags are placed at each machine, where operators collect rejected units throughout the shift; these bags are weighed at the end of each shift, and a total rework value is calculated daily for the entire line. Furthermore, to support real-time monitoring and performance tracking, the line is equipped with a digital dashboard that displays key metrics, while a centralized main server collects and stores production data, enabling traceability, historical analysis, and data-driven decision making.

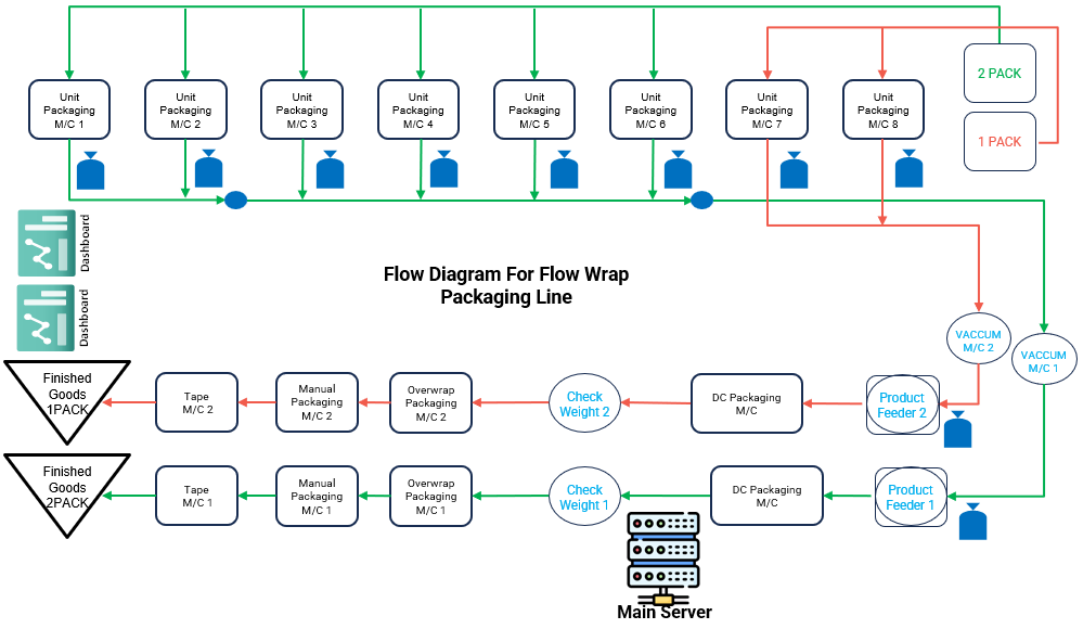


Figure 3-3 Flow Diagram

3.7 CHALLENGES LIMITING OPERATIONAL EFFICIENCY

The packaging line at Company X faced several challenges that significantly impacted on its ability to meet market demand and maintain optimal performance. First, the production capacity was insufficient to fulfill total demand, resulting in unfulfilled orders and limited responsiveness to market needs. This gap between actual output and required volume placed stress on operations. Second, the production line began supplying new international customers after a key Moroccan manufacturer shut down, placing sudden and unexpected pressure on the packaging line to absorb additional volume without prior expansion. This growth in the customer base outpaced the line's ability to scale, highlighting the need for greater capacity and flexibility. Third, the packaging process itself acted as a bottleneck, slowing down the entire production flow. The limitations in both primary and secondary packaging, such as machine downtime, material handling issues, and high rework rates, restricted throughput. Together, these three combined issues made it essential to increase capacity, thus supporting growing market demands.

3.8 PRODUCTION CAPACITY ENHANCEMENT

In response to the growing production challenges and market pressures, several key enhancements were introduced to expand the line's capacity and improve operational performance. The most significant change was the increase in the number of machines and production lines. The primary packaging section was upgraded from 8 to 10 Unit Packaging Machines, while the secondary packaging was expanded from 2 lines to 4, effectively doubling its throughput capability. This expansion not only increased output capacity but also reduced dependency on a limited number of machines, allowing for better load balancing and reduced delays.

Table 3-1 - Capacity Line

Description	Previous Capacity	Upgraded Capacity
Number of Unit Packaging M/Cs (Primary Packaging)	8 M/Cs	10 M/Cs
Secondary Packaging Line	2 Lines	4 Lines
Operational Period	August 2023 – 15th of December 2024	1st of January 2025 – Till now

Additionally, a new production layout was developed to accommodate the increased equipment while streamlining material flow and minimizing handling issues between stages. These adjustments ensured the line could now fulfill both local demand and new export commitments, particularly those inherited from the closure of the Moroccan

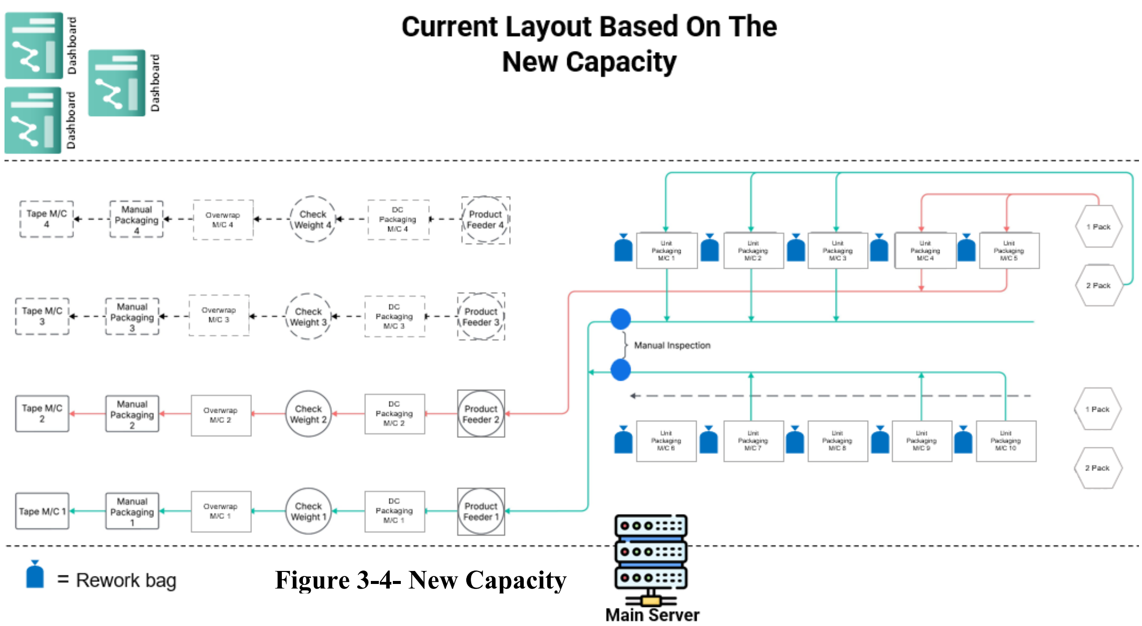


Figure 3-4- New Capacity

manufacturer. The diagram above illustrates the restructured line configuration based on these improvements.

3.9 DIGITAL TRANSFORMATION

Company X has decided to embark on a comprehensive digital transformation to enhance its operations and drive innovation across all aspects of the business.

3.9.1 Reasons for Implementing Digital Kaizen

To streamline operations and foster a continuous improvement in culture, Company X is currently applying Digital Kaizen. By adhering to established protocols, determining the reasons behind deviations, and making the required corrections to preserve consistency, this approach guarantees adherence to standards. By locating inefficiencies, determining their underlying causes, and finding potential areas for improvement, it aims to eliminate waste. The business may track performance indicators, spot issues quickly, and take immediate action to fix them by using real-time KPI monitoring. By avoiding delays, distributing workloads evenly, streamlining procedures, and increasing overall productivity while lowering lead times, the strategy also facilitates seamless production. To develop a sense of ownership and commitment among all employees, it also promotes active participation from all staff members, regardless of their roles. Finally, by facilitating proactive maintenance to avoid malfunctions and reduce unplanned production disruptions, this initiative improves maintainability. As a strategic move to boost productivity, stimulate innovation, and maintain competitiveness in a constantly shifting business landscape, Company X has implemented Digital Kaizen.

3.9.2 Digital system flow of information

The digital system implemented in the confectionery industry for gum and candy production represents a transformative shift from the previous manual method to a streamlined, data-driven approach. Starting with the input obtained from the operator and the packaging line, this system functions based on the cross-functional flow of information. Critical production data, including product flow and efficiency measures, is generated by the packing line, and the operator engages with the system by manually entering data or adjusting as needed. A Programmable Logic Controller (PLC) processes these inputs, gathering raw data from the packaging line and guaranteeing smooth connectivity with the main server. The SQL database and the time series database are two important databases that receive data from the main server, which serves as the system's central hub. While the time series database documents past trends to enable performance monitoring over time, the SQL database arranges structured data for in-depth study and reporting. The system also includes machine learning algorithms, which use information from the SQL database to identify trends, anticipate inefficiencies, and provide recommendations for optimization. Insights generated through this process are compiled by the reporting server, which plays a crucial role in transforming raw data into actionable information. A dashboard that gives operators and technicians real-time performance data to help with instant decision making and management reports that compile important analytics for higher-level strategic planning are the two formats in which the digital system's ultimate outputs are displayed. This cutting-edge digital technology represents a major improvement in the business's operating capabilities since it not only guarantees data correctness and integrity but also minimizes manual intervention, cuts down on inefficiencies, and improves the entire manufacturing process.

3.9.3 Inputs

The Programmable Logic Controller (PLC) and operator input are the two main inputs that the digital system uses to connect to the main server. Critical parameters, including machine speeds, output counts, and information on unscheduled stoppages, are among the real-time data that the PLC directly collects from the packing line. This data ensures precise and current tracking of the production process by acting as a constant stream of operational information. Also, the operator contributes manual inputs to supplement the PLC's automated data collection. These inputs consist of data like the machine in use, the SKU (Stock Keeping Unit), the mass of scrap and rework (in kilograms), scheduled stops, and planned downtimes. When combined, these inputs give the system a thorough grasp of both automated and human-monitored production features, facilitating smooth data integration and assisting in efficient decision making along the production line.

3.9.4 Outputs

A thorough dashboard that offers real-time insights into several crucial performance parameters is the digital system's output. By providing information like the scrap percentage and rework percentage, this dashboard acts as a visual interface that makes it possible to track and reduce production waste. Additionally, it shows the packaging line's global efficiency, which represents the system's overall performance, a crucial performance parameter on the dashboard of the digital system, that measures how well the manufacturing line runs to its maximum theoretical capacity. Under ideal circumstances, the maximum amount of product that may be produced in a day is represented by the theoretical production rate. It is calculated by:

$$Theoretical\ Production\ Rate(\frac{kg}{day}) = rate\ of\ machines\ \times no\ of\ machines\ \times hours\ worked\ per\ day \times weight\ per\ piece\ \times 60$$

Equation 3-1 Theoretical Production Rate

Whereas the Global Efficiency is then calculated by:

$$\boldsymbol{GE\% = \frac{Actual\ Production\ Rate\ (\frac{kg}{day})}{Theoretical\ Production\ Rate\ (\frac{kg}{day})} \times 100}$$

Equation 3-2 GE Efficiency

The actual manufacturing output is then compared to this theoretical capacity to assess global efficiency. With fewer inefficiencies like output losses, machine failures, or downtime, a production line that has better global efficiency is functioning closer to its full capacity. This indicator is the most essential KPI for company X because it shows where adjustments may be made to maximize productivity and gives a general picture of how well the production system is being used. Together with additional parameters like output mass, rework percentage, and scrap percentage, the dashboard displays global efficiency, which helps management and operators evaluate performance, fix inefficiencies, and improve overall production efficiency. Added to that, clarity on production volume is provided by additional important outputs, such as the total number of output boxes and their associated mass. The dashboard, moreover, incorporates indicators such as parts per million (PPM), a crucial quality parameter that monitors defect rates, and Mean Time Between Failures (MTBF), which measures the reliability of machinery. To guarantee correct alignment with production plans, planned stoppages are also displayed, providing a clear overview of anticipated downtime. For operators and management, this output is essential because it facilitates well-informed decision making and encourages ongoing production process improvement.

The Reporting Server is the second important output of the digital system; it gives management comprehensive analytical insights based on past production data. In addition to monitoring performance in real time, this system uses data trends to anticipate possible failures before they happen. Technology facilitates proactive maintenance, lowering unplanned downtime and increasing overall efficiency by spotting trends in machine stoppages, failure numbers, and operator interventions.

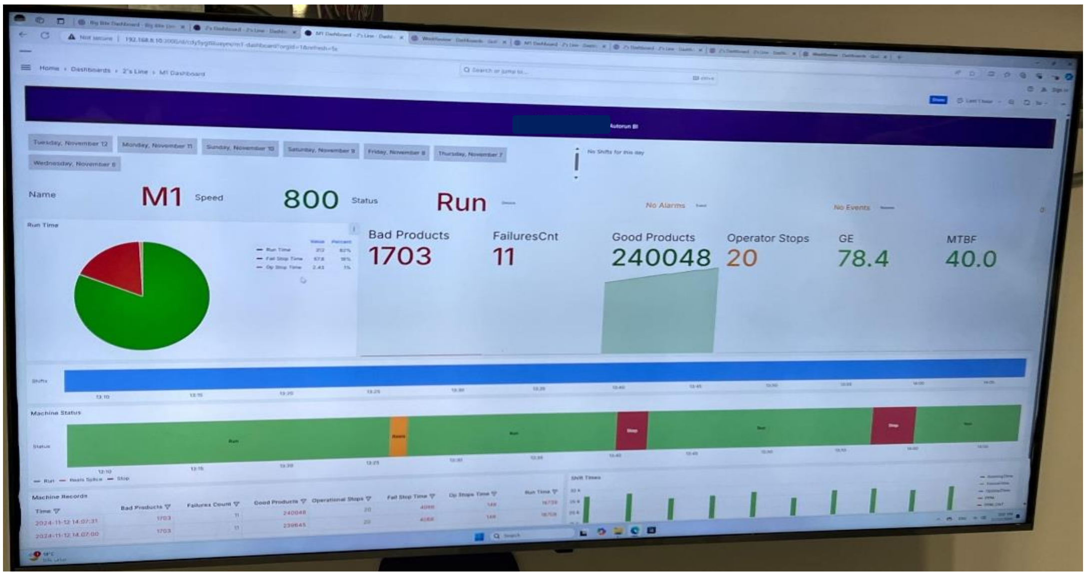


Figure 3-5- Report

C h a p t e r   F o u r

4 PROBLEM IDENTIFICATION

During our visits to Factory X, several critical issues were identified on the packaging line that present significant challenges with operational efficiency and require urgent intervention to ensure long-term performance and competitiveness. One of the key issues is the **high number of machine stoppages**, which frequently interrupt the production flow and negatively affect throughput. These stoppages were observed to result from a combination of factors, including packaging material quality, machine conditions, and operational inconsistencies. Another major concern is the **deficiency in quality performance measures** across the line, particularly in how production metrics, rework quantities, and defect counts are recorded. As data is still collected manually, it results in delays, errors, and limited visibility in real-time performance. To address these challenges, a structured analysis will be conducted using digital tools, observational studies, and root cause methodologies to identify the underlying issues and implement targeted improvements.

4.1 HIGH NUMBER OF STOPPAGES

One of the most persistent challenges encountered on the packaging line at Company X was the frequent and unplanned stoppages that occurred throughout daily operations. These stoppages not only disrupted the production flow but also caused delays, increased rework, and reduced the overall efficiency of both primary and secondary packaging stages. Operators were often required to intervene manually, restart machines, or clear blockage actions that accumulated over time and significantly affected output targets.

Recognizing the critical impact of this issue, a structured investigation was conducted to uncover its root causes. Observations during site visits, along with input from operators and shift supervisors, indicated that these stoppages stemmed from a range of technical and operational sources. To analyze these systematically, we utilized a Fishbone Diagram to map potential causes across several key categories and complemented this with a Pareto Analysis to identify which causes occurred most frequently and had the greatest impact. This dual approach enabled a deeper understanding of the problem and guided our focus toward the most influential contributing factors.

4.1.1 Packaging Material Quality and Gum Pellet Handling "MATERIAL"

Material-related issues were identified as a major cause of repeated stoppages on the packaging line, particularly concerning packaging material quality and gum pellet breakage due to improper handling. One of the most frequent sources of interruption was the use of low-quality packaging material, which created multiple complications during the flow wrapping process. Problems such as shifted carton cores, wrinkled roll surfaces, and frayed edges led to poor feeding, film tension inconsistencies, and jams within the packaging machines. These defects required frequent operator intervention to clear the machines, increasing downtime and reducing the overall efficiency of the line.

In addition to packaging faults, gum pellet breakage was a recurring issue that affected the continuity of the packaging process. Improper material handling between machines or during transfer on conveyors resulted in broken or deformed gum units that could not be wrapped properly. These damaged units often triggered sensor misreads, filter rejections, or misalignment in the feeder, each of which caused stoppages or required manual removal and rework. Gum types with higher fragility, especially mint based products, were particularly vulnerable to damage during handling transitions. These findings emphasized the importance of ensuring consistent material quality and optimizing the physical movement of gum throughout the line to minimize mechanical stress and maintain smooth, uninterrupted operation.

4.1.2 Training and Skill Level of Operators "MAN"

One of the contributing factors to the high number of stoppages is related to operator training and skill level. As part of the capacity expansion described earlier, where the number of primary and secondary packaging machines was increased, the factory had to a larger number of operators to run the additional equipment onboard. Many of these operators were newly recruited and lacked sufficient experience with the machines and the specific procedures of the packaging line. This knowledge gap led to frequent operational errors, such as improper machine adjustments, delayed responses to faults or alarms, and incorrect handling of material jams. Inexperienced operators were also more likely to overlook early warning signs of equipment issues, resulting in preventable stoppages that escalated into longer downtime. These challenges highlight the importance of structured training programs and hands-on supervision, especially when scaling up operations and integrating new personnel into an existing production system.

4.1.3 Environmental Factors and Humidity “ENVIRONMENT”

Another important factor contributing to the high number of stoppages on the packaging line is the factory’s environmental conditions, particularly humidity. The production of mint-based gum introduces inherent moisture into the environment, which significantly affects the performance of photocell sensors and other electronic detection components used on the line. These sensors are responsible for identifying the presence and position of gum units during various stages of packaging. However, in high humidity conditions, sensor sensitivity is reduced, causing them to misread or fail to detect products entirely. This leads to unregistered units, incorrect product alignment, and missed detection points, which trigger machine stoppages to prevent quality defects or downstream collisions.

Moreover, the moisture content in mint gum can also interact with surfaces and material handling components, causing sticking, slippage, or inconsistent movement across conveyors and feeders. These effects create interruptions that require manual intervention to clear or reset the system. Although these stoppages may seem minor individually, they occur frequently and cumulatively impact overall line efficiency.

This highlights the need for solutions that stabilize the production environment such as improved climate control, the use of sensor technologies designed for humid conditions. Addressing this environmental factor is critical to improving sensor reliability and minimizing unnecessary downtime.

4.1.4 Supplier Dependence and Lack of Quality Assurance "MANAGEMENT"

Under the management category, two major factors contributed to frequent stoppages. First, inconsistent supplier performance was a recurring issue, as there were no regular supplier audits in place to ensure the quality and consistency of packaging materials. This allowed poor-quality wrapping paper to reach production, often resulting in machine jams and feeding issues. Second, the factory does not have any backup suppliers in place. If the current supplier fails to deliver on time or provides low-quality material, there is no alternative source to rely on. This lack of flexibility creates a serious risk for the production line, making it vulnerable to delays and unplanned stoppages. Establishing approved backup suppliers is necessary to ensure supply continuity and reduce operational risk.

4.1.5 Sensor Malfunctions and Maintenance Gaps "MACHINE"

Under the machine category, one of the key contributors to frequent stoppages was the malfunctioning of photocell sensors, which are responsible for detecting the presence and position of gum units during the packaging process. These malfunctions were often caused by inconsistent cleaning and maintenance of the sensor lenses. When dust, residue, or moisture accumulates on the lenses, the sensors either fail to detect the product or give false signals, leading to incorrect machine responses and unnecessary stoppages. Since these sensors play a critical role in timing and product positioning, even small inaccuracies directly impact line flow. Implementing a more consistent sensor cleaning schedule and regular functionality checks is essential to improving machine reliability and minimizing avoidable downtime.

4.1.6 Lack of Adherence to PM Plan and OEM Guidelines "METHOD"

Methods that are related to issues were also found to be a key contributor to the frequent stoppages on the packaging line. One major problem was the lack of adherence to the Preventive Maintenance (PM) plan. Maintenance activities were often delayed or skipped, allowing minor issues to escalate into breakdowns that caused unplanned machine stoppages. In addition, operators and maintenance personnel did not consistently follow the Original Equipment Manufacturer (OEM) guidelines for machine operation and adjustment. As a result, machines were often run with incorrect configurations or without the proper setup procedures, leading to frequent malfunctions and reduced process stability. These procedural gaps increased the risk of machine failure and negatively impacted line reliability.

A Fishbone Diagram (Cause-and-Effect Diagram) will help uncover the root causes of the high number of stoppages.

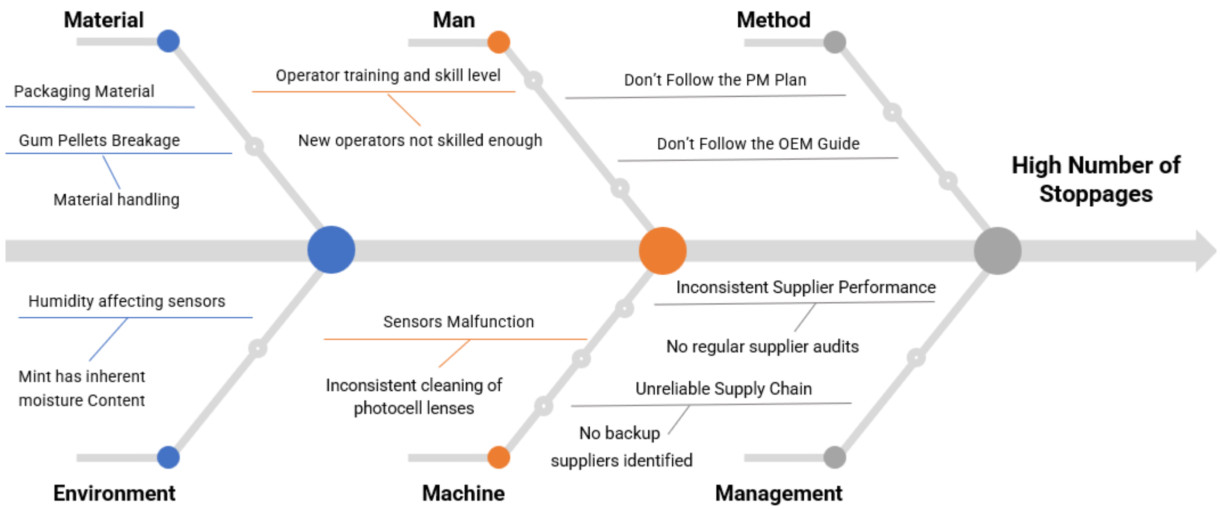


Figure 4-1- Fishbone

4.1.7 Pareto Analysis-Top Causes of Production Line Stoppages

In addition to supporting and validating the findings of the Fishbone Diagram, a Pareto Analysis titled "Top Causes of Production Line Stoppages" was provided by Factory X. This analysis was based on actual stoppage data recorded across the packaging line and was used to identify which causes contributed the most to overall downtime. The Pareto principle 80/20 rule was applied, revealing that a small number of root causes were responsible for most of the stoppages. The chart showed that the most frequent and impactful issues were related to **packaging faults** such as jams, film misfeeds, or material defects, and **gum breakage**, which often caused downstream disruptions and sensor errors. These categories represented a significant portion of the total downtime and aligned with the qualitative insights gathered from the Fishbone analysis. This overlap between observed and data driven findings confirmed the need to focus improvement efforts on packaging material quality and product handling.

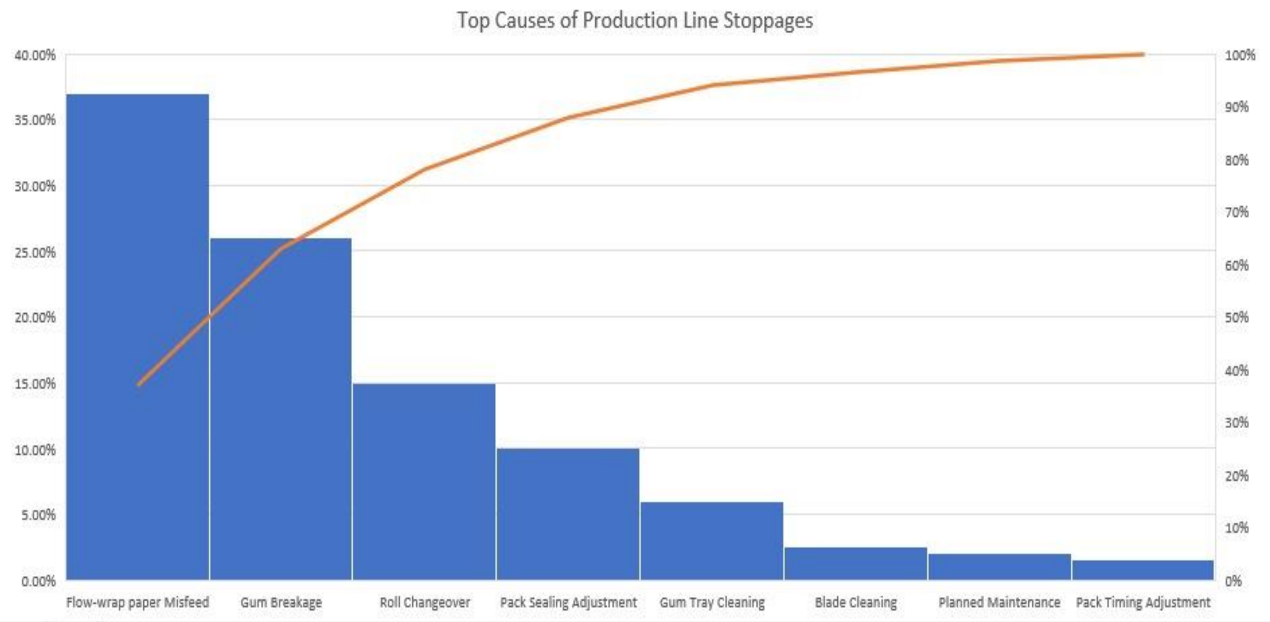


Figure 4-2- Pareto Analysis

4.1.8 5 WHYS Analysis for Material Handling

To understand the root cause behind gum breakage during material handling, a 5 Whys analysis was conducted. The problem originated from frequent stoppages caused by broken gum pellets that interfered with sensor detection and smooth machine operation.

Figure 4-3-Gum pellets

- **Why 1: Why is the line stopping?**

Because gum units are breaking and causing sensors to fail in detecting the product properly.

- **Why 2: Why are the gum units breaking?**

Because they are being mishandled during transfer conveyors or machines

- **Why 3: Why is the material being mishandled?**

Because the transfer between conveyors is not properly aligned, leading to product collisions or bouncing.

- **Why 4: Why is there a misalignment between conveyors?**

Because the line layout was not designed with smooth product flow in mind, particularly after the capacity expansion.

- **Why 5: Why wasn't the layout designed for smooth flow?**

Because the expansion was implemented without reevaluating the handling transitions and rebalancing the new line structure.

This analysis revealed that the true root cause of gum breakage was a lack of proper line balancing and conveyor transition design during the layout change. Addressing this will require adjustments to layout geometry, conveyor speeds, and alignment to prevent mechanical stress on the gum and improve handling throughout the packaging line.

4.1.9 5 WHYS Analysis for Conveyors

Another contributor to frequent stoppages was related to misalignment and inefficiencies in the conveyor system, particularly during transitions between machines.

Figure 4-4- Gum Pellets

A **5 Whys analysis** was conducted to trace the root cause of these conveyor related interruptions:

- **Why 1: Why is the conveyor causing stoppages?**

Because products are getting stuck or misaligned during transfer between conveyor sections.

- **Why 2: Why are the products getting stuck or misaligned?**

Because the conveyors are not properly aligned, especially at connection points between machines.

- **Why 3: Why is there misalignment between conveyors?**

Because the conveyor system was modified during the capacity expansion, but alignment adjustments were not made accordingly.

➢ **Why 4: Why weren't alignment adjustments made after the expansion?**

Because the layout was changed without reengineering the conveyor system to match the new line configuration.

➢ **Why 5: Why was the conveyor layout not reengineered?**

Because there was no formal conveyor design review following the addition of new machines during the line expansion.

This analysis revealed that the root cause of conveyor related stoppages was the lack of proper conveyor redesign and alignment following the line expansion. To resolve this issue, it is essential to reassess the layout, adjust conveyor positions, and ensure smooth product flow between machines to avoid mechanical disruptions and product jams.

4.2 DEFICIENCY IN QUALITY PERFORMANCE MEASURES

One of the critical issues observed on the packaging line at Company X was a deficiency in quality performance monitoring, particularly in tracking rework levels and identifying types of product defects. The existing dashboard, used to visualize line performance, was found to have inaccurate and incomplete data, especially regarding Rework%, which is a key performance indicator. This inaccuracy stems from the fact that data is collected manually, relying on operators to record rework quantities without any automated system to validate or measure the actual figures. As a result, the reported

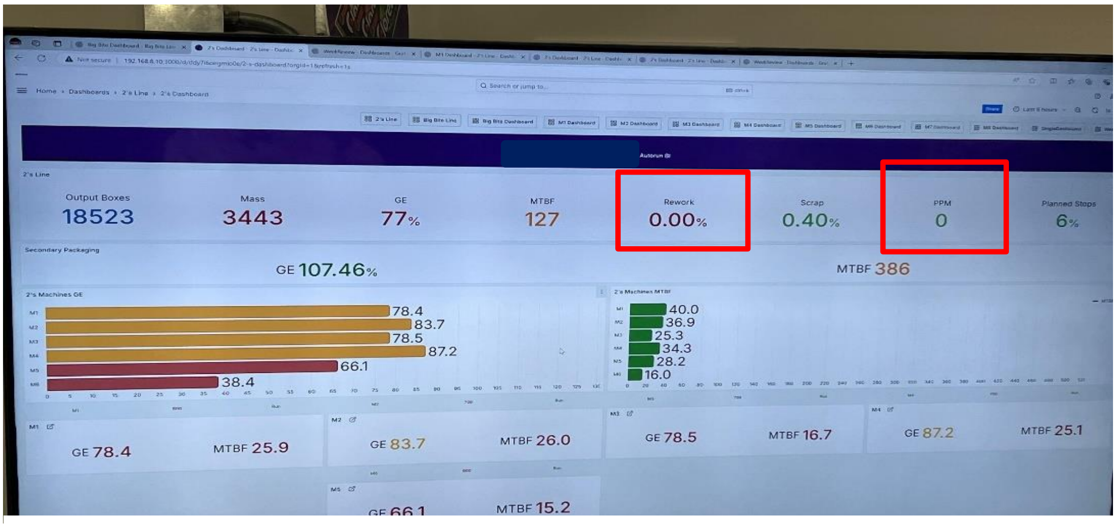


Figure 4-5- Dashboard

rework percentages lack reliability, leading to poor visibility into the true extent of production losses.

In addition to this, the factory does not have a system in place to classify or measure the different types of defects occurring during packaging. All defective units are grouped under a single general category, making it impossible to pinpoint which specific issues are contributing most to quality losses. This limits the ability of the operations team to take targeted corrective actions and track improvement over time. Without accurate, detailed, and automated quality data, performance monitoring remains superficial and hinders informed decision making on the shop floor.

4.2.1 Justification for Implementing PPM Measurement

To address the current deficiency in quality performance monitoring, it is essential to implement a new standardized method for measuring and tracking defects, particularly through calculating PPM (Parts Per Million) for each defect type. Currently, all rejected products are reported under a single general category, making it difficult to identify which types of defects are most frequent or damaging. By introducing standardized defect classifications, a common language is created across operators, engineers, and quality teams, improving communication and alignment in daily operations.

This new approach also enables more accurate defect data input, even if done manually at first, and lays the foundation for calculating PPM per defect type. Tracking individual defect trends helps pinpoint quality weaknesses in real time and supports targeted root cause analysis. It also plays a key role in training new operators, as visual reference standards make it easier to identify and report specific issues.

Most importantly, this new method will be reflected in a digital dashboard using Power BI, where both defect data (PPM per type) and rework percentages will be visualized in real time. This will allow for better monitoring of quality trends, improved transparency, and more informed decision making on the shop floor.

4.2.2 Defect Type Classification

As part of the effort to improve quality performance monitoring, six main defect types were identified and defined for use in the standardized tracking system. Each defect represents a recurring issue that contributes to product rejections and rework, and proper classification is essential for accurate defect reporting and effective root cause analysis.

1. **Deformed Packs:** These are units where the shape or structure of the pack is distorted, often due to mechanical pressure or misalignment during packaging.

2. **Bad Cut:** Refers to packs that were improperly cut by the machine, resulting in uneven edges or incomplete sealing.

3. **One Unit:** Occurs when only a single gum unit is present inside a pack that should contain two, typically caused by product feeding errors.

4. **Ban Empty:** A rejected pack that appears sealed but contains no gum product, usually due to detection or feeding failures.

5. **Open Units:** Packs that are not fully sealed, leaving the product exposed or causing hygiene and shelf-life concerns.

6. **Flapped Units:** Packs where the sealing flaps are not properly closed or folded, affecting appearance and pack integrity.

Standardizing these defect types creates a consistent framework for operators and quality inspectors, supports data driven decision making, and allows the factory to calculate PPM per defect type. This classification also enhances the ability to visualize defects in Power BI and target corrective actions with greater precision.

Chapter Five

5 METHODOLOGY

After analysing Company X's packaging line and identifying the core challenges related to stoppages and the lack of accurate quality performance monitoring, it became necessary to design a structured methodology aimed at addressing these issues and achieving the project objectives, as illustrated in Figure 5.1.

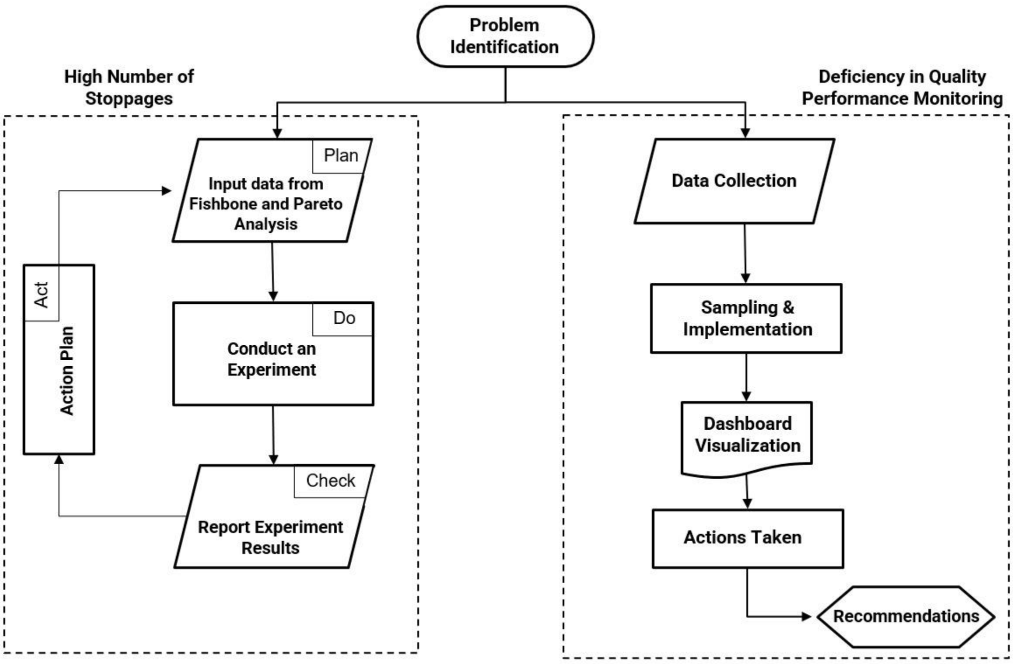


Figure 5-1 Methodology.

5.1 PACKAGING PAPER

The development of the project methodology was driven by the need to investigate the root causes behind frequent production stoppages on the packaging line. Through the integration of insights from both the Fishbone Diagram and Pareto Analysis, packaging material quality emerged as one of the most significant contributors to these stoppages. Based on this analysis, a targeted experiment was designed to evaluate the performance of different types of packaging paper and to assess how material characteristics influence machine reliability and line efficiency.

5.1.1 Packaging Paper Experiment

As part of the methodology, an experiment was conducted to examine the effect of packaging paper quality on machine stability and production flow. Packaging faults were previously identified as a major contributor to stoppages through both qualitative and data driven analysis. To investigate this further, two types of wrapping paper were selected for testing under identical machine and line conditions, one representing high quality material, and the other representing low-quality material. The aim was to observe how factors such as carton core alignment, roll surface condition, edge quality, and tension consistency could influence machine behavior during operation. This evaluation was designed to better understand the role of material characteristics in packaging performance and to support decisions related to supplier quality control and standardization.

5.1.2 Comparison Between Good and Bad Packaging Material

To clearly identify what makes a packaging roll good or bad, a detailed comparison was made. The table below presents the key differences in material characteristics that determine the quality of the packaging paper.

Table 5-1 - Paper Aspects Comparison

Aspect	Good Material	Bad Material
Carton Core Alignment	Carton core is perfectly aligned with the paper width	Carton core is shifted (either outside or inside), width mismatch
Roll Surface Condition	Smooth surface, no visible layers	Wrinkled surface, visible layers, rough texture
Roll Edge Quality	Clean, even roll edges without fraying or waves	Wavy or uneven roll edges, slight fraying visible, lead to poor feeding
Carton Core Integrity	Carton remains attached until the roll is fully used	Carton core detaches and enters the machine, causing machine stoppages
Tension Consistency	Uniform tension across the entire roll	Uneven tension due to wrinkles and rough texture
Machine Performance Impact	No interruptions; smooth flow wrapping	Frequent stops, tension issues, and material jams

5.1.3 Experiment Steps

I. **Start Time to Record Data Manually:** Data collection starts at the beginning of each hour to assess packaging machine performance and material impact.

A set of key metrics is recorded throughout the hour, including:

- Downtime (minutes)
- Operating Time (minutes)
- Planned Production Time (minutes)
- Number of Stoppages

II. **Weigh the Rework (kg)**: The weight of defective or reworked units is measured in kilograms for the specific hour.

III. **Rework Units Produced Every Hour:** The number of reworked units is calculated from the weight by multiplying the rework weight (in kg) by 1000 (to convert to grams) and dividing by the weight per unit (2.8 g):

$$\boldsymbol{Total\ Rework\ Units} = \frac{\boldsymbol{Weight\ of\ the\ Rework\ (kg)\ X\ 1000}}{\boldsymbol{2.8\ g}}$$

Equation 5-1 Rework Units

IV. **Record Machine's Rate:** The machine's Rate is recorded in terms of the number of units produced per minute.

V. **Total Number of Units Produced Every Hour:** The total output for an hour is calculated by multiplying the machine's speed by 60 minutes:

$$Total\ Units\ Produced = Machine\ Speed\ X\ 60$$

Equation 5-2 Total Units Produced

VI. **Rework Percentage Calculation:** Finally, the percentage of reworked units is calculated using the formula:

$$Rework\ Percentage = \frac{Total\ Rework\ Units}{Total\ Units\ Produced} \times 100$$

Equation 5-3 Rework Percentage

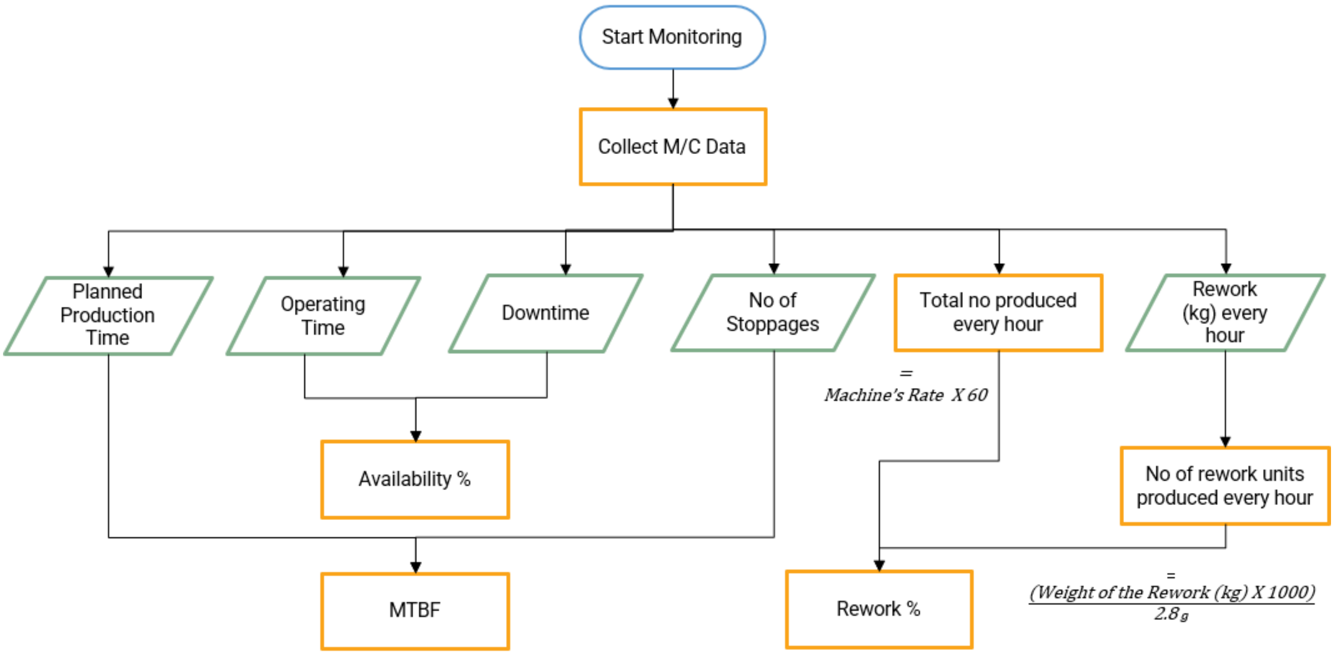


Figure 5-2 Packaging Paper Experiment

Figure **5-2** above shows the flow chart of the process.

5.1.4 Experimental KPI Calculations

Using the data obtained from the packaging paper performance experiment, key performance indicators were calculated to evaluate the effect of packaging material on overall line efficiency. These indicators include **Availability**, **Mean Time Between Failures (MTBF)**, **Gross Efficiency (GE) Per Unit Packaging Machine**, **Mean Time to Repair (MTTR)**, and **Rework Percentage**. Below are the equations used to calculate each of these performance indicators based on the experimental data:

$$\textit{Availability} = \frac{\textit{Operating Time}}{\textit{Planned Production Time}}$$

Equation 5-4- Availability

$$GE\% = \textit{Availability} - \textit{Rework}\ \% - \textit{Scrap}\%$$

Equation 5-5 - GE% of Unit Packaging M/C

$$MTBF = \frac{\textit{Total Available Time}}{\textit{No Of Stoppages}}$$

Equation 5-6-MTBF

$$MTTR = MTBF\left(\frac{1}{Availability} - 1\right)$$

Equation 5-7-MTTR

5.1.5 Experiment Results

Table 5-2 Paper Comparison KPIs

KPIs	Good Quality Paper	Bad Quality Paper
MTBF	13.8	12.4
Availability	88.60%	85.10%
MTTR	1.77	2.166
Average Rework %	2.7875%	6.3544%
GE% Of Packaging M/C	85.81%	78.75%

5.1.6 Experiment Conclusion

The results of the experiment demonstrated that packaging material quality has a direct and measurable impact on production line performance. Rolls categorized as "bad" consistently led to higher rework percentages, increased stoppages, lower availability, and reduced gross efficiency. In contrast, "good" rolls maintained smooth feeding, stable tension, and minimal interruptions, which contributed to improved machine reliability and output consistency. By analyzing KPIs such as Availability, MTBF, GE, and Rework%, it was evident that issues like carton core misalignment, rough roll surfaces, and inconsistent edge quality were common contributors to inefficiency. This experiment validated the importance of standardizing material specifications and implementing stricter quality control on incoming packaging materials to reduce waste, enhance machine utilization, and sustain high operational performance.

5.1.7 Action Plan

To address the high rework levels and frequent stoppages caused by poor packaging material and limited line visibility, a structured improvement approach was adopted using the **Plan–Do–Check–Act (PDCA)** methodology:

5.1.7.1 Plan

Based on the root cause analysis using Pareto and Fishbone diagrams, it was concluded that poor quality packaging material was a major contributor to machine stoppages and rework. To address this, a structured plan was developed to:

- **Test the impact of high-quality rolls versus defective ones** through a controlled experiment.
- **Define clear acceptance criteria** for packaging material based on physical characteristics such as core alignment, tension consistency, and edge quality.
- **Communicate a documented list of recurring defects** to suppliers to ensure corrective action and alignment of quality standards.
- **Inspect incoming packaging rolls before use** to prevent defective material from entering production and triggering stoppages.

5.1.7.2 DO

In the implementation phase, several key actions were carried out to test and validate the impact of packaging material quality on line performance. First, defect data was collected from the currently used packaging rolls, focusing on recurring issues such as misaligned cores, wrinkled edges, and surface irregularities.

To support consistent evaluation, the team developed a visual inspection checklist covering the five main defect aspects, which line operators used during material handling and machine loading.

A pilot batch of improved packaging material was also introduced by the supplier and tested under the same production conditions. Data on rework, stoppages, and defect types were collected during the pilot using standardized data collection sheets. The quality control team and line operators collaborated to monitor performance, inspect materials, and ensure consistent sampling.

5.1.7.3 Check

After executing the pilot and collecting performance data, the results were analyzed to evaluate the impact of packaging material quality. The data confirmed a clear performance gap between good and bad rolls. When using defective material, the time between failures decreased by **10.1%,** indicating more frequent stoppages. Additionally, recovery time after failures increased by **22.3%,** reflecting longer intervention efforts due to material related disruptions. Most notably, rework levels rose by **56.06%** with bad packaging rolls more than double the amount compared to improved materials. Overall line efficiency dropped by **8.2%,** highlighting the broader operational impact.

While the visual inspection checklist proved useful in catching several obvious defects, the integrity of the carton core, which contributed significantly to machine feeding problems, was not always detectable before running the material. This limitation emphasized the need for better material standards and more comprehensive quality control upstream. Nonetheless, the experiment successfully validated the initial assumptions from the Plan phase and provided measurable evidence to guide corrective actions.

5.1.7.4 ACT

Based on the results and insights from the pilot, several corrective and preventive actions were taken to standardize and sustain improvements. A mandatory incoming material inspection process was implemented, using the visual checklist created during the experiment to ensure consistent evaluation of packaging rolls before use. Defect visuals and findings were shared with the supplier, along with proposed material quality KPIs, to align expectations and reduce the recurrence of critical issues. Additionally, line operators were trained to reject any rolls showing visible defects, empowering them to take immediate action without waiting for quality intervention.

To ensure long term stability, a contingency was also established: if the defect rate remains high despite these controls, the team will explore alternative suppliers or materials with better physical integrity. These actions aim to reduce variation, prevent stoppages caused by poor quality materials, and maintain a more stable and efficient packaging process.

5.2 IMPROVING DEFECT DATA ACCURACY THROUGH DYNAMIC SAMPLING

5.2.1 Sampling Experiment

In the earlier stages of production, defect data were collected manually without a clear system for classifying or quantifying the types of defects. This created a gap in quality monitoring, as there was no reliable way to measure how frequently specific defects occurred or to compare performance across machines, shifts, or SKUs. To address this need, an experiment was designed to calculate the **Parts Per Million (PPM)** for each defect type. The goal was to establish a standardized method for measuring quality performance, improve traceability, and lay the groundwork for more structured and data-driven quality control.

5.2.2 Sampling procedure

I. **Weigh an Empty Basket:** At the start of the sampling process, an empty basket is weighed to establish a baseline. This value is used later to calculate the net weight of the output sample.

II. **Weigh the Output Sample:** A full basket of produced units is collected from the output line and weighed. The net product weight is calculated by subtracting the empty basket weight.

III. **Calculate the Number of Units:** Using the known unit weight (2.8 g), the total number of units in the sample is calculated as:

$$\boldsymbol{Total\ Number\ of\ Units} = \frac{\textit{Weight of the output (g)}}{\textit{2.8 (g)}}$$

Equation 5-8 - Total no of units

IV. **Inspect Units for Defects:** Each unit in the sample is visually inspected for any defects. If no defects are found, the full sample is returned to the product feeder. If defects are present, the defective units are separated and classified.

V. **Count and Classify Defective Units:** Every defective unit is counted and sorted by defect type.

VI. **Calculate PPM for each Defect Type:** For each defect type, the Parts Per Million (PPM) is calculated using:

$$\boldsymbol{PPM} = \frac{\textit{Defective units number}}{\textit{Total no of units produced}} \times \mathbf{1,000,000}$$

Equation 5-9-PPM per Defect Type

VII. **Calculate Total Rework%:** Sum all the defective units and calculate the rework%

$$\boldsymbol{Rework}\% = \frac{Total\,Defective\ units\ number}{Total\ no\ of\ units\ produced} \times \mathbf{100}$$

Equation 5-10 - Rework%

VIII. **Log the Results:** All data, including date, shift, machine, SKU, defect counts, and calculated PPM, is recorded in the sampling sheet. These values are later uploaded to Power BI for dashboard visualization.

Figure 5-3 below shows the flow chart of the process.

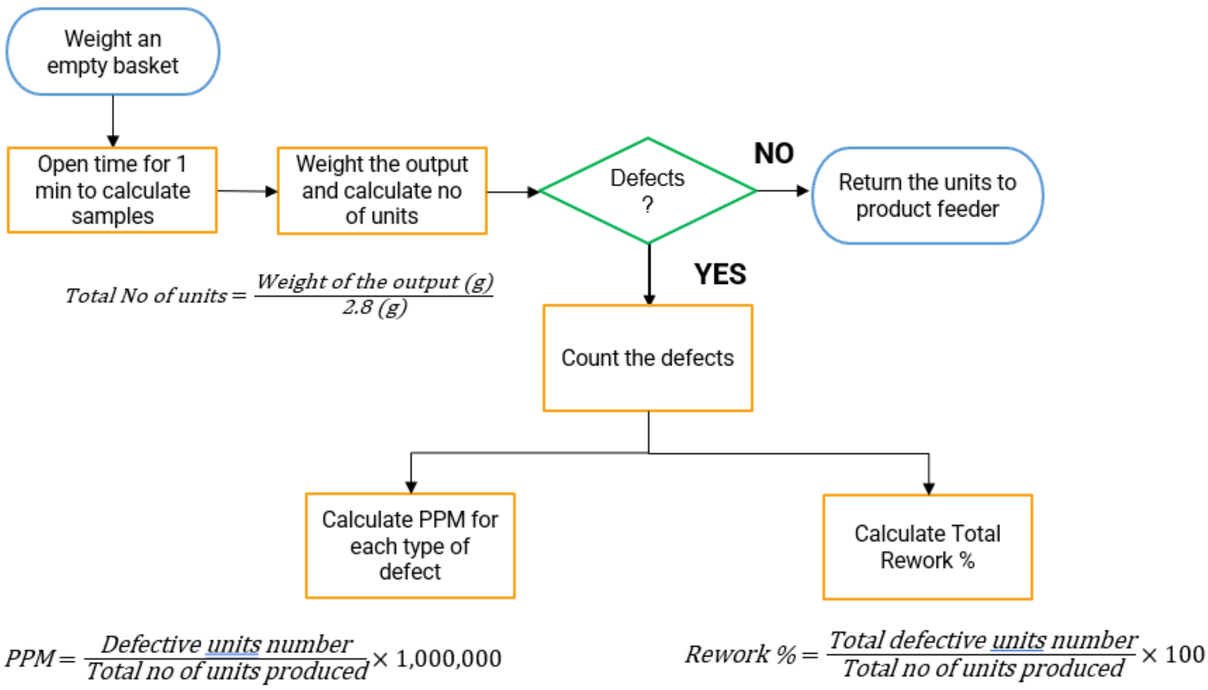
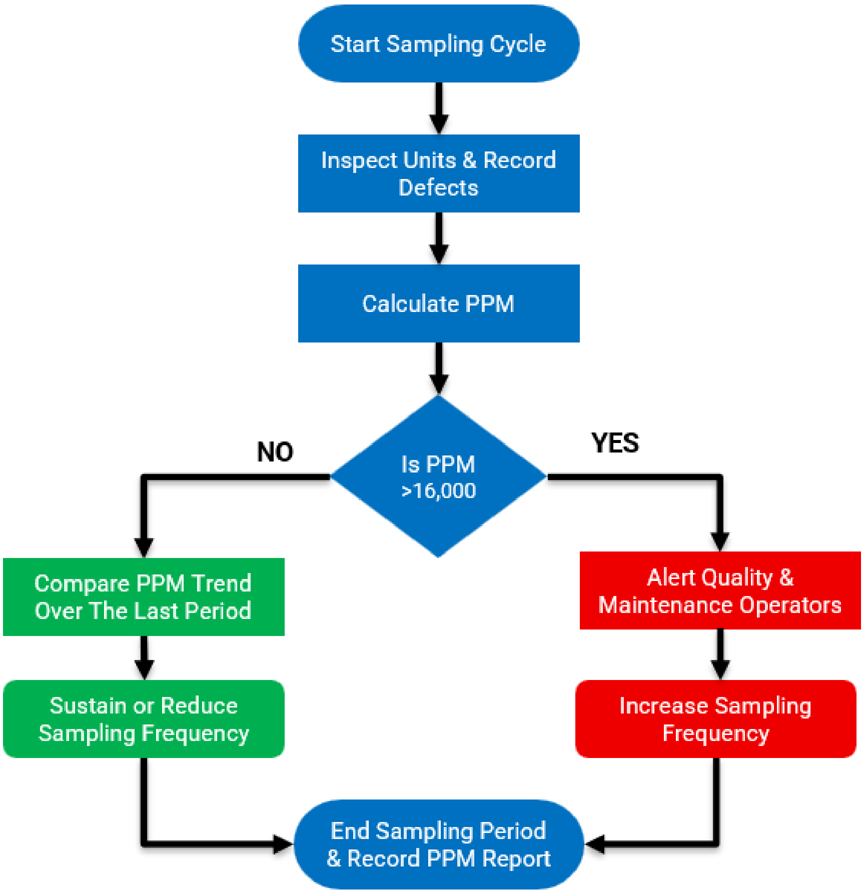


Figure 5-3 - Rework% & PPM per defect

5.2.3 Dynamic sampling

In dynamic sampling, product units are inspected at regular intervals, and each defect is recorded and used to calculate the PPM. If any defect type exceeds the threshold of 16,000 PPM, alerts are triggered for quality and maintenance teams. Based on the results, the sampling frequency is adjusted to increase when defects rise and reduce when performance is stable. Results are then logged and used for dashboard visualization and trend monitoring.



5.2.4 Differences between traditional and dynamic sampling

To overcome the limitations of manual sampling and enhance real-time quality control, a dynamic sampling method was introduced. The purpose of this approach was to establish a responsive and data-driven system that adjusts the frequency of defect sampling based on actual performance trends. Unlike traditional sampling, which follows a fixed schedule, dynamic sampling monitors defect levels continuously and increases or decreases inspection intervals depending on the severity of detected issues. This ensures faster detection of abnormal patterns, reduces operator workload during stable periods, and improves responsiveness during critical quality deviations. In our application, if the PPM of any defect type exceeded the threshold of 16,000, immediate alerts were triggered to quality and maintenance teams, prompting corrective action. The system also tracked PPM trends over time, allowing us to automatically adjust sampling frequency: higher when defects increased, lower when quality stabilized. This method enabled a more proactive and efficient quality control system, aligning with the core principles of Digital Kaizen and supporting continuous improvement through real time insights and rapid decision making.

Chapter Six

6 IMPLEMENTATION OF POWER BI DASHBOARD

The purpose of developing the Power BI dashboard was to address the lack of real-time visibility into key performance indicators on the packaging line and to replace manual, error-prone data tracking methods. The dashboard was designed to centralize critical metrics such as Rework Percentage, Defect PPM, and machine-level KPIs like Availability and MTBF, making them easily accessible and visually clear. By providing interactive filtering by shift, SKU, and machine, it allowed the team to pinpoint the root causes of inefficiencies, monitor performance trends, and track the impact of implemented changes. The dashboard served as a decision support tool that empowered both production and quality teams to act quickly and collaboratively, aligning directly with the project's goal of fostering a data-driven Kaizen culture focused on continuous improvement.

6.1 CUSTOMER CHALLENGES

Before implementing the Power BI dashboard, the packaging line team faced several key challenges that hindered performance monitoring and decision making. There was a lack of visibility into where rework and defects were occurring, making it difficult to trace top defect types by product or machine. Without a centralized view, teams had no easy way to compare performance across shifts, machines, or SKUs, which limited their ability to spot trends or prioritize actions. Decision making was often delayed, as teams struggled to act quickly without real-time data. Additionally, the reliance on manual reporting methods consumed valuable time and introduced frequent errors. There was also no early warning system or trending view in place to proactively detect performance deviations, making the operation reactive rather than responsive.

6.2 CUSTOMER REQUIREMENTS

To enhance operational visibility and support data-driven decision making, customers require a robust and user-friendly Power BI dashboard capable of clearly monitoring rework and defects by production line to identify problem areas efficiently. The dashboard must highlight top loss drivers, such as defect types, lines, machines, and shifts, to aid in quality improvement efforts. It should also feature advanced drill-down filters, including SKU, date, shift, and time, enabling detailed root cause analysis. An intuitive and visual interface is essential for accessibility across both shop floor personnel and management. Ensuring reliable data accuracy with automated updates is critical to minimizing manual errors and maintaining real-time tracking. Additionally, the solution must allow comparisons across different shifts, provide trend evaluation over time, and support centralized live dashboard updates. Exportability and mobile friendliness are also important to facilitate ease of use and remote access across devices.

6.3 PRODUCT DESIGN

6.3.1 Identify Business Questions and KPI Requirements

The first step involved close collaboration with production and quality assurance teams to define the core performance metrics and analytical needs of the dashboard. The primary KPIs identified were:

- **Rework Percentage per Line**
- **Rework Percentage per Machine**
- **PPM (Defects Per Million Opportunities) per Defect Type and Machine**

These metrics were aligned with business needs to track quality, identify bottlenecks, and drive continuous improvement. Additionally, the analysis required dynamic filtering by **Year, Month, Day, Shift, Machine, SKU,** and **Time**, allowing stakeholders to drill down into specific performance windows and root causes.

6.3.2 Collect and Prepare Data

Data was sourced from dynamic sampling processes, which are recorded in two structured Excel files: the PPM Sheet and the Rework Sheet.

A. **PPM Sheet Parameters Included:**

  - Date & Time, Date, Year, Month, Day, Day No

- Shift, Time, Machine No, Machine Rate (units/min)
- SKU, SKU Weight (g/piece), Sampling Time (mins), Sampling Weight (kg), Sampling Number
- Defect Type, Defect Count, Defect Percentage, PPM
- A uniquely generated **Primary Key** for each record

B. **Rework Parameters Included:**

- Date & Time, Date, Year, Month, Day, Day No
- Shift, Time, Machine No, Machine Rate (units/min)
- SKU, SKU Weight (g/piece), Sampling Time (mins), Sampling Weight (kg), Sampling Number
- Total Rework, Rework
- **Primary Key** for consistency and integration

These datasets were imported into Power BI and underwent standard cleaning and transformation processes, including type casting, date parsing, and key generation, as seen in the Power BI Query interface. This structured preparation laid the foundation for accurate KPI calculations, time-based trend analysis, and cross-filtering across operational dimensions.

6.3.3 Cleaned and Transformed Data

To ensure accurate insights, the first step in our process design was cleaning and transforming the raw data.

- Eliminated duplicates, empty records, and formatting errors using Power BI's built-in transformation tools.
- As shown in the interface, data types were standardized, rows were filtered, and key columns like Date, Year, Month, and Day were validated to be 100% error-free.

- ❖ These transformations are tracked in the applied steps panel, ensuring transparency and consistency.

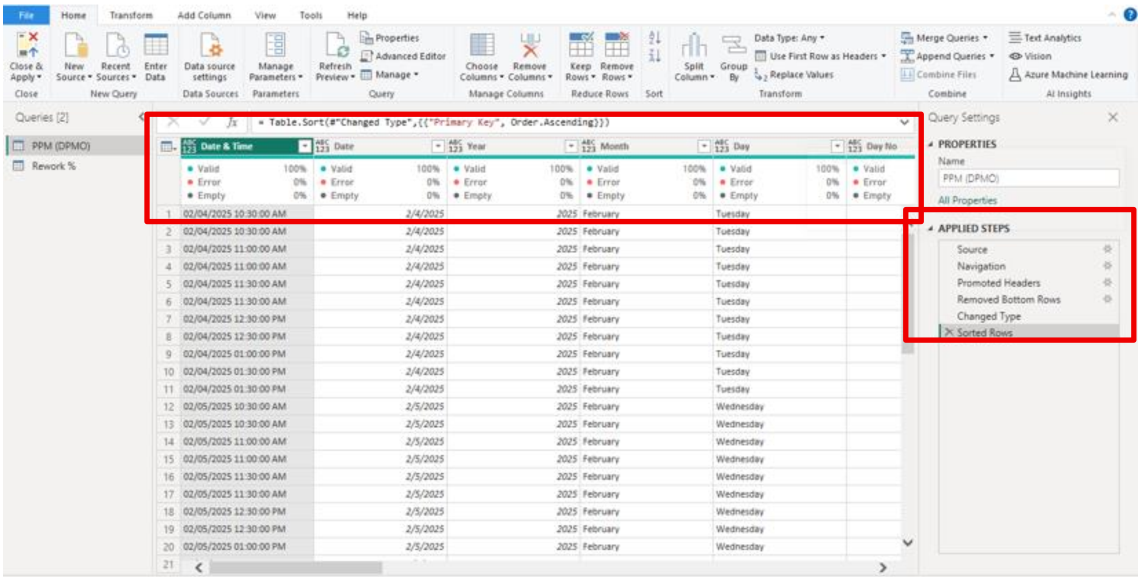


Figure 6-1 - Power BI Query

6.3.4 Built Relationships Between Two Sheets

Next, we created a data model by building relationships between the two key tables:

Rework% & PPM.

- ❖ As shown, **Primary Key** was used to join the tables, enabling **one-to-many relationships**.
- ❖ The relationship editor ensures that the data flows seamlessly, keeping our analysis synchronized across all metrics.

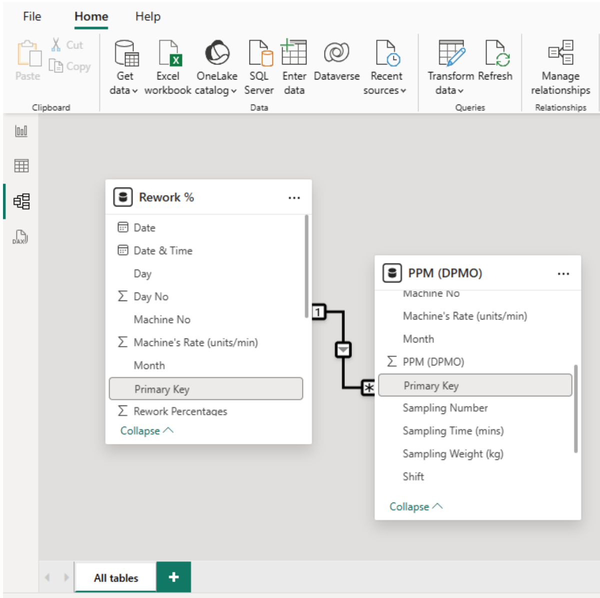


Figure 6-2 - Power BI Relationship

6.3.5 Dashboard Layout and Visualization

Power BI brought everything together on a user-friendly dashboard, designed with clarity and usability in mind. The dashboard includes **interactive visualizations**:

- ❖ A gauge chart displaying average rework percentage.
- ❖ A bar chart showing rework percentages by machine.
- ❖ Breakdowns of PPM by defect type for each machine.

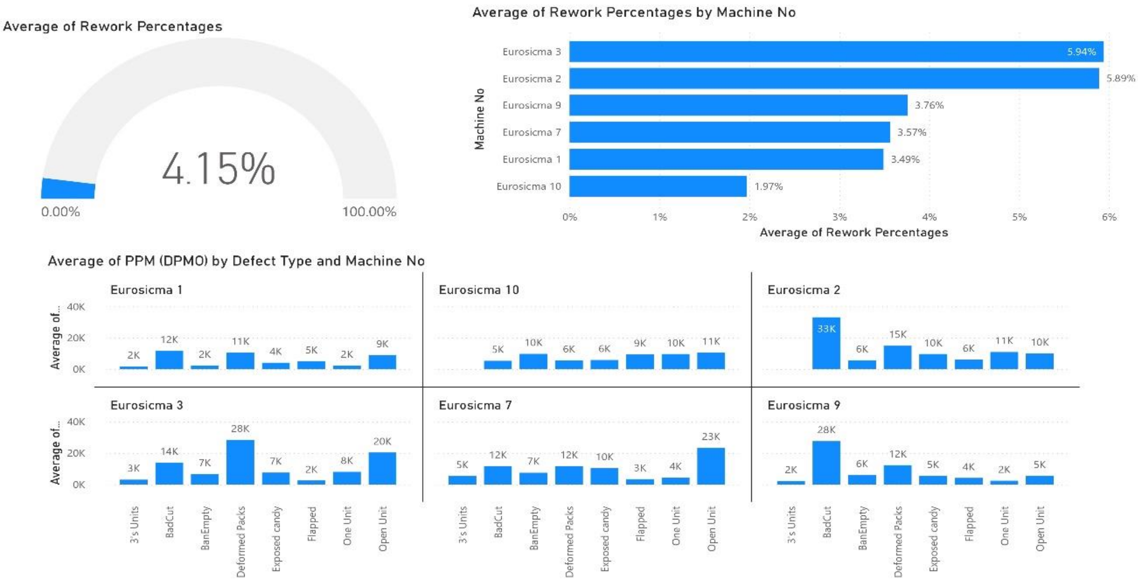


Figure 6-3- Initial Dashboard

6.3.6 Thresholds and Visual Rules Implementation

To make the dashboard more actionable and visually intuitive, conditional formatting and rule-based colour coding were implemented. These visual rules help users instantly identify critical issues:

- **Rework% per Line**

If Rework% exceeds 1.60%, the cell turns RED to flag abnormal performance.

- **PPM (Parts Per Million) per Defect Type**
  - 0 < PPM ≤ 10,000 → Normal (BLUE)
  - 10,000 < PPM ≤ 16,000 → Warning (GREEN)
  - PPM > 16,000 → Critical (RED)
- **Rework% per Machine**
  - 0% < Rework ≤ 1.6% → Normal (BLUE)
  - 1.6% < Rework ≤ 4% → Warning (ORANGE)
  - Rework > 4% → Critical (RED)

These design rules made it easier for operators and managers to spot deviations briefly, prioritize interventions, and monitor line and machine level performance in real time, as shown in the figure below.

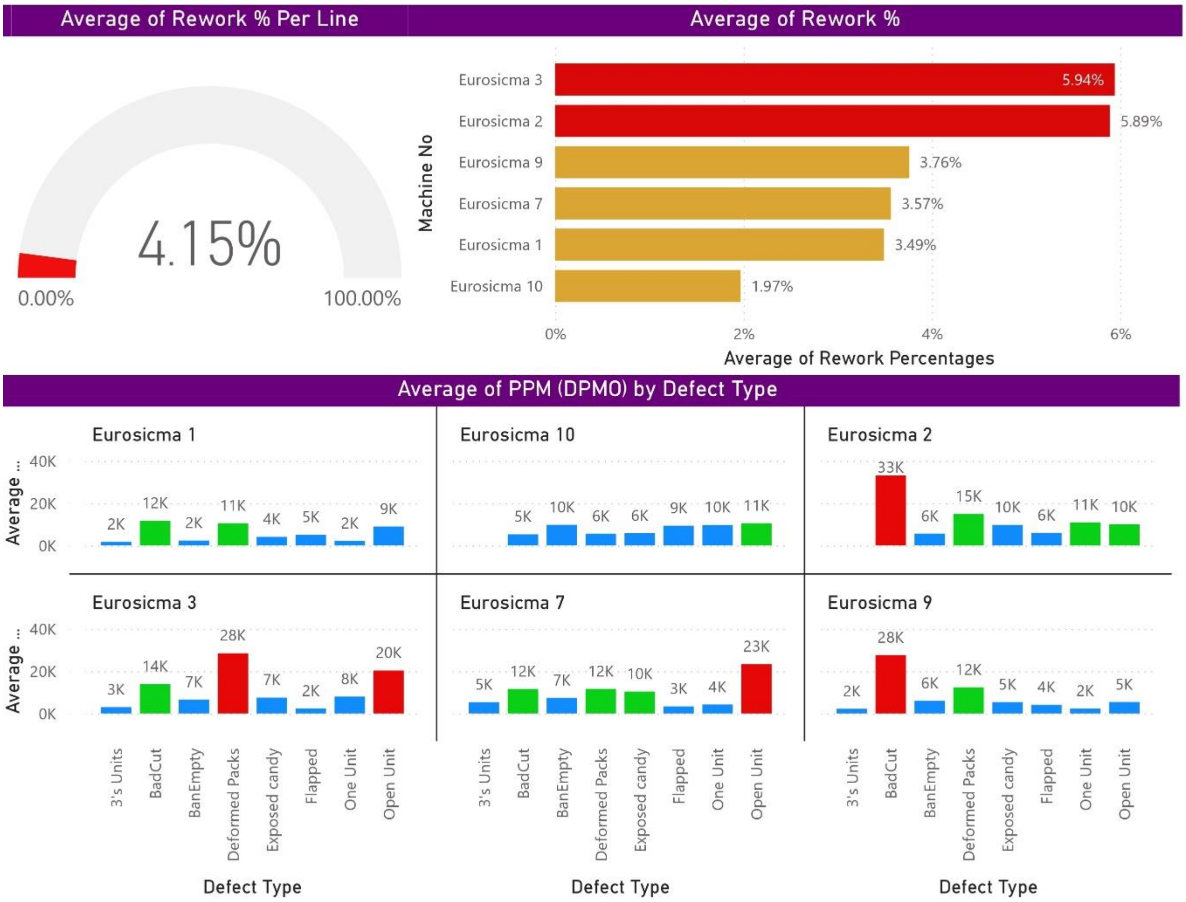


Figure 6-4- Power BI Final Dashboard

The process design reflects best practices in data preparation, modeling, and visualization, turning raw numbers into actionable manufacturing intelligence, all within a sleek and interactive Power BI interface.

6.3.7 Root Cause Analysis & Guide for Every Defect Type

To enable more effective problem solving, this analysis identifies the root cause behind each specific defect type. By understanding the underlying reasons behind each defect, we can implement focused solutions that reduce rework, improve quality, and prevent recurrence.

This step-by-step actions listed for each defect type are to be applied gradually. Start with number 1 in the checklist. If the defect is not resolved, proceed to number 2 and continue sequentially through the steps until the issue is effectively eliminated. This structured approach ensures efficient troubleshooting while minimizing unnecessary interventions.

Defects Handling Log

Date: **Time:**

Machine Number: **SKU:**

PPM:

Defect Type	Root Cause	Step-by-Step Checklist
I. Deformed Packs	• Packed unit overlapped with unpacked gum. • Gum buildup on the CST jaws	☐ 1. Clean the jaws using a cloth ☐ 2. Use a copper brush.
II. Bad Cut	• Low pressure of CST jaws • Low heating temperature • Variation in packaging material • Inefficient CIL Intervals	☐ 1. Increase pressure ☐ 2. Increase the heating temp. ☐ 3. Replace the paper roll ☐ 4. Clean the jaws ☐ 5. Change the CST jaws
III. One Unit	• The photocell sensor does not reject one unit	☐ 1. Clean the photocell sensor using a soft, dry cloth. ☐ 2. Adjust the angle of the sensor
IV. Ban Empty	• Gum missed the disk hole	☐ 1. Adjust the distributing disk and pusher chain to make sure all gums are positioned correctly
V. Open Units	• Low pressure • Poor packaging material • Timing issues in the photocell sensor.	☐ 1. Increase Pressure ☐ 2. Replace the paper roll ☐ 3. Adjust sensors
VI. Flapped Units	• Rolling paper poor material • Paper misalignment	☐ 1. Adjust the position of the paper roll. ☐ 2. Change the paper roll

Figure 6-5 - Defects Handling Log

6.3.8 Dashboard Impact

The purpose of this experiment was to address the inaccuracy and inefficiency in quality performance monitoring on the packaging line. Previously, defect data was collected manually, with no standardized method to classify or measure each defect type, resulting in unreliable rework percentages and unclear root causes. Additionally, the absence of a digital system made it difficult to trace defects by machine, shift, or SKU, leading to delays in corrective actions. This experiment aimed to design and test a dynamic sampling method supported by real time digital dashboards, enabling accurate calculation of PPM (Parts Per Million) per defect type, better defect classification, and faster, data driven decision making. By implementing structured sampling and automating data visualization through Power BI, the experiment sought to enhance traceability, improve response time, and support continuous quality improvement

6.4 POWER BI REPORT

The detailed report offers a comprehensive analysis of quality performance across products and production lines. It includes a defect type breakdown by percentage, highlighting each defect's contribution to total defects. The report also displays the average rework rate per SKU, enabling performance comparison across products, as well as the average rework percentage per line and machine, shown through clear, comparative visuals. Additionally, it provides daily tracking of defect types, making it easy to identify the most frequent issues on any selected day. Finally, a defect type analysis per SKU allows for full traceability, linking specific quality problems to individual products

6.4.1 Line Rework% Report

This report helps quickly identify which shifts or SKUs are contributing to high rework rates, enabling focused troubleshooting. This report shows:

❖ **Average of Rework Percentages by Shift**

Highlights how much each shift (A, B, C) contributes to total rework.

❖ **Average of Rework Percentages by SKU**

Compare how different products (SKUs) perform in terms of rework. This allows identification of underperforming SKUs.

❖ **Average of Rework % per Line**

Displays rework percentage trends over time, highlighting fluctuations and spikes.

❖ **Filter Panel**

Enables users to filter data by **Date**, **Month**, **Shift**, **Time**, and **SKU** to analyze performance at a more granular level.

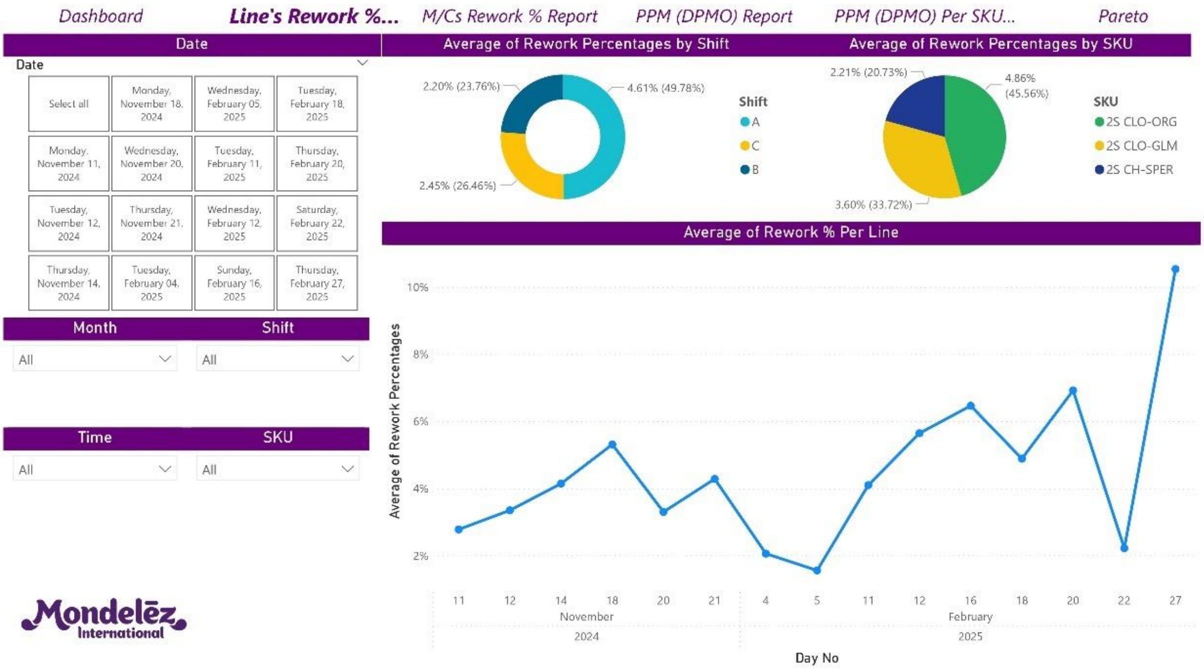


Figure 6-6 - Line Rework% Report

6.4.2 Machine’s Rework% Report

This report pinpoints performance problems at the individual machine level, helping maintenance and operations teams take targeted actions. This report shows:

- **Chart by machine**

  Each small graph tracks the average rework% for a specific machine across time, with different colored dots/lines representing different SKUs (CH-SPER, CLO-GLM, CLO-ORG).

- **Trend lines over time**

  visually detect which machines consistently show higher rework and how performance changes week to week.

- **SKU Color Coding**

  Helps differentiate which product had high rework on which machine. For instance, if the blue dot (CH-SPER) appears high on Eurosicma 3, it means that the SKU is performing poorly on that machine.

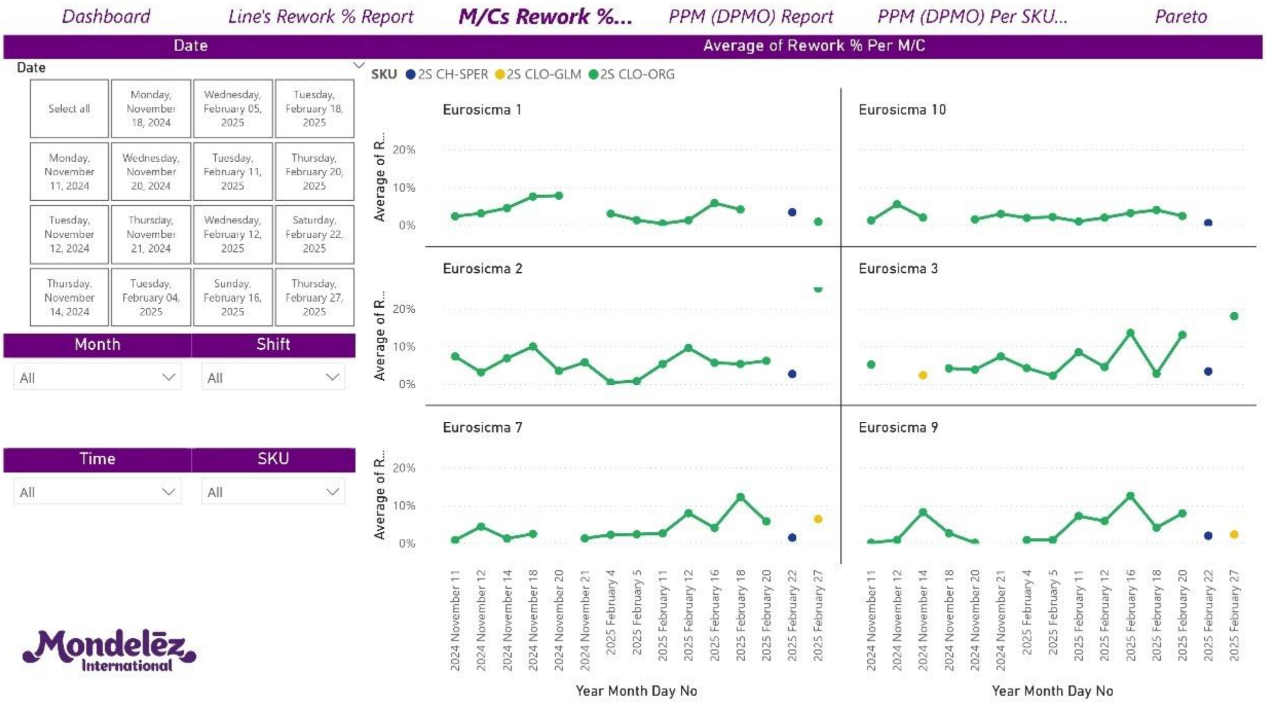


Figure 6-7 - Machine's Rework% Report

6.4.3 PPM Report

This report supports root cause analysis and defect prevention by showing which machines are producing which types of defects, and when. It supports quality assurance teams in applying targeted fixes. This report shows:

- ❖ **Average of Defects**

Breaks down total defects into categories such as:

- ✓ **BadCut**
- ✓ **Deformed Packs**
- ✓ **Open Unit**
- ✓ **Exposed Candy**
- ✓ **One Unit**
- ✓ **Flapped Units**
- ✓ **3's Units**

- ❖ **Defects % per Machine**

Each small graph shows how defect types are distributed per machine.

For example:

If Eurosicma 3 has many red bars, and red = "Open Unit", it indicates this machine frequently produces that defect.

- ❖ **Colour coded by Defect Type**

It makes it easier to visually link specific defects to machines and dates.

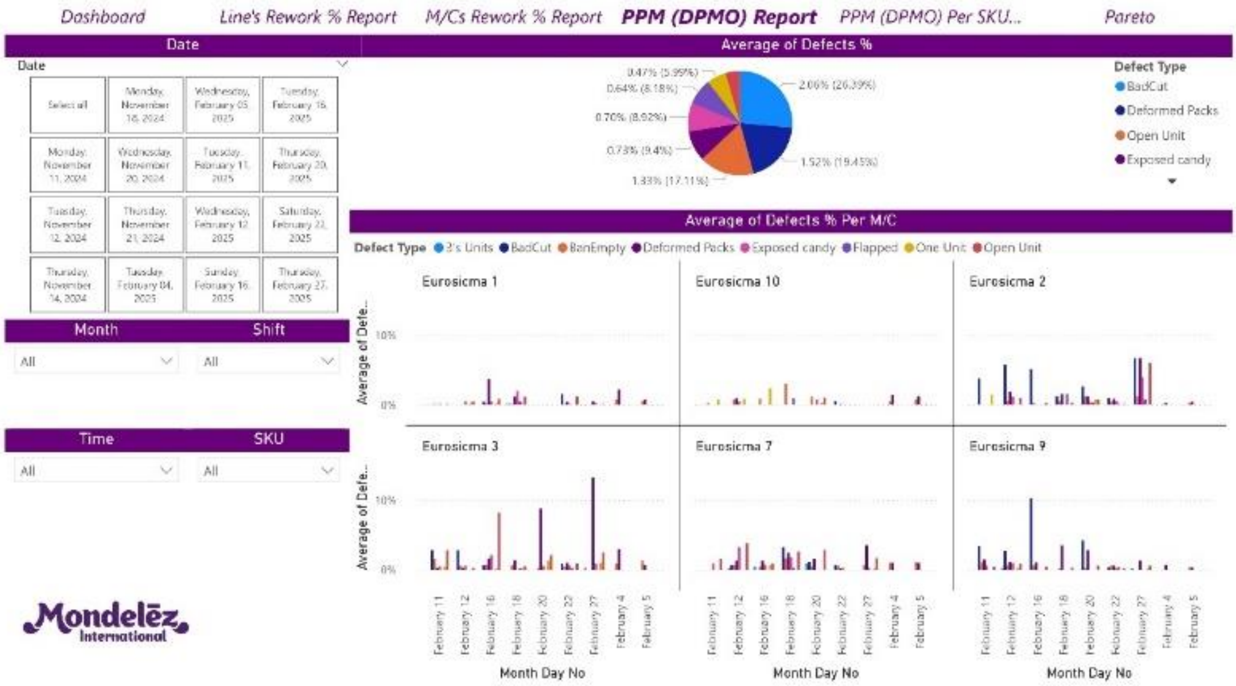


Figure 6-8 - PPM Report

6.4.4 PPM Per SKU

This chart monitors and analyzes the defect rates across different SKUs in production, helping identify quality issues and drive improvements. It Shows:

- **Chart**: Average percentage of each defect type per SKU.
- **Defects Tracked**: Includes Bad Cut, Deformed Packs, Open Unit, etc.
- **Filters**: By date, month, shift, time, and SKU.
- **Insight**: Highlights which SKUs have the highest defect rates and what types of defects are most common.

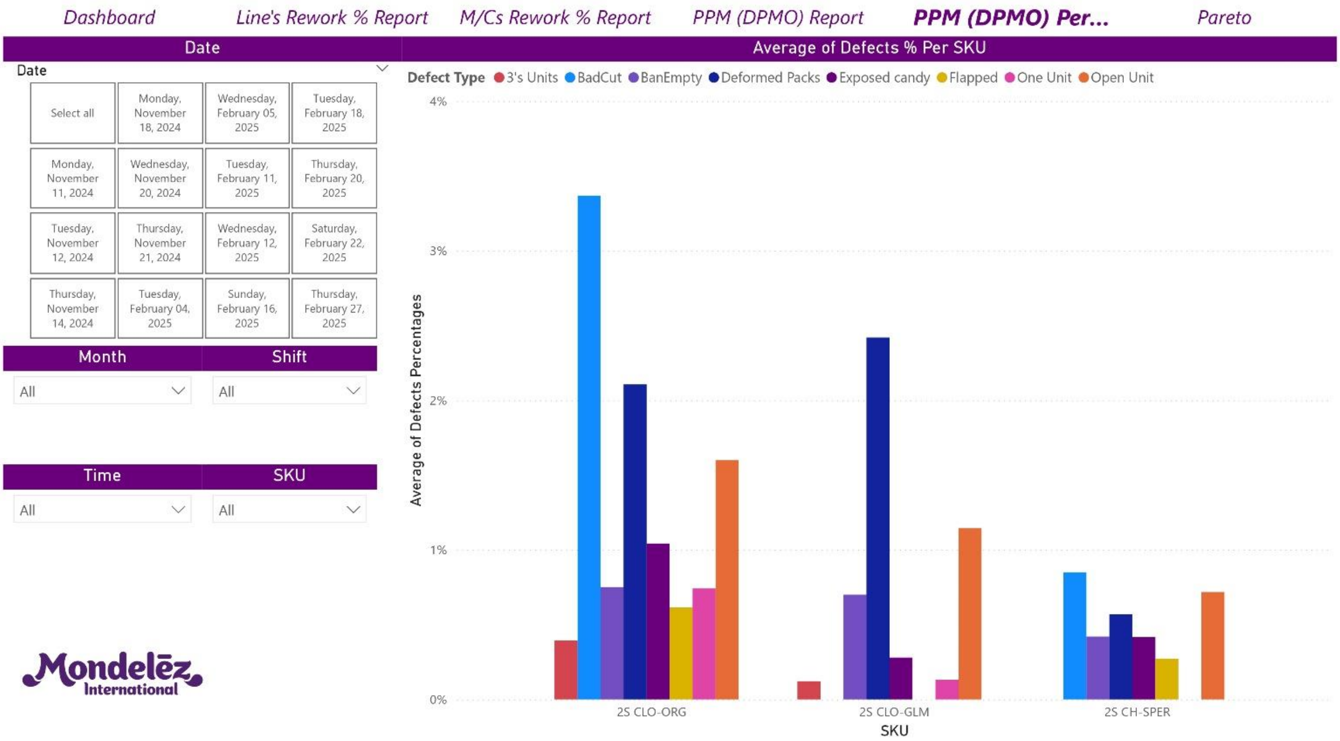


Figure 6-9- PPM per SKU

Chapter Seven

7 SIMULATION ANALYSIS OF OLD VS. NEW CAPACITY

7.1 OVERVIEW OF THE SIMULATION MODEL

To validate the effectiveness of the capacity expansion, a discrete-event simulation model was constructed to replicate the packaging line under both the old and new capacity configurations. The model incorporated the actual operating parameters of the system, including machine rates, availability, mean time between failures (MTBF), mean time to repair (MTTR), and rework levels. By simulating both configurations, the study aimed to quantify the impact of the expansion on throughput, cycle times, and rework percentages.

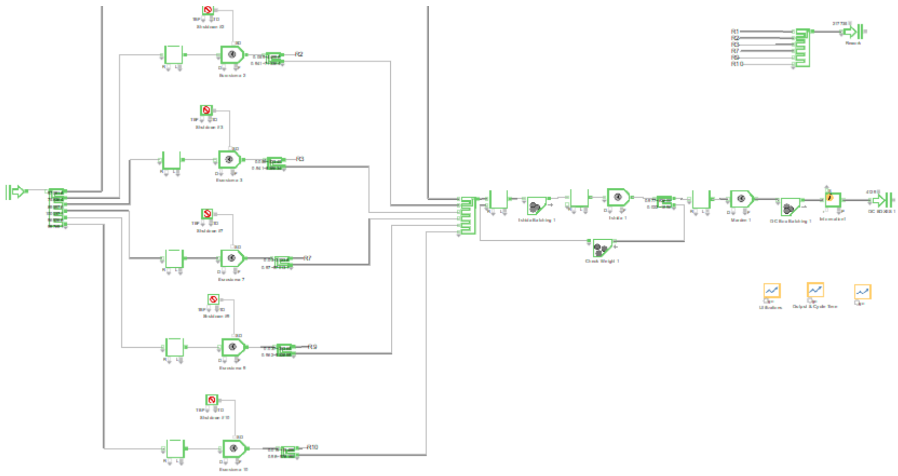
The simulation represented the packaging line as two consecutive stages: primary packaging, where gum units are wrapped individually, and secondary packaging, where wrapped units are batched into display boxes and subsequently packed into outer cartons. The model also accounted for rework flows, where defective units were redirected for reprocessing.

7.2 SIMULATION OF THE OLD CAPACITY

7.2.1 Primary Packaging Parameters

The old capacity configuration was composed of six primary packaging machines connected to a single feeder and supported by two secondary packaging machines (Ishida and Marden).

Figure 7-1 Old Capacity Model



The table below summarizes the performance characteristics of the primary packaging machines under the old capacity. Machine rates ranged between 650 and 900 units per minute. Availability levels were between 83% and 87.6%, with MTBF ranging from 18 to 24 minutes and MTTR between 3.2 and 3.7 minutes.

$$MTTR = MTBF\left(\frac{1}{Availability} - 1\right)$$

Equation 7-1 - MTTR

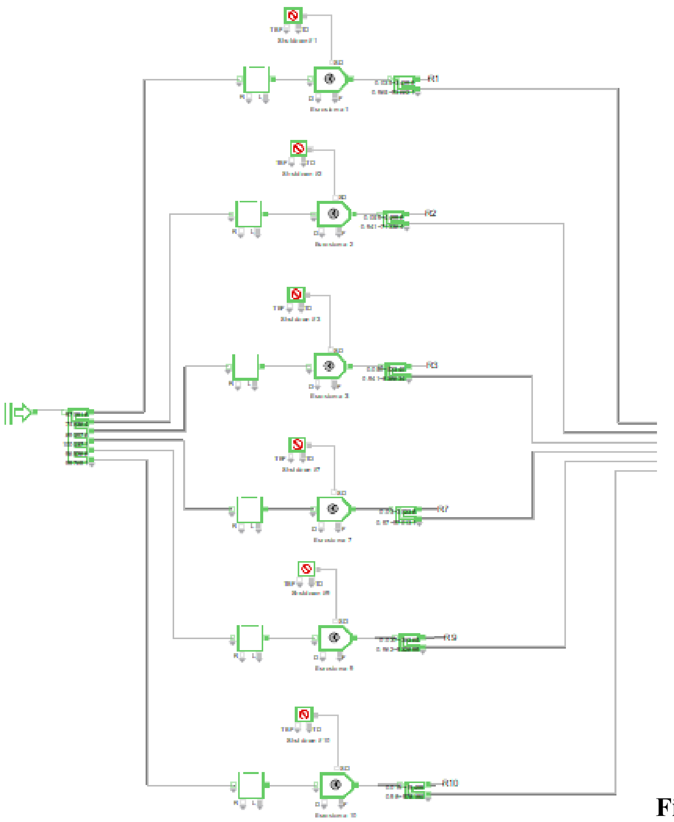


Figure 7-2 Old Capacity Primary

Table 7-1 - Old Capacity Parameters

Machine #	Rate (units/min)	Availability%	MTBF (mins)	MTTR (mins)
1	800	87.6%	24	3.4
2	650	83%	18	3.7
3	700	85%	20	3.5
7	900	85.1%	18	3.2
9	800	83.2%	18	3.6
10	800	87%	20	2.9

7.2.2 Secondary Packaging

At the secondary stage in the secondary packaging, the Ishida and Marden machines each processed 65 boxes per minute. Display boxes contained 65 gum units, and 20 display boxes were grouped into one outer carton.

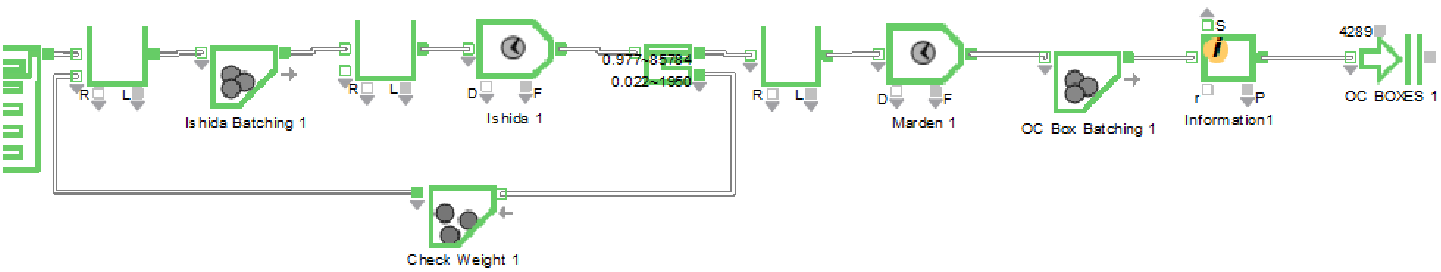


Figure 7-3 Old Capacity Secondary

7.2.3 Rework and Results

The simulation showed that 226,280 units required rework, equivalent to 3,482 boxes or 174 outer cartons.

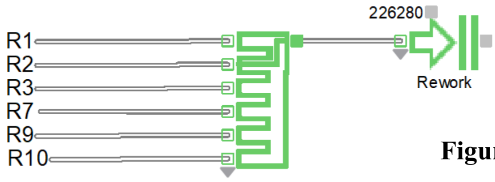


Figure 7-4 Old Capacity Rework

The overall rework percentage was calculated as 4.06%. The cycle time of the line was 0.858 minutes per unit, and the total output was 4,289 outer cartons.

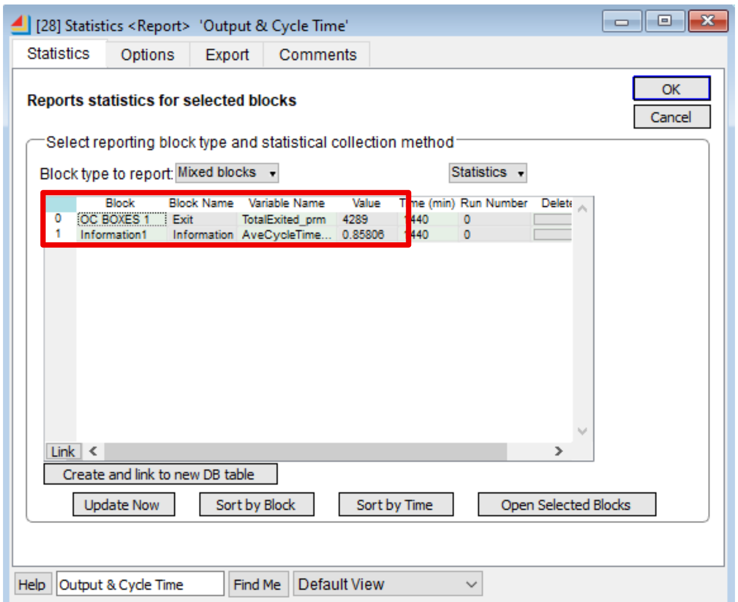


Figure 7-5 Old Capacity Results

$$Cycle\ Time\ of\ The\ Packaging\ Line = 0.858\ mins$$

$$Total\ Rework\%\ of\ The\ Old\ Capacity\ of\ The\ Packaging\ Line =$$

$$\frac{Total\ Rework}{Total\ Output} = \frac{174}{4289} \times 100 = 4.06\%$$

Equation 7-2 Old Capacity Results

7.3 SIMULATION OF THE NEW CAPACITY

The new capacity configuration expanded the system to eight primary packaging machines supplied by two feeders and supported by four secondary packaging machines (two Ishida and two Marden).

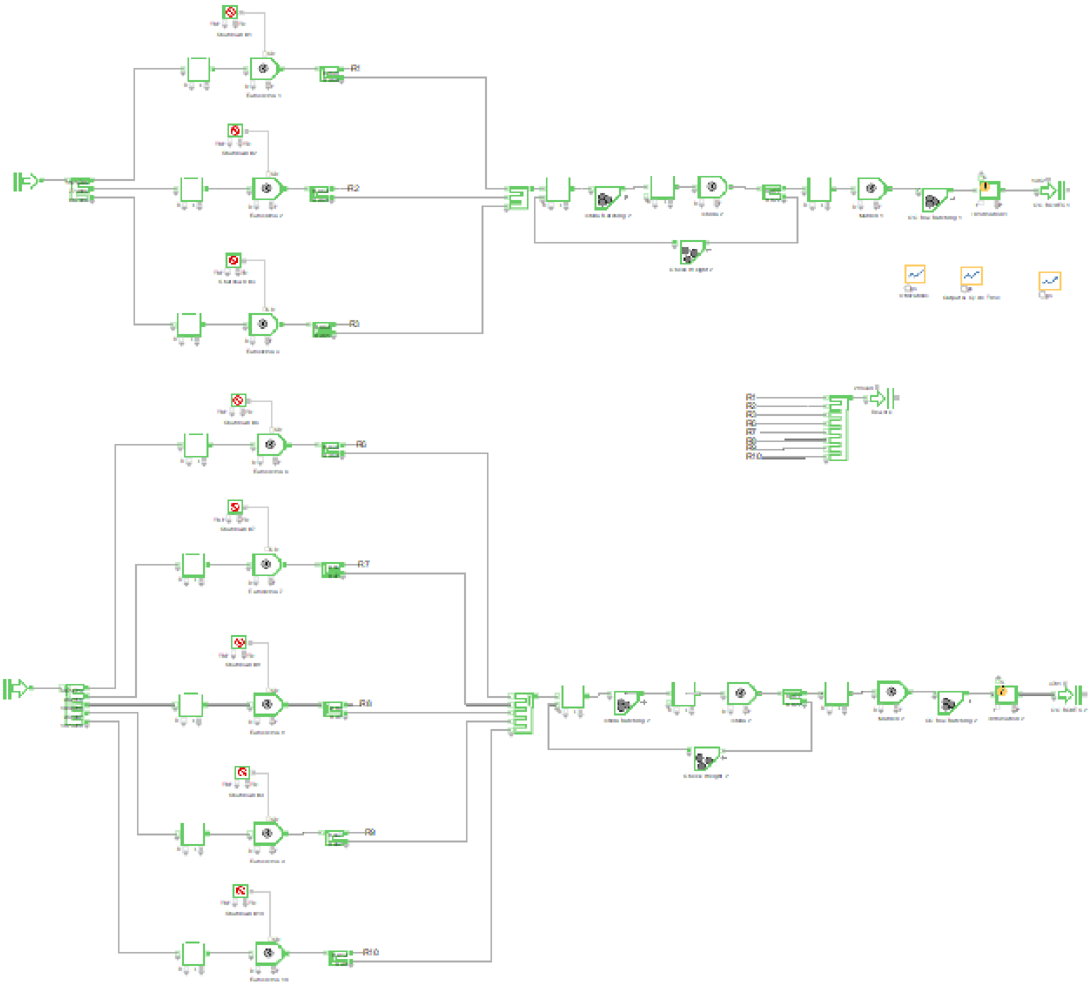


Figure 7-6 New Capacity Model

7.3.1 Primary Packaging Parameters

As shown in the table below, the machines operated at similar rates to the old configuration, between 650 and 800 units per minute. MTBF values ranged from 18 to 24 minutes, and MTTR averaged around 3 minutes. The introduction of two feeders; Feeder 1 serving machines 1, 2, and 3, and Feeder 2; serving machines 6, 7, 8, 9, and 10, allowed for improved workload distribution and reduced bottlenecks.

Figure 7-7 - New Capacity Primary

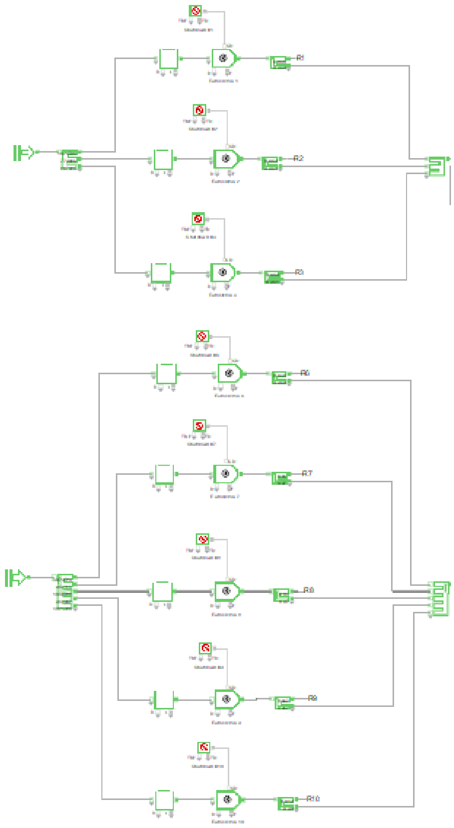


Table 7-2 New Capacity Parameters

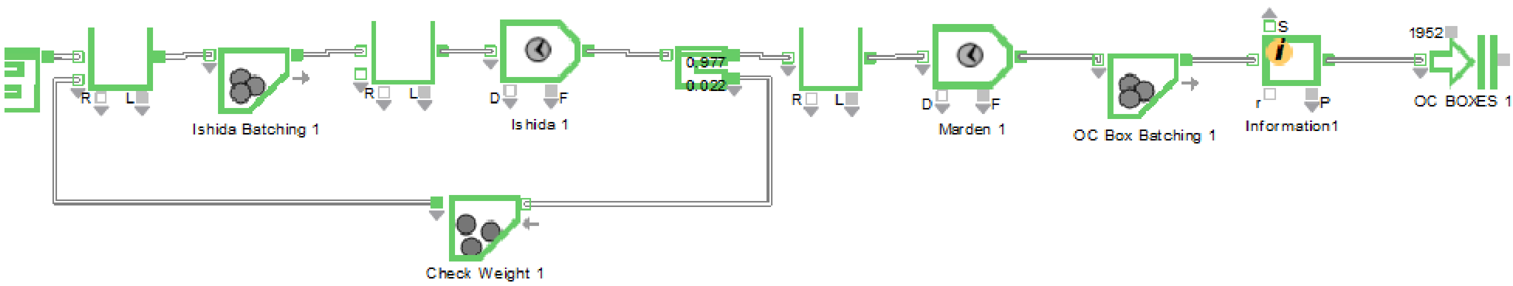
Machine #	Rate(units/min)	Availability%	MTBF (mins)	MTTR (mins)
1	800	87.6%	24	3.4
2	650	83%	18	3.7
3	700	85%	20	3.5
6	800	88%	22	3
7	800	85.1%	18	3.2
8	800	89%	24	3
9	800	83.2%	18	3.6

10	800	87%	20	2.9

7.3.2 Secondary Packaging Parameters

The secondary stage now consisted of two Ishida and two Marden machines, each with a rate of 65 boxes per minute. The batching logic remained identical, with 65 gum units per display box and 20 display boxes per outer carton

Secondary Packaging of machines 1,2, &3:



Secondary Packaging of machines 6,7,8,9, & 10:

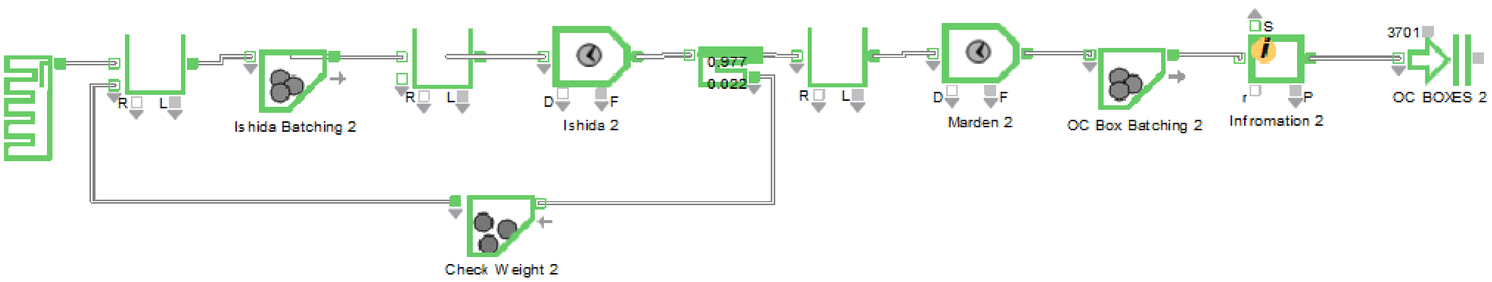


Figure 7-8 New Capacity Secondary

7.3.3 Rework And Results

The simulation recorded 284,330 reworked units, equivalent to 4,374 boxes or 219 outer cartons.

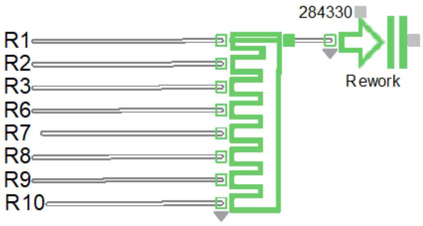


Figure 7-9 New Capacity Rework

Despite the higher number of reworked units, the rework percentage decreased to 3.87% due to the higher output. The cycle time improved significantly, with Line 1 recording 0.770 minutes per unit and Line 2 recording 0.424 minutes per unit. The total output reached 5,653 outer cartons.

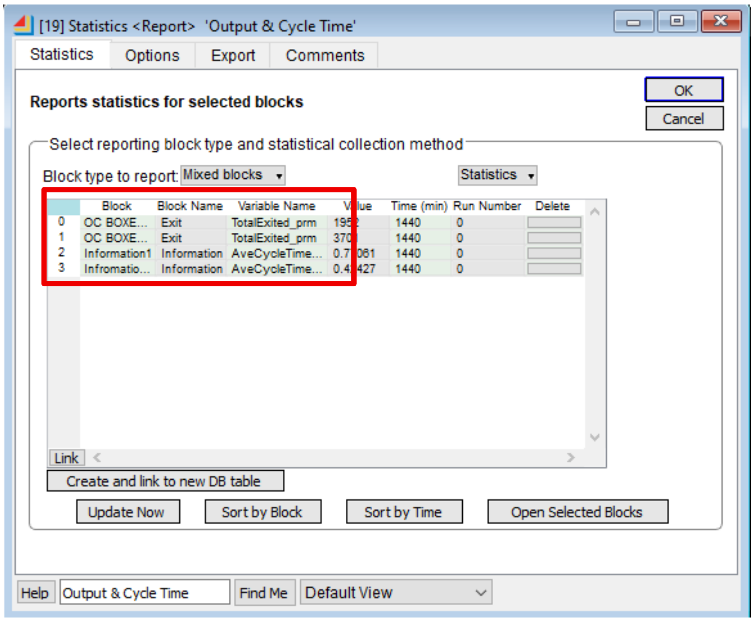


Figure 7-10 New Capacity Results

$$Cycle\ Time\ of\ The\ Packaging\ Line\ 1 = 0.770\ mins$$

$$Cycle\ Time\ of\ The\ Packaging\ Line\ 2 = 0.424\ mins$$

$$Total\ Rework\%\ of\ The\ New\ Capacity\ of\ The\ Packaging\ Line =$$

$$\frac{Total\ Rework}{Total\ Output} = \frac{219}{(1952+3701)} \times 100 = 3.87\%$$

Equation 7-3 New Capacity Results

7.4 COMPARITIVE ANALYSIS

Table 7-3 Comparison Analysis

Parameter	Old Capacity	New Capacity	Change %
Output (OC Boxes)	4289	5653	Increased by 31.8%
Cycle Time 1 (mins)	0.858	0.770	Decreased by 10.3%
Cycle Time 2 (mins)	0.858	0.424	Decreased by 50.6%
Rework %	4.06%	3.87%	Decreased by 4.7%

The simulation analysis demonstrated that capacity expansion led to a significant improvement in system performance. The output increased by nearly one-third, while cycle times were reduced substantially, particularly in the second line where reductions exceeded 50%. The slight decrease in rework percentage confirmed that quality was maintained despite the higher volume. These results validate the decision to expand capacity and emphasize the role of improved feeder distribution and additional secondary packaging machines in enhancing efficiency

Chapter Eight

8 CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

This project aimed to improve the performance and quality control of a gum packaging line by combining traditional industrial engineering tools with modern digital solutions. The initiative began with a structured root cause analysis using Pareto charts and Fishbone diagrams, which revealed that the primary contributors to performance loss were related to packaging material defects and material handling inefficiencies. To validate these findings, two key experiments were conducted: one focused on quantifying the impact of packaging material on performance through manual sampling and KPI analysis, and the other on standardizing quality inspection using PPM based sampling. These experiments provided accurate performance data, enabling the calculation of essential indicators such as Rework Percentage, MTBF, Availability, and Gross Efficiency.

One of the most impactful outcomes of the project was the development and implementation of a Power BI dashboard, which transformed raw data into actionable insights. This dashboard allowed production and quality teams to monitor rework, trace top defects by machine, shift, and SKU, and quickly identify trends and performance gaps. The integration of digital weighing systems and sampling logic into the process further enhanced data accuracy and reduced manual reporting effort. While automated defect detection sensors were explored, limitations in sensor reliability and cost effectiveness led to a more realistic hybrid recommendation, balancing current capabilities with future technological opportunities.

In addition to performance monitoring, the project proposed practical improvements in material handling practices, OEM guideline adherence, and cleaning and maintenance routines, all of which support long term equipment reliability and stability. The use of dynamic sampling, real time visualization, and cross functional collaboration aligned directly with Kaizen principles, promoting a culture of continuous improvement based on data and teamwork.

Ultimately, this project demonstrated the effectiveness of merging lean thinking with digital tools to solve real manufacturing challenges. It provided a scalable framework that not only addressed current pain points on the packaging line but also positioned the operation for sustainable, technology-driven growth. Through digital kaizen, the company can better control quality, reduce waste, and make faster, smarter decisions in an increasingly competitive manufacturing environment.

8.2 RECOMMENDATIONS

8.2.1 OEM MANUAL GUIDE

A key recommendation for sustaining long-term improvements on the packaging line is to ensure strict adherence to the Original Equipment Manufacturer (OEM) Manual Guide. The OEM manual contains the manufacturer's official procedures for machine setup, operating parameters, troubleshooting, and mechanical adjustments. Throughout the project, it was evident that some performance issues, such as sealing errors, misaligned sensors, and improper material handling, could have been avoided if the OEM instructions were regularly followed. Making the OEM manual a routine part of operator training and line setup procedures ensures that the machines are run according to their designed specifications, minimizing errors and preventing avoidable stoppages. This recommendation supports sustainable performance by aligning daily practices with proven equipment standards.

8.2.1.1 Periodical Checks and Maintenance

To ensure long term machine stability and minimize unexpected stoppages, implementing a structured program for periodical checks and preventive maintenance is essential. Throughout the project, it was observed that several issues, such as photocell sensor misalignment, sealing jaw wear, and film tension problems, were the result of irregular maintenance routines. By establishing a scheduled maintenance plan with defined checkpoints, operators and technicians can proactively address early signs of malfunction before they escalate into major disruptions. This also supports machine longevity, improves safety, and reduces unplanned downtime.

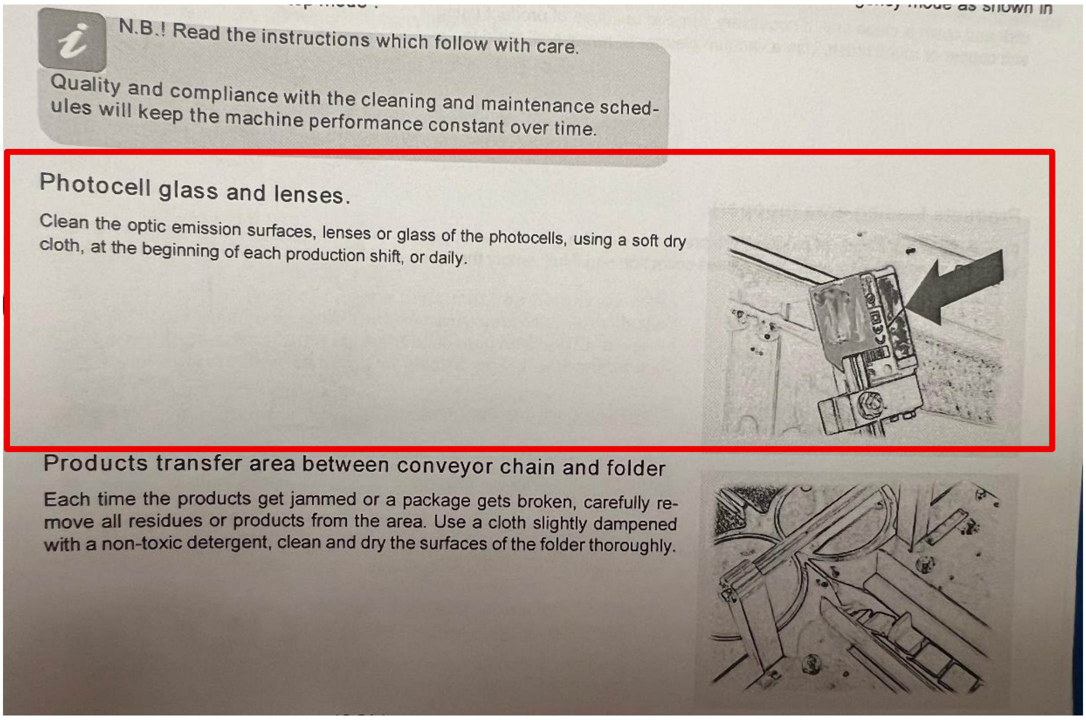
4.8.4 • Table with periodical checks and maintenance

	CHECK	WEEKLY	MONTHLY	THREE-MONTHLY	SIX-MONTHLY	ANNUAL
1	Clean the photocell lenses	X				
2	Calibrate and read the photocells	X				
3	Clean the film driving unit rubber rollers	X				
4	Operation of the safety microswitches	X				
5	Operation of the emergency buttons	X				
6	Operation of the emergency rope	X				
7	Operation of safety micro switches		X			
8	Emergency button operation		X			
9	Emergency rope operation (optional)		X			
10	Lubrication of the bearings of the wrapping material accompanying roller		X			
11	Lubrication of NUC belt bearings (grease)		X			
12	Check correct operation of the reel bakes calibration		X			
13	Check the reading and functioning of sensors of GBA unit		X			
14	Check the elongation of the bench chain			X		
15	Grease the reel-holder bearings			X		
16	Check the state of the motor cables and relative connections			X		
17	Check the heating cables and cylinder probes of the welding machines			X		
18	Check the bench chain pinions				X	
19	Check the wear of reel-holder brakes				X	
20	Check the state of the reducers				X	
21	Check the wear of the longitudinal sealing cylinder transmission gears				X	
22	Check the wear of the transversal sealing cylinder transmission gears				X	

Figure 8-1 -Periodical Checks

8.2.1.2 Photocell Sensors

The reliability of photocell sensors plays a critical role in detecting packaging material position and ensuring accurate sealing and cutting. During the study, several quality issues, including bad cuts and misaligned packs, were traced back to dirty or misaligned photocell lenses. It is recommended that photocell sensors be visually inspected and cleaned regularly, and their calibration verified according to OEM standards. Introducing visual markers and inspection checklists can help operators maintain proper sensor function, improving packaging precision and reducing defect rates.



N.B.! Read the instructions which follow with care.

Quality and compliance with the cleaning and maintenance schedules will keep the machine performance constant over time.

Photocell glass and lenses.

Clean the optic emission surfaces, lenses or glass of the photocells, using a soft dry cloth, at the beginning of each production shift, or daily.

Products transfer area between conveyor chain and folder

Each time the products get jammed or a package gets broken, carefully remove all residues or products from the area. Use a cloth slightly dampened with a non-toxic detergent, clean and dry the surfaces of the folder thoroughly.

Figure 8-2 - Photocell Sensor

8.2.1.3 Suggested Cleaning and Maintenance Method

Inconsistent cleaning routines were found to contribute to sensor failures, film feeding problems, and buildup on mechanical parts. To address this, a standardized cleaning and maintenance method should be adopted across all shifts. This includes assigning cleaning responsibilities, using proper materials and tools, and setting cleaning frequencies based on machine usage. Critical areas such as sealing jaws, sensor lenses, and material feed paths should be part of a clearly defined routine. Documenting these procedures not only ensures consistency but also supports audit readiness and improved equipment performance.

4.8.1 • Scheduled maintenance card (cleaning and checking for wear)

Scheduled cleaning and maintenance shall be carried out weekly. In addition to thorough cleaning of the parts indicated, check these for wear and replace, if necessary. The layout below shows the areas subject to maintenance. The icons, which are explained in the key at the bottom of the page, indicate the suggested cleaning and maintenance method.

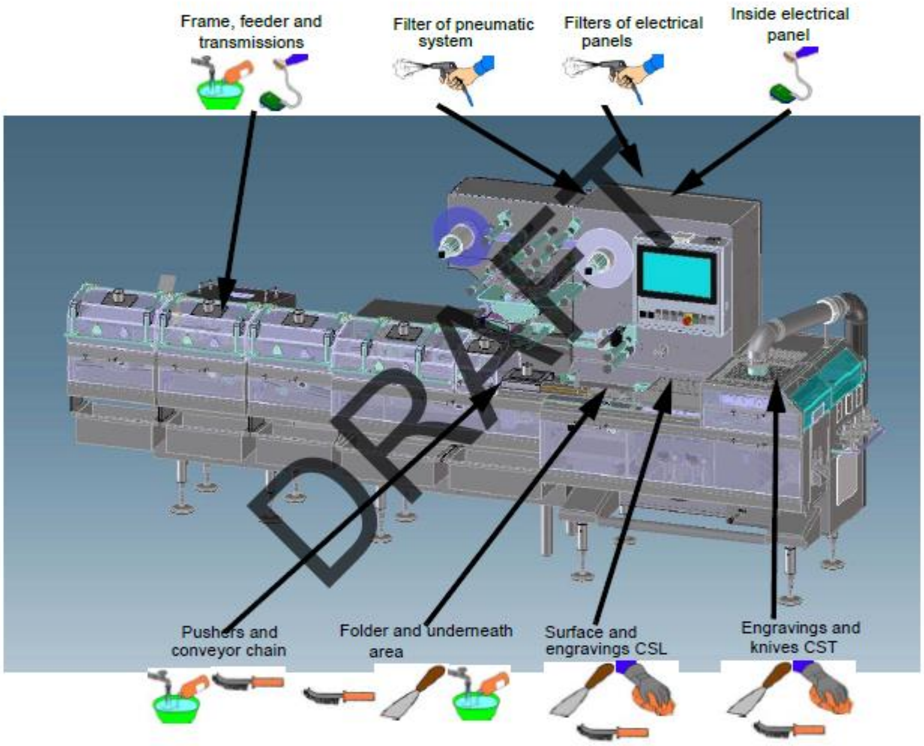


Figure 8-3 - Updated CIL

Icon	Meaning	Icon	Meaning
	Use an air jet. Wear protective glasses.		Use a scraper made of plastic. Wear protective glasses.
	Use a cloth soaked into non-toxic detergent. Wear protective gloves.		Use a vacuum cleaner. Wear protective gloves.
	Use a dry cloth. Wear protective gloves.		Use a copper brush. Wear protective glasses.

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8.3 DIGITALIZATION OF THE PACKAGING LINE

To support the shift toward data-driven manufacturing, digitalizing key aspects of the packaging line is recommended. This includes three main areas: introducing a Power BI dashboard to monitor performance in real time, implementing a digital weight scale to standardize and automate quality sampling, and applying defect detection sensors to reduce reliance on manual inspection. These tools aim to improve visibility, reduce human error, and enable faster, more informed decision-making on the shop floor.

8.3.1 Dashboard

Implementing a digital dashboard is essential for improving visibility into real-time performance metrics. By centralizing data such as rework percentage, defect types, and machine-specific KPIs, the dashboard enables both production and quality teams to monitor trends, identify top losses, and respond quickly to issues. Built using Power BI, the dashboard allows for interactive filtering by shift, SKU, and machine, offering a clear and accessible tool for daily decision making and long-term performance analysis.

8.3.2 Digital Weight

To enhance the accuracy and traceability of rework measurement, the implementation of digital weight scales is recommended. During the project, two industrial models were evaluated: the **Mettler ICS689** and the **Minebea Intec Combics 3**. Both offer reliable performance, high precision, and compatibility with Siemens PLCs for real time data integration.

The **Mettler ICS689** provides a user-friendly touchscreen interface, fast stabilization time, and a compact design suitable for line side use. It supports efficient operator handling and quick sampling routines.

Figure 8-4 -Mettler ICS689

The **Minebea Intec Combics 3** offers robust construction, flexible configuration options, and enhanced features for customized process control, making it ideal for environments that require adaptability.

Figure 8-5 - Minebea Intec Combics 3

By adopting either scale, manual weighing errors can be reduced, data entry can be automated, and consistent quality checks can be maintained across all shifts, supporting a more standardized and digital quality control process.

8.3.3 Digital Defect Detection Sensors

The implementation of digital defect detection sensors was explored to improve packaging quality and reduce reliance on manual inspection. While newer machines on the line are already equipped with built-in sensors, analysis revealed a major flaw: the current system frequently misclassifies good products as defective. Specifically, the sensor measures gum length, but when a correctly sized piece exits the machine at an angle, the diagonal reading triggers false rejections, resulting in nearly **50%** of the rejected products being acceptable. Despite multiple calibration attempts with the OEM, no effective solution has been achieved. Replacing the sensor with a third-party option introduces further challenges, including compatibility issues, synchronization risks, and engineering complexity. Moreover, the cost of high-speed 3D or vision-based sensors is difficult to justify given the low unit value of gum products. As a result, a hybrid approach is recommended: in the short term, disable the current sensor to prevent unnecessary waste and rely on dynamic sampling. In the Long term, continue to evaluate AI driven vision systems that may offer better detection accuracy at a feasible cost.

8.4 MATERIAL HANDLING PROPOSAL

To minimize product and material damage during transport, improvements in material handling systems are essential. One key recommendation is to adopt a **Tubular Cable Conveyor System**, which can reduce product damage rates from **10 to 15% down to 1 to 2%**, particularly for delicate items. This closed, gentle transport method minimizes friction, impact, and product breakage compared to conventional conveyor systems. Additionally, it's recommended to eliminate sharp edges and transfer points that may cause tearing or surface damage to package materials. For edges that cannot be removed, applying hardened treatments such as nitriding can reduce wear and protect both materials and equipment. These actions collectively enhance material integrity, reduce stoppages caused by damaged inputs, and improve overall line reliability.

Figure 8-6 - Tubular Conveyor

8.5 ACTION PLAN

Table 8-1- Action Plan

	Oct.				Nov.				Dec.				Jan.				Feb.				March				April				May				June			
Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Factory selection																																				
Project selection																																				
Factory visits																																				
Data Collection																																				
Data analysis																																				
Problem Identification																																				
Literature review																																				
Power BI Model																																				
Conducting the Packaging Paper Experiment																																				
Dynamic Sampling																																				
Implement Counter measures																																				
Presentation																																				
Report Writing																																				

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