REDUCING MATERIAL LOSSES IN A BLENDING PRODUCTION LINE: A CASE STUDY IN AN AIR FILTER MANUFACTURING COMPANY

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Industrial Engineering

Faculty of Engineering and Green Technology
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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"REDUCING MATERIAL LOSSES IN A BLENDING PRODUCTION LINE: A CASE STUDY IN AN AIR FILTER MANUFACTURING COMPANY"** was prepared by **OH SU YA** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Industrial Engineering with Honours at Universiti Tunku Abdul Rahman.

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ABSTRACT

Material losses are a common issue in production lines at manufacturing companies. Even with advanced technology invested in the production line, material losses still occurred due to various factors, such as material handling and transportation. This study was conducted at Factory X, an air filter manufacturing company located in Perak, Malaysia, with the main objective of reducing material losses in the chemical blending production line by 5%. The DMAIC (Define, Measure, Analyse, Improve, Control) approach was chosen as the primary methodology, supported by on-site examinations, Material Flow Analysis (MFA), the 5 Whys analysis, and Kaizen. A framework was developed to guide the step-by-step implementation in the factory, keeping the project on track and ensuring a systematic improvement process. After measuring and analysing data before and after the test run, the results showed a reduction in material losses, decreasing from 17.86% to 11.97%, representing an improvement of 5.89%. The study demonstrated the success of the framework and proposed several recommendations for future research, including testing the framework in different production lines and industries, applying it to other sections of the same production line, optimising MFA for more accurate measurement, and investigating alternative materials for reducing material losses.

Keywords: Blending Production Line; Material Losses; Manufacturing System; Material Flow Analysis (MFA); FESEM Analysis

Subject Area: TS155-194

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter includes the background, problem statement, objectives, scope of the study, and the outline of this thesis. Subsection 1.2 provides the background of the study while subsection 1.3 presents the problem statement. Furthermore, subsection 1.4 outlines the objectives of the study, and subsection 1.5 defines the scope. Lastly, subsection 1.6 presents the structure of the entire thesis.

1.2 Background

A blending production line involves the blending of various chemical substances to produce different products in modern industries. This process is important for producing a wide range of modern products that can be used daily. For instance, cleaning agents, health supplements, processed foods, cosmetics, and paints, require chemical blending during their production. The chemical should be accurately mixed in producing these products to ensure the quality and the effectiveness of the final product. According to Bakri et al. (2015), the powder blending process is a crucial step in pharmaceutical manufacturing for producing solid-form drugs. Ensuring content uniformity in these drugs is vital, particularly for high-potency medications, to guarantee patient safety.

When chemical powders are mixed and blended, Bakri et al. (2015) point out that the physical properties of the ingredients can change due to the mixing process. Some of the factors such as the particle sizes, electric charge, and the shapes of the ingredient can be influenced during the process. Additionally, the design of the blender, the blending duration, the blending speed, and the surrounding environmental conditions can affect the effectiveness of the chemical blending process. By focusing on these details, the quality and potency of the final product can be ensured that meet the industry standards and consumer expectations (Bakri et al., 2015).

Automated production refers to manufacturing processes that use technology and machinery to produce goods, often with minimal or no human involvement. Various types of automated manufacturing systems exist, including single-station automated cells, automated assembly systems, flexible manufacturing systems, and computer-integrated manufacturing systems. Single-station automated cells involve fully automated machine cycles without human intervention. Automated assembly systems utilize handling systems that implement robots to replace manual labour in the assembly process (Qin et al., 2016). Furthermore, Qin et al. (2016) explained that flexible manufacturing systems are designed to efficiently adapt processes for specific part families. Computer-integrated manufacturing systems are fully automated, with all functions controlled by computers. While these systems differ in implementation, they share a common goal: enhancing productivity and efficiency on the production line.

The advantage of automated manufacturing systems is their ability to eliminate buffers and reduce throughput time on the production line. Systems that require less manpower also enhance layout flexibility on the shop floor, allowing for more efficient utilization of free space and streamlined production processes. Additionally, automated manufacturing systems help minimize errors in production, thereby improving and maintaining product quality. Machines are more precise than humans and less prone to errors during the manufacturing process (Reinhart & Werner, 2007).

An automated blending production line uses an automated manufacturing system to streamline production, resulting in precise and consistent outcomes. Obiora-Dimson et al. (2015) stated that a flexible automated manufacturing system is beneficial in the beverage blending industry. The automated beverage blending system helps adjust the content ratio of fruit juices. It enables wireless control of the machine to meet customer preferences and accommodate seasonal variations. This system reduces the need for extensive setup changes when producing a new product, thereby streamlining the production process and minimizing disturbances to ongoing production.

Material loss is a prevalent issue in manufacturing lines that significantly impacts raw material efficiency. Raw materials can be lost in the form of waste, scrap, defects, and spoilage. According to Allwood et al. (2011), material losses in manufacturing are often discussed under the concept of "yield losses". This term refers to the materials lost at various stages of production along the manufacturing line. It can also be described as the difference between the initial amount of raw material and the amount that ultimately becomes the final product after processing.

Yield losses can result from various factors or processes, such as start-up losses, scalping, and trimming during the manufacturing process, over-ordering, and quality issues. For example, up to 50% of cast metal is wasted in the production of sheet metal components due to various process steps. Additionally, material losses have implications for product quality, economics, and the environment. They can compromise the quality of final products by increasing the likelihood of defects during production, raising production costs, and reducing overall organizational profitability. Lastly, material losses contribute to higher overall energy requirements for producing each unit of the final product (Allwood et al., 2011).

Therefore, achieving high material efficiency is always a key goal in developing a successful manufacturing line and industry. One strategy to achieve this goal is optimizing the production process. Advanced technologies can be implemented or utilized in the production line to minimize material losses at various stages of production. Increasing recycling rates by recovering and reusing materials is another effective approach. This reduces the need for new raw materials by utilizing excess materials from previous production processes (Allwood et al., 2011).

Allwood et al. (2011) also emphasize that designing for material efficiency can significantly reduce material losses in the production line. Organizations can design products that require less raw material without compromising product quality. Thus, performance standards for the product can still be achieved even with reduced raw material usage.

1.3 Problem Statements

Nowadays, technology is advancing rapidly, with improvements occurring from year to year and even day to day. People often believe that technology can solve every problem in the world. If a problem cannot be solved, there may be an effort to innovate more advanced technology. However, even advanced technologies implemented in production lines may not entirely eliminate material losses. This can also occur in industries that utilize high-tech machinery and equipment. On the other hand, advanced technology can be effectively used to identify, measure, quantify, and address material losses in the production line, thereby improving the efficiency of raw material use and reducing overall losses (Castiglione et al., 2024). Static measurement refers to measurements taken at a fixed point where the material is not moving. Conversely, dynamic measurement refers to measurements taken during ongoing production. Dynamic measurement helps understand the fluctuations of materials in transit, which static measurement does not provide (Bicker et al., 2024). Dynamic measurement is easier and more cost effective to implement than static measurement when the material is in motion. It allows for the total amount of materials transported over a specific period to be determined during ongoing production. However, measuring material losses during the transportation of raw materials from one station to another is challenging. Comparing dynamic measurement with static measurement reveals that weighing the flow at a particular point is less accurate than weighing the accumulated material in a container. Dynamic measurement involves more parameters that can influence the accuracy of the data.

Furthermore, several factors can cause material losses in an industry, such as the transportation of materials and the production process itself. Additionally, the methods of material handling can be a significant factor. Improper material handling in a production line, such as incorrect containment, transfer, and processing, can contribute to material losses. For instance, the spillage of chemical powder can result in waste and pose health risks to workers in the surrounding environment. Bilska et al. (2021) emphasize that material handling methods can affect the physical and chemical properties of materials in the food industry. Therefore, improper handling of materials can be a major factor contributing to material losses in a manufacturing line. Material losses may occur in multiple areas within the manufacturing line, and some of these areas may be easily overlooked. Thus, identifying specific areas where material losses occur is crucial, making dynamic measurement more challenging in the study.

1.4 Objectives

The study will focus on the following objectives:

1. To identify suitable methods in detecting and reducing material losses in an automated blending production line
2. To develop a framework to reduce material losses in an automated blending production line
3. To validate the framework in an air filter manufacturing company

1.5 Project Scope

The framework developed was tested in an air filter manufacturing company due to:

1. The time constraints of the study. The time allocated for the study is only two trimesters, which is 28 weeks. Additionally, the study requires data collection and discussions with engineers at Factory X. Thus, time constraints are a crucial limitation of the project, as it takes around 40 minutes to travel to Factory X, and only time slots without scheduled classes can be used for factory work.

2. The availability of the study provided by the air filter manufacturing company. The study is introduced and proposed by engineers at Factory X based on its availability. Moreover, the study addresses a problem recently faced by the engineers in the factory. Additionally, access to the production line in Factory X is crucial, as it may impact the confidentiality of sensitive information related to the production process

1.6 Outline of the Thesis

This thesis consisted of five chapters. Chapter 1 presented the background, problem statement, objectives, and project scope. Chapter 2 provided a literature review, where journal articles were reviewed to identify methods for detecting and reducing material losses. These methods were then discussed, and the most suitable approach was selected. Chapter 3 outlined the study's methodology and the framework implemented in Factory X. Chapter 4 presented the results and discussion, including data collected before and after the test run. The advantages and limitations of the implemented framework were also analysed. Lastly, Chapter 5 concluded the thesis and proposed several recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter includes the literature review referenced in the study. The literature review focuses on methods to detect and reduce material losses in the production line. Subsection 2.2 presents a review of methods for detecting material losses. Subsection 2.3 discusses methods to reduce material losses. Furthermore, subsection 2.4 outlines the summary table of literature review. Lastly, subsection 2.5 shows the discussion of literature review.

2.2 Methods to Detect Material Losses

The generation of material losses in a factory can lead to inefficient use of resources and increased costs. The study done by Daian & Ozarska (2009), aimed to raise awareness and understanding of wood waste within wooden furniture factories, particularly in financial terms. Six wooden furniture factories in Australia underwent on-site observation to detect wood waste within each company. These examinations and reviews aimed to comprehensively assess the type, quantity, origin, and flow of wood waste within the factories. It was found that wood waste in wooden furniture factories ranged from 7% to 50% of the annual supply of raw materials. Consequently, the research presented various practices aimed at reducing wood waste in factory settings.

In electronics assembly, the loss of electronic components such as resistors and capacitors is a common problem that is difficult to detect and address. The study done by Ping Yi et al. (2012), aimed to tackle and reduce the losses of electronic components in an electronics assembly plant. The DMAIC approach, which stands for Define, Measure, Analyse, Improve, and Control, was implemented to detect and reduce material losses in the production process. DMAIC provides a focused and systematic methodology, helping to reduce variability in the process. After identifying the root causes of material losses, changes were made to the shop floor layout, reducing component losses to a more manageable level. This improvement not only enhanced efficiency of the process but also resulted in significant cost savings for the plant.

Bai et al. (2015) outlined that material losses in the production line can be addressed and quantified by identifying all materials at the input and output of the production system. The study, conducted at a lead smelting enterprise in China, aimed to research the metabolism of the lead production process, focusing on pollution prevention and control. Substance Flow Analysis (SFA) was implemented to detect and measure material losses in the smelting process. Data was collected over a three-day period, measuring the input and output of lead-containing materials and calculating the lead content in each flow. This approach not only detected and measured material losses but also revealed unsuspected losses in the lead production line. The study found that a difference of approximately 10% between input and output was a common occurrence in the production line.

Ding et al. (2016) introduced the importance of aluminium due to its attractive characteristics such as being lightweight, corrosion-resistant, and having a high strength-to-weight ratio. Given the rapid development of the aluminium industry in China, the study was conducted to quantify the flows, stocks, and losses in the aluminium life cycle. Raw material losses were detected by implementing Substance Flow Analysis (SFA). Various stages were involved, including mining, alumina refinement, smelting, casting, and fabrication. Data on input and output at each stage was collected to detect material loss. Subsequently, loss flows were calculated using a specific equation to quantify material loss. As a result, the material loss rate was successfully detected and quantified at different stages of the aluminium production line.

Tannady (2019) emphasised the challenges faced by a manufacturing factory in achieving production targets, primarily due to quality issues and raw material waste. This research was conducted at the largest instant noodle production company in Southeast Asia. Interviews were conducted with production supervisors and employees from the PPIC department to understand the material flow and production processes. The Lean Six Sigma approach, incorporating tools such as Value Stream Mapping (VSM) and the Waste Assessment Model (WAM), was then implemented to identify, address, and analyse material losses. This approach facilitated a more systematic collection of information throughout the production process. The identification of material losses revealed that waste due to product defects was the most significant, accounting for 25.03% of the total waste.

Braglia et al. (2021) introduced a systematic approach implemented in production lines to detect material losses. The approach was tested in a European multinational group in the food and beverage industry, demonstrating its capability to identify material losses effectively. The approach, called Materials Cost Deployment (MaCD), was developed from the framework of Manufacturing Cost Deployment (MCD). MaCD helps identify, quantify, and prioritize improvement actions to reduce material losses. The material losses identified in the industry were quantified in monetary terms, and the cost implications of these losses were assessed. By implementing MaCD, overall material losses in the production line were reduced, and material efficiency was enhanced.

The study by Kholil et al. (2021) was conducted in a two-wheeled automotive spare parts manufacturing company located in Indonesia. The aim was to reduce waste and enhance production efficiency to meet high customer demand using Lean Six Sigma approaches. DMAIC served as the primary methodology for the study. In the

Define stage, material waste was identified using Value Stream Mapping (VSM). Both current and future state maps were created to pinpoint areas where waste occurred. Additionally, Value Stream Analysis Tools (VALSAT) were implemented in the Analyse stage to find the root cause of material losses through the Waste Relationship Matrix and Waste Assessment Questionnaire. Subsequently, improvement and control actions were implemented. By the end of the study, the total cycle time was reduced, demonstrating a significant decrease in material losses.

Salwin et al. (2021) emphasised that Value Stream Mapping (VSM) is a well-known and straightforward tool that can be used to visualise production processes in a factory. The study was conducted in a steel pipe manufacturing company to reduce material waste and increase the quality and efficiency of the production process. VSM was implemented in the plant through several steps, including observation and data collection, development of current and future state maps, and finalisation and analysis. The study began with observation of the production process and data collection on machine operations. After that, the maps were created based on the collected data. The current state map was then finalised, helping to identify waste and areas for improvement. The study successfully detected material losses in the production line, and subsequently, material losses were reduced by 1.7 times compared to the previous state.

Food losses and waste have been a global concern, contributing to social, economic, and environmental issues. Amicarelli et al. (2021) conducted a study in an Italian meat industry to measure food waste. The study aimed to assess the suitability and effectiveness of Material Flow Analysis (MFA) for measuring food waste in the industry. During the study, the state and change of material flows were assessed and quantified over a period of time. The quantification of input and output material flows included fresh meat production, co-products, by-products, and food waste. Additionally, eco-efficiency indicators were analysed to evaluate the sustainability of the industry. As a result, there were approximately 0.2 Mt to 0.3 Mt of material losses at retail and final consumption stages in the meat industry.

Mousa & Aziz (2023) conducted a study at the "Rasan Steel" plant, a steel structure manufacturing factory. The aim of the study was to reduce waste losses in the production processes and to explore the utilization of a specific method. Material Flow Cost Accounting (MFCA) was implemented to track and analyse material flow throughout the production processes. MFCA enables the detection of material losses comprehensively because all inputs, such as raw materials, and all outputs can be identified within a quantifiable boundary. This method helped identify material inefficiencies, pinpoint areas where material losses occurred, and calculate the associated costs of these losses. Some improvements have been made, leading the steel factory to achieve a more sustainable and cost-effective production process.

2.3 Methods to Reduce Material Losses

Banuelas et al. (2005) highlighted research on the application and benefits of Six Sigma. The study focused on waste reduction in a coating process using Six Sigma tools, a topic not previously explored in the existing literature. The aim was to identify, quantify, and eliminate causes leading to material losses. The Six Sigma tool DMAIC (Define, Measure, Analyse, Improve, Control) was utilized to reduce waste in the continuous film-coating process. DMAIC enables material reduction by defining goals, analysing root causes, implementing targeted improvements, and introducing control actions. After implementing these improvements, material losses were successfully reduced by £50,000 per year in the coating process.

The study done by Murugaiah et al. (2010), focused on reducing scrap loss in one of the largest barrel manufacturing industries in the ASEAN region, which faced the problem of last piece material scratch defects in its production line. This company supplies barrels to industries in oil and gas, chemical, and cosmetics. The root cause analysis technique in lean manufacturing, known as the 5 Whys analysis, was implemented to provide a structured method for addressing the root cause of the problem. This technique involves repeatedly asking "why" to uncover the underlying cause of the material losses. The analysis identified two possible root causes: friction with the forklift arm and friction with the end-of-line machine rollers. By implementing corrective actions based on these findings, material losses were reduced, and last piece material scratch defects were eliminated in the production line.

Kasemset et al. (2013) conducted study in a plastic packaging factory in Thailand that produces plastic water bottles. The production of these bottles involves five processes: crushing, mixing, blow molding, printing, and molding. The aim of the study was to identify and reduce material losses in the blow molding process. By integrating Material Flow Cost Accounting (MFCA) with motion study and the ECRS (Eliminate, Combine, Rearrange, Simplify) method, the researchers employed systematic approaches to minimize material losses. MFCA identified process inefficiencies, the motion study optimized work processes, and ECRS eliminated material losses in the production system. The results showed that the cost associated with material losses was reduced, and material losses in the blow molding process decreased by 26.07%.

Hassan (2013) emphasised the waste generation in a welding wire manufacturing company. The study aimed to improve the quality of the manufactured welding wire, reduce manufacturing waste, and increase the yield of the manufacturing process. The DMAIC process, which is part of Lean Six Sigma, was implemented to achieve these goals. The steps in the DMAIC process included identifying the problem of waste generation, collecting and mapping data, identifying the root causes of waste, implementing improvements, establishing control actions, and monitoring waste levels. By implementing the DMAIC process, material losses were reduced by 2.25%, achieving a waste ratio of 2%.

The study by Patel and Thakkar (2014) focused on a ceramics manufacturing company in India that faced problems in its production line, including process inefficiencies and material waste. The aim of the study was to enhance process efficiency, eliminate material losses, and improve safety and storage facilities by implementing lean manufacturing tools. The 5S methodology was used to create a more organised and effective work environment in the company. The Seiri (Sort) step in the 5S methodology was implemented to identify unnecessary materials in the production line. This allowed for a systematic segregation of materials, such that unneeded items could be disposed of, and necessary materials could be organised properly in designated areas. As a result, space in the production line was saved, contributing to a reduction in material losses.

The study by Kasemset et al. (2016) was conducted in an electronics factory in Thailand. The production of trigger coils was chosen for improvement due to its high production volume and significant amount of waste generated. The aim of the study was to reduce material waste and enhance environmental and financial performance in the factory. Material Flow Cost Accounting (MFCA), integrated with ECRS principles, was implemented to achieve this. MFCA was used to identify the sources and factors of material waste, while ECRS principles helped in designing a new jig that could minimise tool holding allowance and reduce material waste. As a result, the new jig design led to a 34.71% reduction in material losses.

Lean manufacturing tools are highly effective for helping companies eliminate waste and non-value-added activities in the production line. In the study done by Kaneku-Orbegozo (2019), a company that produces kitchen equipment was chosen. The production process includes five operations: design, cutting, bending, welding, and surface finishing. Lean manufacturing tools such as 5S, standardization of work, and preventive maintenance were implemented to reduce material waste. The 5S method improved workplace cleanliness on the shop floor, standardization of work streamlined the manufacturing process, and preventive maintenance ensured the reliability of equipment. By implementing these lean manufacturing tools, the company reduced manufacturing costs by 13%, cut material waste by 6% in the cutting and bending process, improved manufacturing times, and enhanced overall efficiency.

Goyal et al. (2019) highlighted the generation of waste from hazardous materials resulting from manufacturing activities, which significantly impact the environment. The study was conducted in a power plant in India with the aim of exploring waste reduction techniques to improve manufacturing processes and reduce the generation of hazardous waste. The integration of the PDCA (Plan-Do-Check-Act) cycle and the Kaizen approach was implemented to reduce material losses in the production line. The PDCA was applied through the following steps: identifying areas for improvement and developing a strategy for waste reduction, implementing the planned strategies, monitoring the results, and making necessary adjustments for continuous improvement. Material losses were ultimately reduced by 13.8% after implementing the waste reduction strategies.

PT. XYZ, a seafood processing company in Makassar, specialises in processing frozen raw octopus commodities. The company faced issues with material losses in the gutting process due to excessive shrinkage. The study by Fauzan et al. (2019) aimed to identify the factors contributing to these material losses and propose solutions to optimise corporate profits. The Kaizen method was implemented to analyse the workflow from raw materials to end products, identify inefficiencies in the production line, and implement improvements to reduce material losses. By implementing the Kaizen method, the company was able to reduce material losses by approximately 1%, resulting in cost savings.

Hartini et al. (2021) emphasised that trees must be cut down as wood is the primary raw material in the furniture industry. Consequently, the furniture industry can contribute to global warming due to the significant amount of wood used annually. The study aimed to identify and reduce material losses, improve resource efficiency, and minimize environmental impacts in the furniture industry. Value Stream Mapping (VSM) was initially used to identify material losses. Subsequently, the 6R strategy (reduce, reuse, recycle, recover, redesign, remanufacture) was employed to address these losses. In the study, only the reuse and redesign strategies were implemented, specifically repurposing wood waste into coffee tables. Despite this limited implementation, material losses were still reduced by approximately 46% in the production line.

2.4 Summary

Table 2.1 and Table 2.2 present summaries of the methods used to detect and reduce material losses.

Table 2.1: Methods to Detect Material Losses

Methods to Detect Material Losses	Papers									
	1	2	3	4	5	6	7	8	9	10
On-site examination	√									
DMAIC (Define, Measure, Analyse, Improve, Control)		√					√			
Substance Flow Analysis (SFA)			√	√						
Value Stream Mapping (VSM)					√		√	√		
Waste Assessment Model (WAM)					√					
Materials Cost Deployment (MaCD)						√				
Material Flow Analysis (MFA)									√	
Material Flow Cost Accounting (MFCA)										√

References: 1) Daian & Ozarska (2009), 2) Ping Yi et al. (2012), 3) Bai et al. (2015), 4) Ding et al. (2016), 5) Tannady (2019), 6) Braglia et al. (2021), 7) Kholil et al. (2021), 8) Salwin et al. (2021), 9) Amicarelli et al. (2021) 10) Mousa & Aziz (2023)

Table 2.2: Methods to Reduce Material Losses

Methods to Reduce Material Losses	**Papers**									
	1	2	3	4	5	6	7	8	9	10
DMAIC (Define, Measure, Analyse, Improve, Control)	√			√						
5 Whys analysis		√								
Material Flow Cost Accounting (MFCA)			√			√				
ECRS (Eliminate, Combine, Rearrange, Simplify)			√			√				
5S methodology					√		√			
Standardization of work					√					
Preventive maintenance					√					
Kaizen								√	√	
Value Stream Mapping (VSM)										√
6R strategy (Reduce, Reuse, Recycle, Recover, Redesign, Remanufacture)										√

References: 1) Banuelas et al. (2005), 2) Murugaiah et al. (2010), 3) Kasemset et al. (2013), 4) Hassan (2013), 5) Patel & Thakkar (2014), 6) Kasemset et al. (2016) 7) Kaneku-Orbegozo (2019), 8) Goyal et al. (2019), 9) Fauzan et al. (2019), 10) Hartini et al. (2021)

2.5 Discussion of Review

Various methods could be implemented to detect, measure, and reduce material losses in the production line. The literature review was discussed in the following sub-subsections and summarised in Table 2.1 (page 15) and Table 2.2 (page 16).

2.5.1 Methods to Detect Material Losses

Based on the summary table shown above, only one study conducted an on-site examination to detect material losses. While this method was useful for obtaining a general overview and identifying visible issues, it had several limitations, such as inconsistencies, overlooking hidden losses, and limited quantification of material losses. However, on-site examination helped in the immediate detection of visible material losses. For instance, material losses occurred in areas or situations that were difficult to measure. It also helped reveal inefficiencies that might not have been apparent from data alone.

DMAIC (Define, Measure, Analyse, Improve, Control) was conducted in two studies to detect and measure material losses in factories. DMAIC is a structured approach that involves five stages, providing step-by-step guidance to identify and quantify material losses, ensuring nothing is overlooked. This method can be complicated for organisations unfamiliar with Lean Six Sigma methodologies. However, despite its complexity, DMAIC enables accurate data collection and analysis.

The method of Substance Flow Analysis (SFA) was implemented in two studies. This method detects and measures material loss by calculating the input and output material flow at every stage. It allows for easier measurement of material loss as the data is collected in flow rate terms. However, the limitation of SFA is that it typically focuses on a single material, which may not provide a comprehensive view of all material flows.

Value Stream Mapping (VSM) was implemented in three studies to detect material losses in the production line. It can be said that VSM is a popular method due to its low complexity in implementation. VSM provides a comprehensive overview of every station in the production line, helping to visualise and address material flow and material losses. However, VSM does not provide precise quantitative data on material losses, and additional methods are needed to quantify these losses.

Only one study had implemented the Waste Assessment Model (WAM) to detect and measure material losses. WAM was used to categorise different types of waste, such as materials, scrap, defects, and waiting time. However, WAM was not suitable for implementation in a chemical blending production line, as the process operated continuously. This method was unable to accurately quantify the flow of materials.

Material Cost Deployment (MaCD) was conducted in only one study, as the author adapted MaCD from the framework of Manufacturing Cost Deployment (MCD). Accurate detection of material losses in a chemical blending production line requires detailed information on material input and output. MaCD may not offer the level of detail necessary to track the flow of chemicals through the production line, particularly in a dynamic environment. Additionally, while MaCD facilitates periodic data collection and analysis, it does not provide immediate feedback to the production line.

The approach of Material Flow Analysis (MFA) was implemented in one study. MFA is similar to Substance Flow Analysis (SFA), but MFA focuses more on multiple materials, where several substances are blended together in the production line. By using MFA, material input and output are measured at every stage to detect and quantify material losses. This method is more suitable than SFA when dealing with mixed chemicals.

Material Flow Cost Accounting (MFCA) was implemented in only one study. This method involves quantifying material flow in both physical and monetary terms. In a chemical blending production line, MFCA may be unsuitable due to challenges in isolating costs for specific material losses in mixed chemicals. This is because MFCA, like SFA, focuses on a single material. Additionally, MFCA is not suitable for implementation in dynamic environments where the process is continuously operating.

2.5.2 Methods to Reduce Material Losses

There are two studies that have implemented DMAIC (Define, Measure, Analyse, Improve, Control) to reduce material losses. DMAIC not only helps in detecting and measuring material losses in the production line but is also effective in reducing them. This is due to the five steps involved: Define, Measure, Analyse, Improve, and Control. The reduction of material losses typically occurs in the last three steps of DMAIC. DMAIC is useful because it is not limited to a single method; different methods can be used to complete the DMAIC process.

The 5 Whys analysis was used in only one study to reduce material losses. This method helps uncover the root cause of material losses by repeatedly asking "why" until the fundamental issue is identified. As a result, a complex problem can be broken down into a few manageable parts, making it easier to develop potential solutions to reduce material losses. Additionally, the 5 Whys analysis supports continuous monitoring and improvement of the production line to further minimise material losses.

Material Flow Cost Accounting (MFCA) was implemented in two studies to reduce material losses. MFCA requires substantial time and financial investment to set up and implement. For instance, organisations wishing to implement MFCA in their production lines must provide proper training to employees, develop accurate measurement systems, and continuously monitor material flows. Additionally, MFCA, like SFA, focuses on single material flows.

The ECRS (Eliminate, Combine, Rearrange, Simplify) method was conducted in two studies. Using ECRS to reduce material losses may require higher initial costs due to retraining staff, reconfiguring production lines, or purchasing new equipment and machinery. Moreover, overly simplifying processes can lead to the oversight of necessary steps in the production line.

According to the summary table above (Table 2.1, page 15 and Table 2.2, page 16), two studies implemented the 5S methodology to reduce material losses in the production line. The methods commonly used to address material losses were Seiton (Set in Order) and Seiso (Shine). While 5S provides an effective approach to reducing material losses through its five steps, it may not address all aspects of material flow or handling that can contribute to material losses.

Standardisation of work was implemented in only one study. It helps to standardise the working procedures of operators and employees, contributing to the elimination of non-value-added activities. Despite this, the method may overlook variations in material types, which can impact the effectiveness of the standard procedures.

Only one study implemented preventive maintenance to reduce material losses. The actions were taken after failures occurred. Additionally, quantifying the improvement in material losses proved to be challenging.

Two studies implemented Kaizen to reduce material losses in manufacturing lines. Kaizen involves identifying areas for improvement, implementing small changes, and continuously monitoring progress. It is suitable for gradually reducing material losses and can be applied to various aspects of the production line. However, it requires time, and the incremental nature of changes might lead to the potential overlooking of larger issues.

The method of Value Stream Mapping (VSM) was implemented in one study to reduce material losses. This method may not be suitable for reducing material losses as it does not provide quantitative data. Therefore, whether material losses have been reduced cannot be clearly quantified or visualised.

The 6R strategy (Reduce, Reuse, Recycle, Recover, Redesign, Remanufacture) was implemented in one study to reduce material losses. By utilising the reuse and recycling aspects of the 6R strategy, material waste such as offcuts and scraps can be returned to the production line. This waste can be used to produce new products or be processed back into raw materials. However, some processes may be irreversible, meaning that certain types of material waste cannot be reused or recycled.

There is not a single solution to every problem in the world. In the study, several tools were used to detect, measure, and reduce material losses in the chemical blending production line. The DMAIC approach (Define, Measure, Analyse, Improve, Control) was conducted step by step to reduce material losses. First and foremost, on-site examination was implemented in the define stage to identify the areas where material losses occurred, providing a comprehensive understanding of the production flow and allowing for the effective detection of visible material losses. In the measure stage, the approach of Material Flow Analysis (MFA) was implemented to measure the flow of materials at every stage, as the raw materials were blended throughout the production process. During the analyse stage, 5 Whys analysis was utilised to identify the root causes of material losses. In the improve stage of DMAIC, Kaizen was implemented to reduce material losses in the production line. Finally, in the control stage, all relevant documents were submitted to the engineer in charge to continue monitoring the blending production line after the study.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the study's methodology, divided into two parts. Subsection 3.2 outlines the methodology used to conduct the study. Subsection 3.3 presents the step-by-step explanation of the methodology developed for the study. Subsection 3.4 presents the study framework at Factory X, while subsection 3.5 explains the framework in detail.

3.2 Methodology to Conduct the Study

The study followed a structured methodology to ensure it stayed on the correct track. These steps provide comprehensive coverage of the study's flow, from the beginning to the end. The methodology used to conduct the study is shown in Figure 3.1.

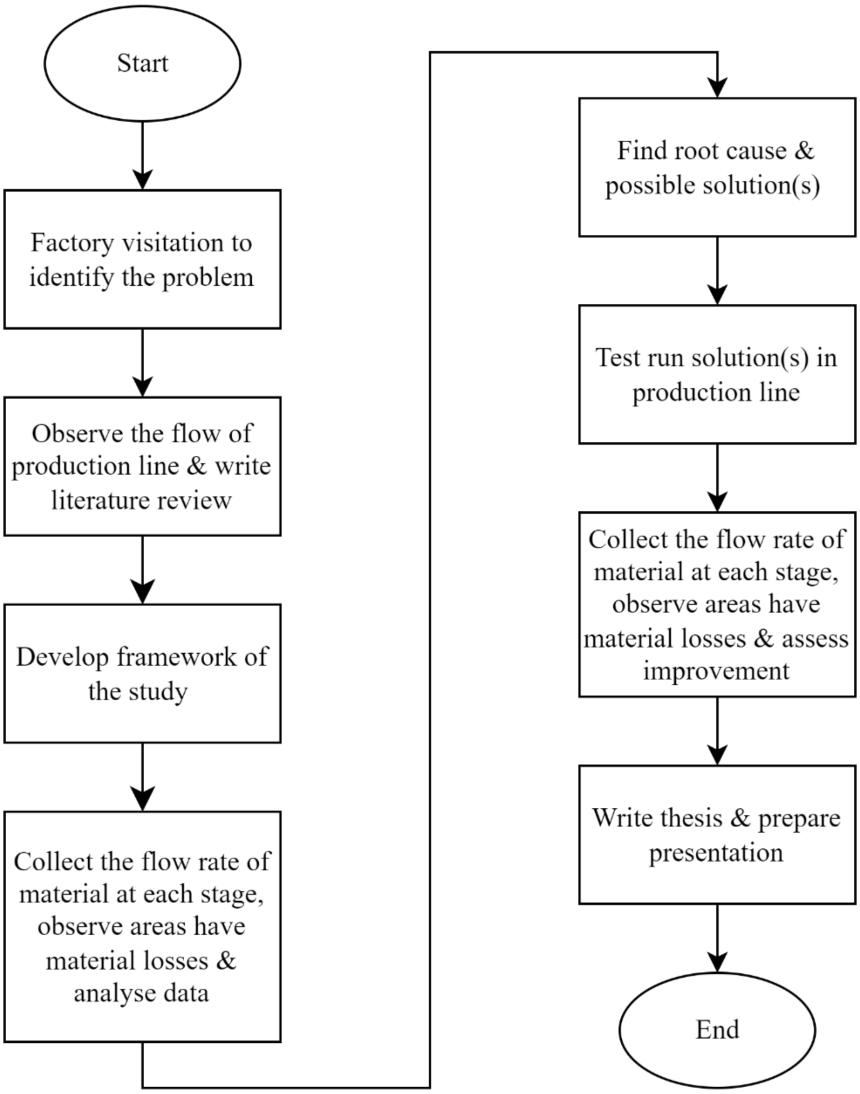

Figure 3.1: Methodology to Conduct the Study

3.3 Explaination of Methodology

The study began with a visit to Factory X to identify the problem. A meeting was held with the engineer to discuss issues in the chemical blending production line. By pinpointing the problem in the production line, the main objective of the study could be addressed. During the meeting, overall production information was explained, including the types of products produced, the layout of the production line, and the raw materials used. Additionally, a guided tour of the production line was conducted by the engineer in charge, who explained the production flow in detail and shared their ideas about the study.

The production flow was observed during another visit to draft the entire process from raw materials to the final product. This draft covered each stage of the production line, from start to finish, including the transportation of materials between stages. Simultaneously, a literature review was written for the thesis report, focusing on potential tools to detect, measure, and reduce material losses in the production line. A total of 20 references were reviewed.

The framework for the study was then developed to conduct the main part of the research. Suitable methods to detect, measure, and reduce material losses were chosen based on insights gained from the literature review. In addition, the framework provides a comprehensive guideline for other researchers to conduct studies in the chemical blending production line. The details of the framework, including each phase and step, will be discussed further in the thesis.

After the framework was developed, the study continued with data collection. This step is crucial for detecting and measuring material losses in the production line. The flow rate of material at each stage was measured using Material Flow Analysis (MFA), making further analysis more effective. Additionally, on-site examinations were conducted to observe where material losses occurred. These losses may occur in areas that are difficult to measure but can be easily visualised. The collected data was then analysed to determine the occurrence of material losses in the chemical blending production line.

Subsequently, the root causes of material losses were identified and addressed using the 5 Whys analysis. This method helps reveal the primary causes that lead to material losses. The root causes may vary since different handling methods are employed at each stage of the production process. By identifying these root causes, more precise and relevant solutions can be proposed to address the core issues rather than just the symptoms. While there may be multiple possible solutions, only a few will effectively reduce material losses in the chemical blending production line.

After addressing the root causes of material losses, a meeting was held with the engineer at Factory X. During the meeting, the root causes of material losses in the production line were discussed. A comprehensive view of these causes was clearly visualised, which helped in identifying and prioritising the order in which they should be addressed. Furthermore, feasible methods for reducing material losses were discussed and will be implemented in a test run.

A test run of the selected solution(s) should be conducted to practically visualise their effectiveness. Additionally, a test run helps determine the feasibility of the proposed solutions for material losses in the chemical blending production line. During the test run, cooperation from the company and operators is crucial to streamline and smoothen the process. Furthermore, this ensures that everything functions properly throughout the test run.

The data was collected once more to identify whether there was improvement after implementing the selected solution(s). Similarly, the flow rate of material at every stage was measured. Additionally, the areas where material losses occurred were observed again to determine if there had been any improvement. The methods used to detect and measure the material losses were the same as those used during the previous data collection. If the material losses have reduced with the implementation of the selected solution(s), the study can proceed to the final step. However, if no improvement is observed, the selected solution(s) should be revised. Before proceeding to the final step, all relevant documents were handed over to Factory X.

The final step of the study involved writing the thesis and preparing the presentation. The thesis was completed, ensuring that all aspects of the study were thoroughly addressed and nothing was overlooked. Following this, a presentation was prepared to share and explain the findings of the study on the chemical blending production line. This step ensures the validation and engagement of the study by all stakeholders.

3.4 Framework of the Study

Figure 3.2 illustrates the framework implemented at Factory X for systematically detecting, measuring, and reducing material losses in the chemical blending production line.

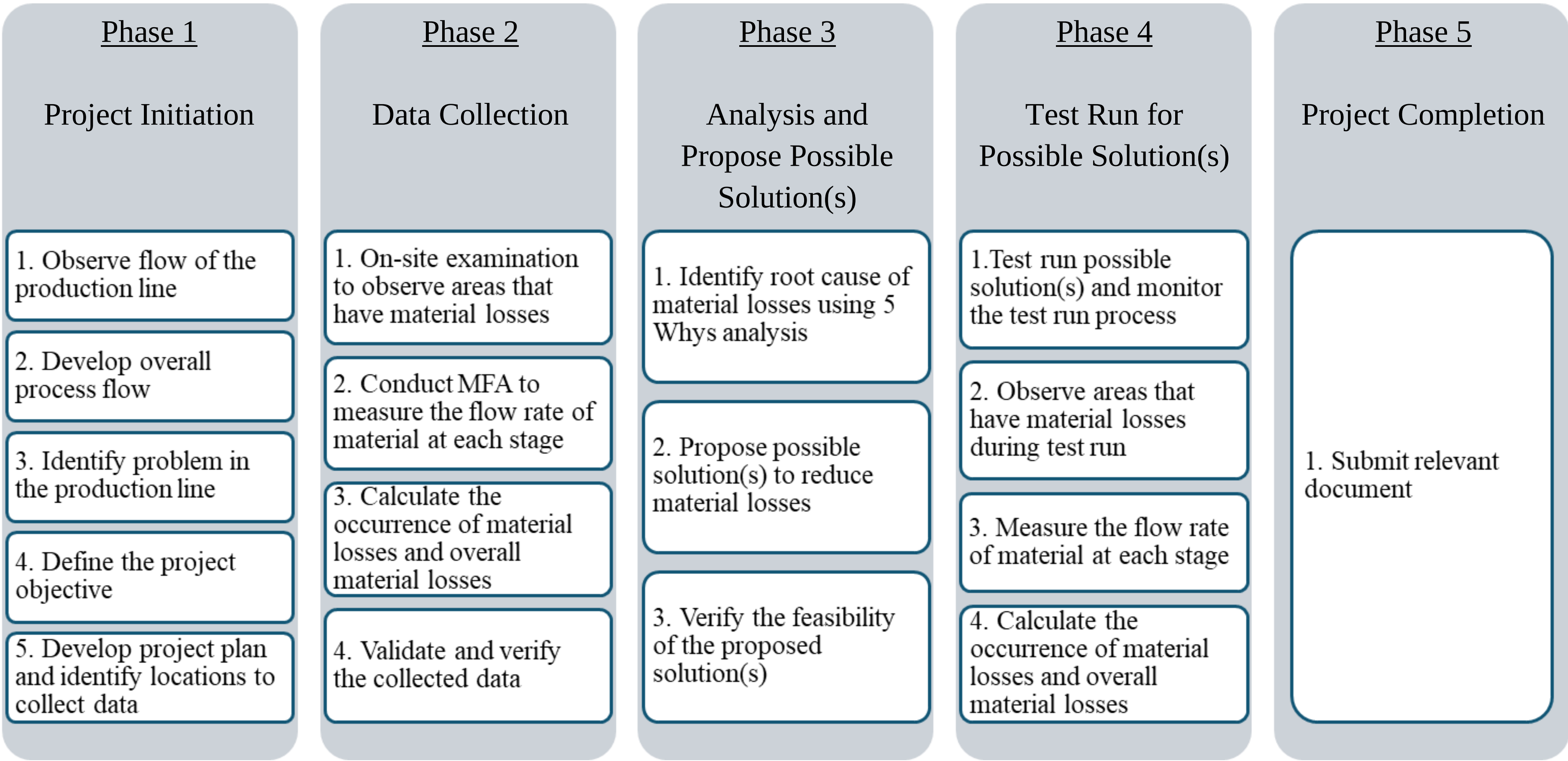

Figure 3.2: Framework Adopted in Factory X

3.5 Explaination of the Framework

Based on the framework outlined in Figure 3.2 (page 27), five phases are involved in the developed framework. Each phase of the framework is explained step by step in the following sub-subsection.

3.5.1 Phase 1: Project Initiation

The project began with observing the process flow of the production line. This observation covered each stage of the manufacturing process and the transportation of materials throughout the production line. The reason for initially observing the process flow, rather than directly collecting data in the chemical blending production, was to gain a comprehensive overview of the entire process. Additionally, this approach allowed for better planning of subsequent steps to streamline the data collection process.

Following this, an overall process flow diagram was developed to clearly visualise and understand the situation in the chemical blending production. This process flow diagram included information on the types of raw materials, the transportation methods for these materials, and the tasks performed by operators at each stage of the production line. By developing this process flow diagram, preliminary issues such as material losses were revealed and identified.

The observed problems, such as material losses, were then defined in the chemical blending production line. This provided a general idea of the areas where issues might exist. However, these insights were typically generated by the engineers in charge of the chemical blending production line, as they possessed a deeper understanding of all processes involved. Furthermore, the study objective was defined to provide clear direction (for example, the targeted percentage reduction in material losses).

The last step in the project initiation phase was to develop the project plan and identify locations for data collection. A project plan ensured that the progress of the project remained on schedule. In this phase, a Gantt chart was useful for planning the project schedule by outlining the duration of each task. Moreover, identifying data collection locations with the engineer in charge was crucial for the data collection phase. This was because the chemical blending production line could have implications for human health and safety.

3.5.2 Phase 2: Data Collection

The first step of the data collection phase was an on-site examination to observe areas where material losses occurred. An on-site examination provided a comprehensive insight into the operations of the chemical blending production line. Moreover, it offered ideas on how to proceed with the data collection phase. Material losses could occur in places that were difficult to measure. Therefore, an on-site examination was crucial for visualising the chemical blending production line in detail and identifying where material losses occurred. If material losses could not be accurately measured, they were documented through photographs or video recordings, with the company's permission.

Consequently, a Material Flow Analysis (MFA) was conducted to measure the flow rate of material at the identified stages of the chemical blending production line. MFA was suitable for data collection in a continuous production line and allowed for the measurement of blended chemicals within the production line. The flow rate of blended materials was measured in kilograms per minute (kg/min), indicating the weight of material at the input or output over a given time interval.

After determining the flow rate of material at the input and output of each identified stage of the production line, the material losses were calculated. The amount of material loss at each stage was determined by calculating the difference between the input and output material quantities. For example, a loss in a closed system was indicated when the output flow rate of material was lower than the input flow rate.

Subsequently, the overall material losses in the chemical blending production line were calculated. The mass balance table was used as a reference to construct a flow rate balance table, which provided the input flow rate, output flow rate, and the amount of losses at each identified stage. This approach offered a clear visualisation of material losses at each stage and the total losses across the entire production line.

The collected data was validated and verified in the final step of this phase. The validation and verification of data ensured that the collected data was clear and accurate, helping to keep the project on the right track. This step was typically carried out by submitting the collected data to the engineer in charge for validation and verification.

3.5.3 Phase 3: Analysis and Propose Possible Solution(s)

The third phase of the study was data analysis and proposing possible solutions. The collected data from the previous phase was analysed to identify the root cause of material losses. In this step, the 5 Whys analysis was used to reveal the primary cause of material losses. This method allowed for a deeper identification of the issue rather than just addressing the superficial symptoms. Additionally, the 5 Whys analysis was straightforward and easy to use, as the root cause was systematically arranged in a table. Identifying and addressing the root cause saved time in reducing material losses in the chemical blending production line.

Possible solutions were then proposed to reduce material losses in the chemical blending production line. These solutions were based on the root causes identified in the data analysis step. It was possible that one solution could address more than one problem identified from the 5 Whys analysis. Furthermore, the proposed solutions included multiple options, as a simple solution could effectively reduce material losses in the chemical blending production line.

After that, the proposed solutions were verified for their feasibility. This was because the proposed solutions might not have been suitable for the chemical blending production line. Therefore, a meeting with the engineers in charge was held to assess the suitability of the proposed solutions by evaluating their pros and cons. By verifying the feasibility of the proposed solutions, the next phase of the study was streamlined.

Several factors were considered when verifying the feasibility of the proposed solutions. For instance, cost, time required, and manpower were significant factors for a company seeking to improve its production line. It was preferable to minimise spending on improvements rather than incur unnecessary costs. Additionally, the time required for implementing improvements needed to be minimal, as operators might have been reluctant to cooperate if the process was complex and time-consuming; they might have felt that the current conditions were more comfortable for performing their tasks. Furthermore, when planning further improvements, it was advisable to avoid adding extra manpower to the production line, as this would have increased labour costs. Therefore, the proposed solutions that required the least resources were prioritised to enhance the chemical blending production line. By using minimal resources, the revenue from the chemical blending production line could be maximised.

3.5.4 Phase 4: Test Run for Possible Solution(s)

Once the feasibility of the proposed solutions had been verified, a test run was conducted on the chemical blending production line. Each proposed solution was tested individually to ensure that everything remained under control and that attention was focused on the specific issue and solution at hand. During the test run, the engineers in charge closely monitored the process. This monitoring helped to identify any hidden or unforeseen issues and hazards that might have arisen as a result of the proposed solution.

The next step in the test run phase was to observe the areas where material losses occurred. During the data collection phase, an on-site examination had been carried out to identify material losses that could not be measured. Therefore, this method was employed again in this phase to determine whether there had been any improvement in material losses at each identified stage. With the company’s permission, photographs and video recordings were taken as evidence. The changes in material losses were assessed by carefully reviewing all the photographs and videos taken during the process.

Subsequently, Material Flow Analysis (MFA) was conducted to measure the flow rate of materials at each identified stage after implementing the proposed solution. The input and output of blended materials at each stage were measured to gather sufficient data for comparison purposes. Moreover, during the data collection process, the unit of measurement for the flow rate was kept consistent with the unit used in Phase 2. This ensured that the subsequent comparisons were easier and more effective.

The occurrence of material losses and overall material losses was then calculated from the data obtained in the previous step. Additionally, a flow rate balance table was constructed for each identified stage using the data collected after the test run was completed. This table enabled a clear comparison of the data before and after the implementation, allowing for the assessment of the proposed solution's effectiveness.

3.5.5 Phase 5: Project Completion

The study proceeded to the final phase if material losses had been successfully reduced in the chemical blending production line. The last step involved submitting relevant documents, such as collected data, analyses conducted, and all pertinent documentation. These documents were submitted to the company upon completion of the study.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the collected data, results, and discussion of the study. Subsection 4.2 provides the background of Factory X, while subsection 4.3 outlines the project initiation. Furthermore, subsection 4.4 describes the data collection process, and subsection 4.5 analyses the findings and proposes possible solutions. Consequently, subsection 4.6 details the test run for the proposed solution(s), and subsection 4.7 explains the completion procedures of the study. Lastly, subsection 4.8 discusses the framework used in the study.

4.2 Background of Company

Factory X is an air filter manufacturing company located in Batu Gajah, Perak, Malaysia. The headquarters of Factory X was founded in 1963 and is based in Sweden. However, Factory X focuses on the Malaysian market, meeting local needs by offering a wide range of products designed for different environments, such as commercial and industrial air filtration. It serves various industries, including healthcare, food and beverage, manufacturing, and pharmaceuticals. The factory's vision is based on the belief that clean air should be a human right. They also believe that clean air can enhance the productivity of workers and equipment and benefit human health. Additionally, Factory X emphasises the development of energy-efficient air filters that can reduce carbon emissions and energy consumption.

4.3 Phase 1: Project Initiation

First and foremost, observing the flow of the production line was the initial step when conducting the study. This was to gain a comprehensive understanding of the production line, as it was important to be familiar with it before starting the study. Observations were conducted once a week and took around two hours each time. The number of visits was limited due to time constraints and the availability of slots at the factory. A total of three visits were conducted during this phase. During these visits, material losses in the blending production line were observed. For instance, material was lost in the form of spillage, became airborne, or was lost during transportation.

Following this, the overall process flow of the production line was developed. After several observations of the production line, the process flow was drafted and refined. This process flow illustrated each stage of production that the products had to go through. Figure 4.1 shows the developed process flow in the blending production line.

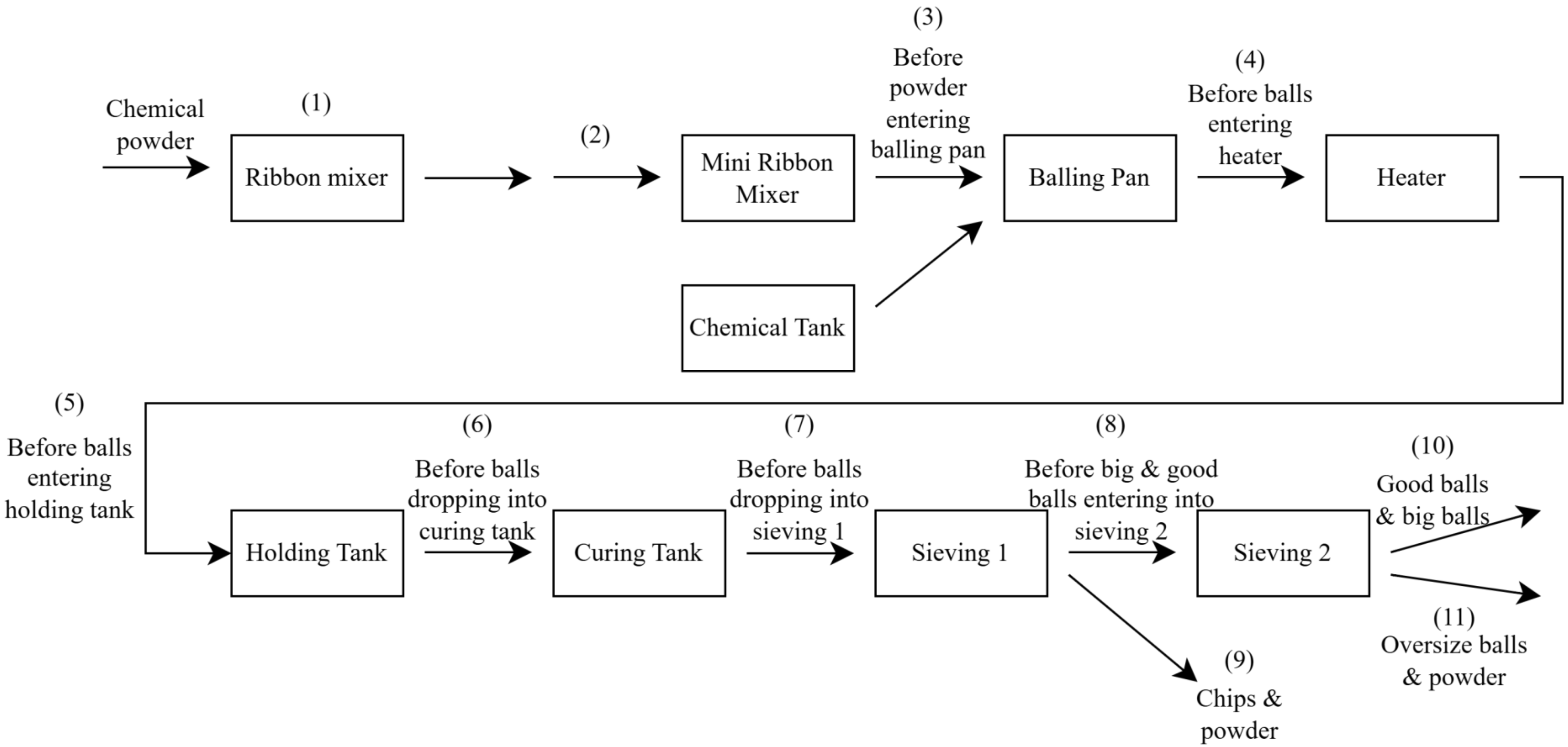

Figure 4.1: Process Flow in the Blending Production Line

Based on Figure 4.1 (page 35), each stage of the production line is depicted. At the beginning of the process, several types of chemical powders (colour powder, alumina, sodium carbonate, and sodium bicarbonate) are poured into a ribbon mixer to blend all the substances together. The blended powder is then transported to a mini ribbon mixer. After that, a controlled amount of chemical powder and chemical liquid (a mixture of hot water and potassium permanganate) is released into the balling pan. In the balling pan, the blended powder and liquid undergo centrifugation to form the semi-finished product. The semi-finished product is then heated in a heater and collected in a holding tank before being transferred to the curing tank. After drying for two days, the product undergoes two rounds of sieving to achieve the final product that meets the requirements.

The next step of this phase was to identify the problem in the production line. The problem in the blending production line could be identified more clearly and in a structured way as the overall process flow was developed. Each stage and transportation step was outlined in Figure 4.1 (page 35), allowing problems to be identified by observing the production line step by step. By observing the issues in the production line, a hypothesis could be formed in the early phase of the study. The main issue in Factory X was the material losses occurring in different sections of the blending production line due to the discrepancies between the input and output volumes. These material losses indicated that material efficiency was low, which posed an obstacle to maximising profit in Factory X. Moreover, material losses in the in different sections of the blending production line could also affect the health of surrounding workers.

Consequently, the objective of the study was defined once the main problem had been identified. The primary objective of the study was to reduce material losses in the blending production line by a minimum of 5% and a maximum of 10%. Defining this objective provided a clear and focused goal that guided all activities and decisions throughout the study. By the end of the study, the defined objective should be achieved following the test run of the proposed solution(s).

The final step of this phase was to develop a project plan and identify locations for data collection. The project plan ensured effective communication with the engineer in charge at Factory X and that tasks were completed on time. Clear communication was essential for securing available time slots for data collection and keeping everything on track. Additionally, the locations for data collection were identified. The numbers shown in Figure 4.1 (page 35) represent the different sections of the blending production line where data was intended to be collected. However, some sections were difficult to measure, as normal production at Factory X could be affected. Figure 4.2 presents the Gantt chart for the factory visits.

No.	Task	June - September (2024)														October - December (2024)							February - April (2025)								
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W1	W2	W3	W4	W5	W6	W7	W8	W9
1	Identify problem			P																											
				A																											
2	Develop overall process flow				P																										
					A																										
3	Objectives Definition				P																										
					A																										
4	Develop project plan					P																									
						A																									
5	Data collection						P	P	P	P																					
							A	A	A	A																					
8	Data compilation						P	P	P	P																					
							A	A	A	A																					
9	Data analysis										P																				
											A																				
10	Discussion with engineer in charge											P	P																		
												A	A																		
11	Test run for possible solution(s)															P	P	P	P	P	P	P									
																				A	A	A									
12	Data analysis																						P								
																							A								
13	Presentation																														P
																															A
14	Submission of document																														P
																															A

P	Plan
A	Actual

Figure 4.2: Gantt Chart for the Factory Visits

4.4 Phase 2: Data Collection

The first step of this phase was to conduct an on-site examination to observe areas where material losses occurred. The on-site examination ensured comprehensive oversight of the blending production line and helped develop a deeper understanding over time. However, the day and duration of factory visits for conducting the on-site examination depended on the factory's scheduled processes. During this phase, a total of five visits were conducted, with one to two visits per week. Each visit lasted two hours, extending to a maximum of three hours. The relevant details were communicated to the engineer in charge at the factory, ensuring clear communication and that everyone remained on track. Furthermore, different stages required different methods of data and evidence collection, ensuring the completion of data for material loss calculations in subsequent steps. During the on-site examination, dust or airborne can be observed to determine the occurrence of material losses in the blending production line. Therefore, the on-site examination played a crucial role in collecting evidence when material was difficult to measure and quantify at certain stages and under specific conditions.

After that, Material Flow Analysis (MFA) was conducted to measure the flow rate of materials at specific stages, provided the materials could be measured and quantified. Material collection was assisted by operators, as the factory prioritised the safety of both workers and visitors. Only skilled operators were permitted to handle material collection, as improper handling of chemical substances could pose hazards. In addition to data collection at specific stages of the blending production line, some samples from the outputs of the balling pan process were collected for Field Emission Scanning Electron Microscopy (FESEM) analysis. This analysis aimed to examine the microstructure of the materials, particularly to identify fragmentation on their surfaces.

Based on Figure 4.1 (page 35), data collection was conducted only in sections (3), (4), (5), (8), (9), (10), and (11), as sections (1), (2), (6), and (7) were deemed unsuitable for data collection after several discussions with the engineers in charge at Factory X. Section (1) involved the mixing of different types of chemical powders, which served as the first input in the blending production line. Operators poured a large amount of powder into the ribbon mixer using a forklift due to the heavy weight of the powders. This prevented data collection in section (1), as the flow rate of the powders was highly inconsistent. Additionally, section (2) was a completely closed system where data collection could only be conducted if all the screws on the mini ribbon mixer were removed. To avoid disrupting normal production in the blending line, the engineers in charge at the factory decided that data collection could not be conducted in section (2). Moreover, section (6) was unsuitable for data collection due to safety constraints. There was no cushion or safe location for the operator to collect data between the holding tank and the curing tank. In addition, the output from the holding tank dropped quickly into the curing tank, as the holding tank was positioned directly above the curing tank. Furthermore, section (7) was similar to section (2), being a completely closed system that made data collection difficult without impacting normal production.

In the study, three stages of the blending production line were examined: the balling pan, heater, and sieving 2. As mentioned previously, each section of the blending production line shown in Figure 4.1 (page 35) represents the input and output of each stage. Generally, three plastic bags were used to collect the semi-finished or finished product in each section. The average of the three readings obtained was then calculated for each section.

In section (3), constraints such as the speed and angle of the balling pan were recorded. Moreover, since the blended chemical powder was centrifuged with liquid in the balling pan, the flow rate of the liquid from the chemical tank was also recorded. Initially, the flow rate of the mixed chemical powder was collected by holding a plastic bag at the output pipe, which transported the mixed powder from the mini ribbon mixer to the balling pan. Subsequently, the flow rate of the liquid was factored into each reading for section (3). Furthermore, three readings were also collected at section (4). In this section, the flow rate of the liquid was included in the readings, as in section (3), to ensure the accuracy and consistency of data across different sections of the blending production line. After the semi-finished product underwent the heating process, it was dropped into the holding tank, and the flow rate at the input of the holding tank at that time was obtained. Data collection in section (5) was challenging, as the operator needed to ensure their safety while collecting data. Firstly, the semi-finished product was hot at the heater's output, and the location was more hazardous compared to other sections of the blending production line. Nevertheless, three readings were collected.

Moreover, sections (8), (9), (10), and (11) were required to study the sieving 2 process in the blending production line. Section (8) involved good balls and big balls after the first sieving, while section (9) involved chips and powder. Only section (8) served as the input for the sieving 2 process, whereas section (9) was collected and used for other purposes in Factory X. Furthermore, section (10) involved good balls and big balls after the sieving 2 process, while section (11) contained oversized balls and powder. Since the sieving 2 process was the final stage of the blending production line, section (10) was used for filter production, while section (11) could not be used, as the output did not meet the required standards. In sections (8), (9), (10), and (11), the output was sieved, transported, and collected in different containers. Therefore, three readings were taken for each container, the average of the three readings was calculated, and the total was determined.

Consequently, the occurrence of material losses and overall material losses was calculated to guide the study more effectively, helping the process proceed smoothly. In the study, a flow rate balance table, shown on the right side of Table 4.1 (page 43), was summarised and constructed to compare the material flow rates at the input and output of each specific stage. As mentioned above, the flow rate balance table was based on the reference of a mass balance table, with flow rate (measured in kg/min) replacing mass in the study. In the flow rate balance table, material waste was calculated for three stages: the balling pan, heater, and sieving 2, and it was noted whether the system was an open or closed system at each stage. Additionally, the amount of material losses could be represented by either a positive or negative value. In an open system, a negative value indicated material losses, while in a closed system, a positive value indicated the occurrence of material losses. The reason material losses in an open system result in a negative value is that, the input is less than the output. This happens because material from the surroundings may enter the system, causing the measured output to exceed the input.

Lastly, all collected data were validated and verified by Factory X. The data were arranged in an organised manner before being submitted to the engineer in charge at the factory. The engineer then validated and verified all the data by comparing it with their own internal data over a few working days. In conclusion, the collected data were considered verified if the difference between the collected data and internal data was less than 10%. Following this, the study could proceed to the next phase.

Table 4.1 presents the material flow rate in different sections of the blending production line and provides a summarised flow rate balance table after several factory visits.

Table 4.1: Material Flow Rate and Summarised Flow Rate Balance Table (Before)

No.	Locations		Readings (kg/min) 1	2	3	Average	Total	Input No.	Input (kg/min)	Output No.	Output (kg/min)	Waste (kg/min)	Remarks	Open/ Closed System	Yes/No material losses
1	Before ribbon mixer		-	-	-	-	-	-	-	-	-	-	-	-	-
2	Before mini ribbon mixer		-	-	-	-	-	-	-	-	-	-	-	-	-
3	Before balling pan	Speed = 28Hz	3.43	3.97	3.75	3.72	3.72	3	3.72	4	4.76	-1.04	Input = chemical + powder	Open	Yes
		Angle = 45.78°													
		Chemical tank = 85kg/hr = 1.250kg/min													
4	Before heater		4.84	4.70	4.75	4.76	4.76	4	4.76	5	3.75	1.01	-	Closed	Yes
5	Before holding tank		3.68	3.86	3.70	3.75	3.75								
6	Before curing tank		-	-	-	-	-	-	-	-	-	-	-	-	-
7	Before sieving 1		-	-	-	-	-	-	-	-	-	-	-	-	-
8	Before sieving 2	Good balls	10.91	8.33	9.60	9.61	10.39	8	10.01	10	3.91	6.10	Input = big balls + good balls	Closed	Yes
		Big balls	0.41	0.40	0.40	0.40									
9		Chips	0.20	0.26	0.22	0.23									
		Powder	0.12	0.18	0.14	0.15									
10	After sieving 2	Good balls	3.45	3.77	3.58	3.60	4.01								
		Big balls	0.31	0.32	0.31	0.31									
11		Oversize balls	0.05	0.04	0.05	0.05									
		Powder	0.04	0.05	0.05	0.05									

On the left side of Table 4.1 (page 43), the overall data from multiple data collection sessions at Factory X were presented. The “No.” column indicated each section of the blending production line, from section (1) to section (11), as outlined in Figure 4.1 (page 35). Following this, the “Locations” column detailed the different sections, listing inputs from section (1) to section (9) and outputs for section (10) and section (11). Moreover, “Readings” column showed that three readings were collected for each section of the blending production line, and the average of these three readings was calculated. For sections (8) and (9), the total of the average readings was required because good balls and big balls served as both inputs and outputs for sieving 2, with the output from sieving 2 being used in further production.

The summarised flow rate table was presented on the right side of Table 4.1 (page 43). The “Input No.” and “Output No.” columns represented the numbered sections for each stage studied, while the “Input” and “Output” columns displayed the flow rate of input and output materials for each section in kg/min. The waste generated at each specific stage was calculated for all three stages, shown in the “Waste” column. Calculating waste was crucial in determining the occurrence of material losses, and these calculations later allowed for comparisons after the test run of possible solutions at Factory X. Additionally, the “Remarks” column provided details for each stage, such as indicating if a stage had more than one output. For instance, the input of the balling pan consisted of a mixture of chemical liquid and chemical powder (Section (3)). Moreover, after the Sieving 1 process, only good balls and big balls were sent for a second sieving in sieving 2 (Section (8)). The system type—whether it was open or closed—was also observed and recorded in Table 4.1 (page 43). Lastly, the final column in Table 4.1 (page 43) indicated whether material losses occurred at a specific stage. As shown in the table, material losses were observed at all three stages. Equation 4.1 was used to calculate the waste in specific sections of the blending production line, as shown in Table 4.1 (page 43).

$$\text{Waste} = \text{Raw Material Input} - \text{Finished Good Output} \tag{4.1}$$

4.5 Phase 3: Analysis and Propose Possible Solution(s)

After data collection in different sections of the blending production line, the results were analysed to identify the root cause of material losses in the balling pan, heater, and sieving 2. The 5 Whys analysis was used in the study to identify the fundamental cause of the problem. This method was chosen as it provides a more systematic and structured approach, showing how the root cause was revealed step by step. Furthermore, by uncovering the root cause of material losses in the blending production line, it helped to smoothen the next steps of the study, offering insights for proposing an effective solution to the problem.

Table 4.2 presents the 5 Whys analysis for the study, identifying three significant problems: material losses in the balling pan, heater, and sieving 2 processes.

Table 4.2: 5 Whys Analysis for the Study

No.	**Problem**	**1st Why**	**2nd Why**	**3rd Why**	**4th Why**	**5th Why**	**Solution**
1	Material loss occurs in the balling pan process.	Blended powder escaped from the balling pan.	The balling pan was not fully sealed.				Seal the balling pan.
2	Material loss occurs in the heater process.	Many defects are produced during the process.	Material handling at the heater input was improper.	Material dropped directly from the balling pan without a cushion.			Add a plastic lining before the heater input.
3	Material loss occurs in the sieving 2 process.	Some of the output did not meet the standards for further production.	Many defects were produced in the heater process.	Material handling at the heater input was improper.	Material dropped directly from the balling pan without a cushion.		Optimise sieving parameters.

Material losses in the balling pan process were caused by blended powder escaping during centrifugation, becoming airborne and dispersing into the surroundings, which posed hazards and harmful effects to operators. The root cause was identified as the balling pan not being fully sealed, making it an open system. In the heater process, material losses were traced to the production of many defects, primarily due to improper material handling at the heater's input, as the output from the balling pan was dropped directly into the heater without a cushion in between. Meanwhile, material losses in the sieving 2 process began with outputs failing to meet standards for further production. The second Why revealed that many defects originated from the heater process, as the input for sieving 2 came directly from the heater's output. The third and fourth Whys traced back to the second and third Whys of the heater process, further emphasising their contribution to the material losses in sieving 2.

According to Table 4.2 (page 46), three possible solutions were proposed for each identified problem. To address material losses in the balling pan process, sealing the balling pan was suggested to convert the open system into a closed one. This solution not only reduced material losses but also prevented blended powder from escaping into the surroundings during centrifugation, ensuring a safer and healthier environment for operators. For material losses in the heater process, adding a plastic lining at the output of the balling pan was proposed to provide a cushion between the balling pan and the heater. This adjustment facilitated smoother transportation, ensured more consistent flow rates, and reduced defects caused by the cracking of the balling pan's output. Lastly, optimising the sieving parameters in the sieving 2 process was recommended. Adjusting the speed or vibration of the sieving machine could improve separation efficiency, reduce rejected outputs, and increase usable output, thereby alleviating production burdens and supporting order fulfilment across production lines.

For the final step in Phase 3, the feasibility of the proposed solutions was verified by the engineer in charge at Factory X. A meeting was held between the engineer in charge to present the proposed solutions and the expected outcomes of each one. However, not all proposed solutions could be test-run, as the normal production of the blending production line needed to be maintained without significantly disrupting it. Therefore, once the idea was presented, an internal discussion was held between the engineers at the factory to assess the suitability of the proposed solutions and select the one best suited to the current situation. After careful consideration by the engineer in charge, the solution to add a plastic lining at the output of the balling pan was verified and deemed suitable for a test run in the blending production line. This solution was verified because it did not disrupt the normal production of the blending line. Moreover, it was economical, reducing the investment costs associated with improving the blending production line.

On the other hand, fully sealing the balling pan machine was considered time-consuming, as Factory X would need to purchase a customised cover suitable for the specific balling pan machine used in the blending production line. Additionally, the proposed solution to optimise sieving parameters was rejected by the engineer in charge after internal discussions. This decision was due to the current parameters already being optimised to produce outputs that met certain requirements and standards for further operations. Adjusting the sieving parameters could disrupt the existing production line, as the engineer in charge and operators would need to identify new optimal settings. While this adjustment might reduce material losses, it also introduced constraints such as increased time, manpower, and investment costs.

4.6 Phase 4: Test Run for Possible Solution(s)

The first step of this phase was to conduct a test run of the verified solution from the previous phase and monitor the test run process. As mentioned earlier, the solution involved adding a plastic lining at the output of the balling pan to provide cushioning for the output, preventing it from crashing and reducing the yield in the blending production line. The test run was divided into several small procedures. Firstly, the engineer in charge measured the appropriate dimensions of the plastic lining to be installed. It was decided that the lining would be made of high-density polyethylene (HDPE) because its flexibility, rigidity, and durability allowed it to act as a cushion, absorbing shocks and reducing impact during direct contact. The installation date was then determined and communicated to all personnel involved in the blending production line to ensure proper preparation. On the scheduled date, the installation was carried out, and a briefing was provided to the technicians, explaining the purpose and usage of the improvement. This step was crucial to avoid misunderstandings or miscommunication between technicians, engineers in charge, and operators, while also raising awareness about the changes in the blending production line. During the test run, the engineers in charge remained on standby for about one hour to monitor the process, ensuring that the blending production line operated smoothly and that the placement of the HDPE lining did not result in additional cracks in the output. Once the test run confirmed smooth operation without adverse outcomes, the production was allowed to proceed, allowing the system to stabilise continuously in the blending production line.

Consequently, areas with material losses were observed during the test run. After the HDPE lining was installed, every stage of the blending production line was re-examined to identify the occurrence of material losses. This procedure not only ensured a positive outcome from the improvement but also helped determine the specific sections of the blending production line for data collection. According to Figure 4.1 (page 35), only sections (4), (10), and (11) were selected to measure the flow rate of material losses in the next step of this phase. These three sections were chosen because, after months of collaboration and several discussions, it was found that the engineers in charge at Factory X were primarily focused on the output in these sections. Moreover, based on Table 4.2 (page 46), the root causes of the identified problems were found to be correlated with one another. The purpose of the improvement was also centred on enhancing and increasing the yield of the output in the blending production line. Thus, only the output of the balling pan process and the output of the sieving 2 process were selected for measurement.

Table 4.3 outlines the material flow rate in sections (4), (10), and (11) of the blending production line after the test run of the proposed solution.

Table 4.3: Material Flow Rate and Suumarised Flow Rate Balance Table (After)

<table>
<tr><th rowspan="2">No.</th><th rowspan="2" colspan="2">Locations</th><th colspan="5">Readings (kg/min)</th><th rowspan="2">Input No.</th><th rowspan="2">Input (kg/ min)</th><th rowspan="2">Output No.</th><th rowspan="2">Output (kg/ min)</th><th rowspan="2">Waste (kg/ min)</th><th rowspan="2">Remarks</th><th rowspan="2">Open/ Closed System</th><th rowspan="2">Yes/No material losses</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>Average</th><th>Total</th></tr>
<tr><td>1</td><td colspan="2">Before ribbon mixer</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td rowspan="16">4</td><td rowspan="16">2.59</td><td rowspan="16">10</td><td rowspan="16">2.28</td><td rowspan="16">0.31</td><td rowspan="16">Input = big balls + good balls</td><td rowspan="16">-</td><td rowspan="16">Yes</td></tr>
<tr><td>2</td><td colspan="2">Before mini ribbon mixer</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Before balling pan</td><td>Speed = 26Hz</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td></tr>
<tr><td>Angle = 45.78°</td></tr>
<tr><td>Chemical tank = 85kg/hr = 1.250kg/min</td></tr>
<tr><td>4</td><td colspan="2">Before heater</td><td>2.48</td><td>2.70</td><td>2.60</td><td>2.59</td><td>2.59</td></tr>
<tr><td>5</td><td colspan="2">Before holding tank</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>6</td><td colspan="2">Before curing tank</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>7</td><td colspan="2">Before sieving 1</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">8</td><td rowspan="4">Before sieving 2</td><td>Good balls</td><td>-</td><td>-</td><td>-</td><td>-</td><td rowspan="4">-</td></tr>
<tr><td>Big balls</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">9</td><td>Chips</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Powder</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">10</td><td rowspan="4">After sieving 2</td><td>Good balls</td><td>1.74</td><td>1.92</td><td>1.80</td><td>1.82</td><td rowspan="4">2.67</td></tr>
<tr><td>Big balls</td><td>0.44</td><td>0.48</td><td>0.45</td><td>0.46</td></tr>
<tr><td rowspan="2">11</td><td>Oversize balls</td><td>0.34</td><td>0.34</td><td>0.36</td><td>0.35</td></tr>
<tr><td>Powder</td><td>0.04</td><td>0.05</td><td>0.05</td><td>0.05</td></tr>
</table>

As mentioned previously, only the material flow rate in sections (4), (10), and (11) of the blending production line was collected because the engineers in charge at Factory X focused primarily on the output from these three sections. The layout of Table 4.3 (page 50) was similar to that of Table 4.1 (page 43), where the left side displayed the readings obtained during data collection, with average values calculated for each location. Meanwhile, the right side of the table presented the summarised flow rate balance table, showing the input (section (4) – before the heater) and the output of the production line (section (10) – after sieving 2).

Material Flow Analysis (MFA) was conducted again in sections (4), (10), and (11) to measure the flow rate of materials at each specific stage. Data collection in this phase was crucial to ensure and verify whether the proposed solution jeopardised the output of the blending production line. As mentioned previously, data collection was assisted by skilled operators due to safety concerns. It was essential to involve skilled operators who had experience working on the blending production line and were familiar with the production processes. Additionally, some samples from the outputs of the balling pan process were collected for FESEM analysis, enabling comparisons to be made to demonstrate the effectiveness of the proposed solution.

Lastly, the occurrence of material losses and overall material losses in the blending production line were calculated for comparison with the previously collected and calculated data in Phase 2. A flow rate balance table was also constructed in this phase, as shown on the right side of Table 4.3 (page 50), to compare the material flow rates across the overall production process. During the calculation of material losses in Table 4.3 (page 50), the output of the balling pan served as the input to the blending production line, while the output of the sieving 2 process served as the overall output of the blending production line. Based on Table 4.3 (page 50), it was not clear whether the system was open or closed. This was due to the combination of open and closed systems throughout the blending production line. Additionally, the calculated overall material losses in the blending production line resulted in a positive value, indicating the occurrence of material losses. However, the collected and calculated data were useful and helpful for further comparison in the study. Equation 4.2 was used to calculate the percentage of waste, while Equation 4.3 was used to calculate the percentage of yield before and after the test run of the proposed solution. Additionally, Equation 4.4 was used to calculate the percentage of improvement to make the data easier to visualise the reduction of material losses after the test run.

$$\% \text{ Waste} = \frac{\text{Waste}}{\text{Input}} \times 100\% \tag{4.2}$$

$$\% \text{ Yield} = \frac{\text{Output}}{\text{Input}} \times 100\% \tag{4.3}$$

$$\% \text{ Improvement} = \% \text{ Waste (before)} - \% \text{ Waste (after)} \tag{4.4}$$

Table 4.4 presents a comparison of the analysed data before and after the test run of the proposed solution implemented in the blending production line.

Table 4.4: Comparison of Data Before and After the Test Run

Status	**Input No.**	**Input (kg/ min)**	**Output No.**	**Output (kg/ min)**	**Waste (kg/ min)**	**% Waste**	**% Yield**	**Open/ Closed System**	**% Improvement**
Before	4	4.76	10	3.91	0.85	17.86%	82.14%	-	5.89%
After	4	2.59	10	2.28	0.31	11.97%	88.03%		

Based on Table 4.4, the output of section 4, which served as the input to the blending production line, decreased. This change may have been attributed to the installation of the HDPE lining at the output of the balling pan, which likely made the material flow rate more consistent compared to the previous process. Additionally, the lining provided cushioning to the output before it entered the heater, ensuring minimal material usage while maximising protection and reducing excess raw material consumption in the blending production line. HDPE material, being more elastic than metal, absorbed and dissipated impact energy during direct contact, thereby reducing the impact force exerted. It also minimised friction and abrasion between the output and the material during production, as plastic typically has a lower coefficient of friction than metal. Furthermore, the occurrence of material losses was calculated, showing a reduction from 0.85 kg/min to 0.31 kg/min. With the material losses reduced, the percentage yield of the blending production line increased after the test run of the proposed solution, indicating that the amount of output meeting the standards had risen. For easy reference in subsequent procedures, the percentage improvement was calculated, revealing a 5.89% improvement resulting from the proposed solution.

Figures 4.3 and 4.4 display the FESEM images of the output from the balling pan before and after the test run of the proposed solution, enabling a comparison to visualise the microstructure.

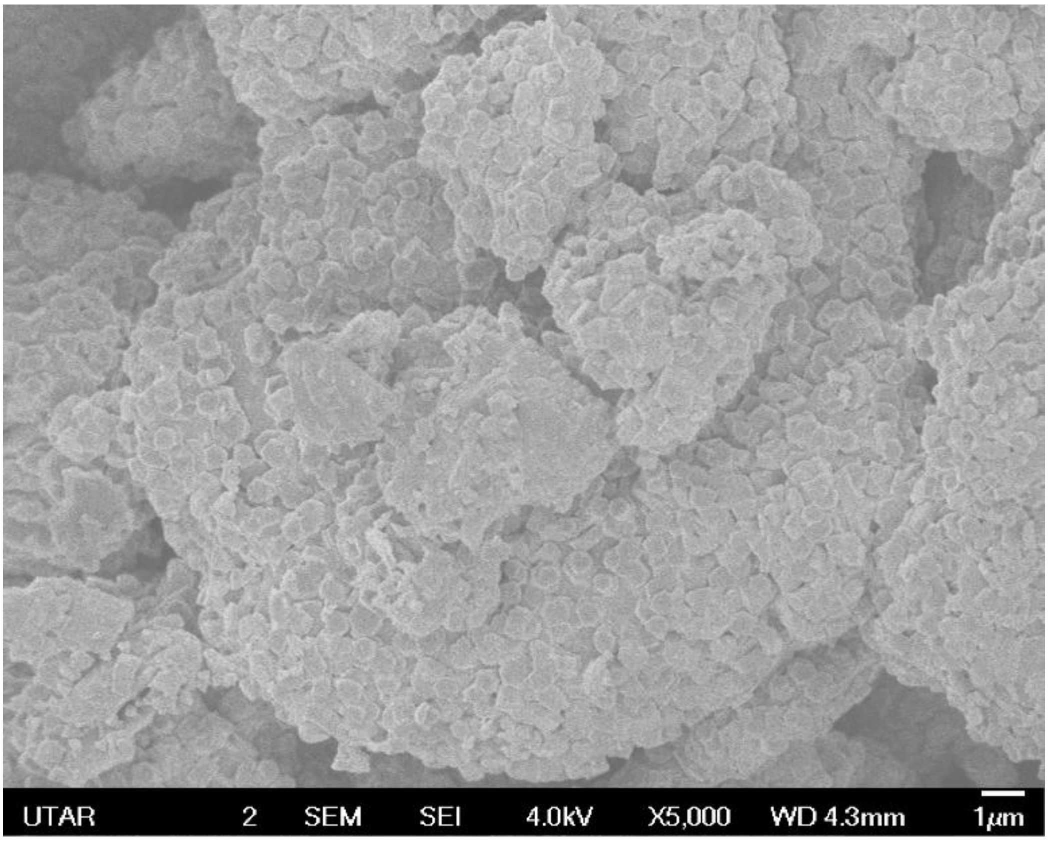

Figure 4.3: FESEM Image Before the Test Run

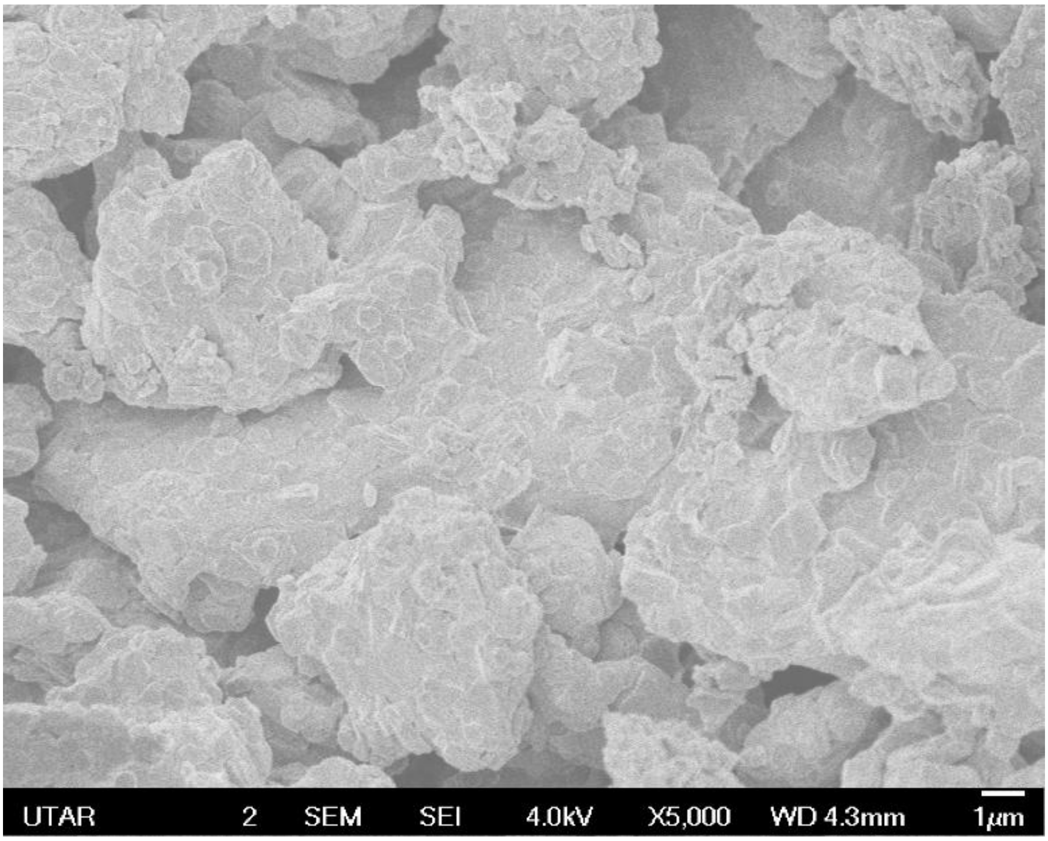

Figure 4.4: FESEM Image After the Test Run

The microstructure in Figure 4.3 (page 53) exhibited more fragmentation than in Figure 4.4 (page 54). The output from the balling pan was considered brittle because the mixture of different chemical powders (colour powder, alumina, sodium carbonate, and sodium bicarbonate) formed a composite with brittle characteristics. Fan et al. (2021) stated that higher stress concentrations could lead to fragmentation in brittle materials, supporting the observation that, before the improvement, the output impacted metal, resulting in higher stress concentrations. The stress concentration created by the metal led to crack initiation and propagation, causing greater fragmentation, as shown in Figure 4.3 (page 53). On the other hand, the HDPE lining, which was more flexible than metal, generated lower stress concentrations, leading to less fragmentation in the output, as seen in Figure 4.4 (page 54). This indicated that the proposed solution did not deteriorate the quality of the output but rather improved it from a microstructural perspective.

4.7 Phase 5: Project Completion

As the occurrence of material losses had been successfully reduced in the blending production line, the study reached its final phase before being considered complete. There was only one step remaining in this phase: submitting the relevant documents to the engineer in charge at Factory X. The documents, which included the collected and analysed data, were submitted for final validation and approval. Additionally, the document submission ensured that all communication with the engineer in charge was clear, and that they were properly and accurately informed about the study. It was also crucial that the engineers in charge at Factory X maintained a record of the study, which would be useful for future research, process reviews, or when implementing similar solutions in other areas of the production line at Factory X. Furthermore, a presentation was held at Factory X to present the findings of the study and explain the process thoroughly to the engineers and personnel in charge. The presentation allowed for a better understanding of the study, and any inquiries could be addressed directly on the spot, preventing misunderstandings now and in the future. Lastly, the study at Factory X was completed.

4.8 Discussion on the Framework

As the study was conducted over several months, planning before execution was crucial for the study in Factory X. It ensured that objectives were clear, resources were allocated effectively, and potential obstacles or challenges were anticipated at the beginning of the study.

First and foremost, the developed framework (Figure 3.2, page 27) provided a comprehensive understanding of the study's process flow. With the framework in place, engineers responsible for the case study project at Factory X were able to offer their professional perspectives on the process flow and enhance collaboration throughout the study. It also ensured that everyone was well-prepared to achieve the desired goals and outcomes by the end of the study. Moreover, the format of the developed framework was user-friendly, allowing for quick reference when needed. It enabled users to gain a fundamental understanding of the framework and future processes before exploring them more profoundly in their case study. Additionally, the framework encouraged a step-by-step approach throughout the study, preventing the skipping or overlooking of important steps that could have led to material losses at Factory X. Besides providing an overview of the process, it also served as a simple checklist for users, ensuring that everything remained on track and was completed as expected. Given its clear advantages, the developed framework could be replicated for other studies on material losses at Factory X or in other factories within relevant industries.

On the other hand, the developed framework had some drawbacks, as nothing is perfect. It provided only limited details since it served as a summary of each phase of the study and did not offer in-depth information for readers. Therefore, supplemental explanations through verbal or written discussions were necessary to ensure all stakeholders fully understood the context of the framework. Additional elaboration, explanation, and collaboration with engineers in charge were provided to facilitate a deeper understanding, rather than relying solely on the brief descriptions in the framework. Furthermore, the framework lacked visual differentiation, as its layout presented all phases with equal complexity. This could result in the varying levels of complexity across different steps and phases not being properly highlighted or recognised during the study, potentially leading to confusion or misinterpretation. However, applying colour management could help address this issue—for instance, more complex steps could be highlighted with darker backgrounds, while simpler steps could be assigned lighter backgrounds to improve visual clarity and emphasis.

In addition, based on Figure 4.2 (page 38), the factory work took approximately six months to complete. The study was divided into three trimesters, covering about 23 weeks from 2024 to 2025. Each task had planned weeks for execution, and the actual weeks during which the tasks were carried out were recorded. The schedule showed that all tasks were aligned with the planned timeline. However, Task 11, which involved the test run for possible solutions, experienced a slight delay compared to the planned schedule but was still completed within the overall timeframe. Furthermore, the presentation and document submission were planned and completed in Week 9 of the third trimester, as time arrangements had to be made with the engineers in charge at Factory X. To improve efficiency, the document submission was carried out on the same day as the presentation, ensuring minimal disruption to the engineers' workflow.

Therefore, planning a timeline for the factory work was crucial for tracking the study's progress and ensuring that it stayed on the right path. A well-structured timeline helped to organise all tasks logically and systematically. Moreover, it improved time management throughout the study at Factory X. This was because a planned timeline allowed the team to allocate sufficient time for each task, preventing last-minute rushes or unnecessary delays. Furthermore, effective time management enabled contingency measures to be implemented early in case of unexpected disruptions, ensuring that the study could still proceed smoothly. Additionally, the most important aspect of time management was ensuring the study’s completion. By following the planned timeline, the overall study was more likely to be completed within the scheduled duration, avoiding unnecessary extensions and time wastage.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter concludes the study with several subsections. Subsection 5.2 presents a summary of the entire thesis, covering Chapter 1 to 4. Furthermore, subsection 5.3 outlines recommendations for future work related to the study.

5.2 Summary of Thesis

The case study addressed the problem of material losses in an automated chemical blending production line at Factory X, an air filter manufacturing company. In the first chapter of the thesis, it emphasised the importance of precise chemical blending for the quality and safety of the products. Material losses in the production line could lead to inefficiencies and increased costs in producing a high-quality product. However, material losses could still occur even if the company operated advanced technologies or machinery in the production line. Furthermore, these losses could also be caused by the method of material handling during production. The goals of the case study were to identify suitable methods for detecting and reducing material losses in an automated blending production line, develop a framework for minimising these losses, and validate its effectiveness in an air filter manufacturing company.

The literature review was crucial for exploring existing methods that could be implemented to solve similar problems in other industries, providing a positive reference and a fundamental understanding of the study at Factory X. The literature review was conducted in two parts: detecting and measuring material losses in the blending production line, which included different types of process analysis, strategies, and solutions applied to other industries. For instance, on-site examination, Value Stream Mapping (VSM), Kaizen, and Lean Six Sigma were discussed. All reviewed methods were summarised in tables (Table 2.1, page 15 and Table 2.2, page 16) for ease of reference and were analysed for their pros and cons. As the blending production line at Factory X is dynamic and continuous, this limitation narrowed down the applicability of various existing methods. It helped focus the study on a few methods, namely: on-site examination, Material Flow Analysis (MFA), 5 Whys analysis, and Kaizen. These methods were implemented during each phase of the DMAIC approach (Define, Measure, Analyse, Improve, Control).

Consequently, Chapter 3 outlined the methodology used throughout the study, from identifying the problem to proposing solutions (Figure 3.1, page 23). Additionally, a framework was developed for the study (Figure 3.2, page 27). The key difference between the methodology and the framework was that the methodology provided a brief overview of the entire study, including the completion of the thesis and the final presentation. In contrast, the framework represented the step-by-step approach implemented in the blending production line at Factory X. The study followed five phases: project initiation, data collection, analysis and proposal of possible solutions, test run of the proposed solution, and project completion.

During the study, factory visits were conducted at least once per week to communicate with the engineer in charge, gain a better understanding of the blending production line, and collect data. On-site examinations and MFA were carried out to observe and measure material losses in the blending production line. The application of the 5 Whys analysis helped to identify the root cause of material losses, leading to the proposal of potential solutions.

Data collection focused on three specific stages: the balling pan, heater, and sieving processes. At the beginning of data collection, sections (3), (4), (5), (8), (9), (10), and (11) were selected for Material Flow Analysis (MFA), and several pieces of physical evidence were collected (Table 4.1, page 43). The collected data were then summarised to construct the flow rate balance table, presenting the data more efficiently by showing waste in kilograms per minute (kg/min). As previously mentioned, the 5 Whys analysis (Table 4.2, page 46) was conducted to identify the root cause of each problem, helping to propose possible solutions.

Three possible solutions were identified: converting the balling pan from an open system to a closed system, adding a plastic lining at the output of the balling pan, and optimising the sieving parameters. However, to ensure minimal disruption to the production line, only one solution was chosen—the addition of a plastic lining at the output of the balling pan. The plastic lining, made from high-density polyethylene (HDPE), was flexible and durable, providing a cushion for the output. Careful planning was necessary to ensure the installation did not lead to unexpected issues.

Following the implementation of the plastic lining, MFA was conducted again during the test run. However, only sections (4), (10), and (11) (Table 4.3, page 50) were analysed, as the engineers at Factory X focused primarily on the output of these sections. A comparison of data before and after the test run (Table 4.4, page 52) showed that material waste was reduced from 0.85 kg/min to 0.31 kg/min, resulting in a 5.89% improvement. This met the primary objectives of the study. Lastly, all relevant documents were submitted to the engineer in charge at Factory X for documentation purposes.

This study contributes to SDG 9 (Industry, Innovation and Infrastructure) by promoting the use of approaches such as DMAIC, MFA, and Kaizen in the blending production line, and by strengthening sustainable industrial practices through the development and implementation of an improvement framework. Furthermore, it aligns with SDG 12 (Responsible Consumption and Production) by encouraging the minimisation of material waste in the blending production line, supporting the more sustainable use of raw materials in the air filter manufacturing process.

5.3 Recommendations

Material losses were a common problem faced by many factories worldwide. Although factories operated in different industries, material losses remained a persistent challenge to be addressed. Company leaders continuously sought to learn and explore ways to maximise revenue and profit margins while minimising waste of resources such as time, materials, and manpower. Therefore, several recommendations for future research were discussed in this subsection.

1. Test it in different production line and industry

   The developed framework could be replicated and adapted for different production lines or industries, as it focused on reducing material losses in manufacturing processes. Material losses could result in significant time and financial losses, especially in large-scale production. However, each industry had unique operating conditions, material properties, and loss mechanisms. Therefore, further exploration was essential to evaluate the effectiveness of this approach in different industries, such as food and pharmaceutical manufacturing.

2. Apply in same production line but different section

   The study implemented the solution at the balling pan output due to time constraints. However, other sections, such as the heater and sieving processes, may also contribute to material losses in the blending production line. Future research could extend the approach to these sections within the chemical blending production line at Factory X. Continuously addressing material losses across different sections would help to optimise the production process over time, ensuring higher efficiency and maximised output.

3. Optimising Material Flow Analysis (MFA) for more accurate measurement

   MFA was the primary analysis method used in the study to assess material flow in the blending production line. It has been widely applied by other researchers and has proven effective in measuring material flow, providing precise data for analysis. However, future research could explore more advanced data collection methods to enhance accuracy, such as real-time sensors or automated tracking systems. Since the study relied on MFA, which required manual data collection, the possibility of human error could not be eliminated. Implementing advanced data collection methods would allow for more detailed insights, such as identifying loss patterns, while also making the data collection process more efficient.

4. Investigating alternative materials for reducing material losses

   The study installed a plastic lining made of HDPE at the balling pan output. Although HDPE is flexible, rigid, and durable, other materials with better properties could be explored to extend the study. For instance, rubber-based linings, polymers, or composite materials might offer better cushioning at the balling pan output. However, test runs in the blending production line should be conducted to compare different materials under real production conditions, ensuring the selection of the most effective option for long-term use.

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