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DEVELOPING AND VALIDATION OF A PREVENTIVE MAINTENANCE PLAN FOR SENMUL GARMENT PLC SEWING MACHINES BY USING PROCESS FAILURE MODE AND EFFECT ANALYSIS (PFMEA)

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DEVELOPING AND VALIDATION OF A PREVENTIVE MAINTENANCE PLAN FOR SENMUL GARMENT PLC SEWING MACHINES BY USING PROCESS FAILURE MODE AND EFFECT ANALYSIS (PFMEA)

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June 2026

APPROVAL SHEET

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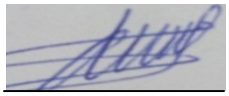
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DECLARATION

I hereby declare that this thesis, entitled" Developing Preventive Maintenance Plan for Senmul Garment Plc, Sewing Machines by Using Process Failure Mode and Effect Analysis " is my original work which, had not been presented in this or other universities, I made it on my own with the close assistance and guidance of my advisor. All sources and materials used in its preparation have been fully acknowledged.

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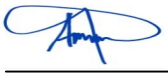


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This is to confirm that the thesis titled "Developing and validation of Preventive Maintenance Plan for Senmul Garment Plc, Sewing Machines by Using Process Failure Mode and Effect Analysis" had been submitted by Asnakew Eshetie as part of the requirements for the Masters degree in garment technology, within the postgraduate studies program of the federal technical and vocational training institute. The research was conducted under my supervision. I hereby certify that the student have met all the necessary requirements and is therefore eligible to submit the thesis to the institute.

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ABSTRACT

Production is disrupted and productivity is decreased by frequent machine failures and prolonged downtime. In order to increase machine dependability and production achievement, this study sought to create a PMP for sewing machines utilizing PFMEA. The study design used was a convergent mixed technique. Pre-tested surveys, interviews, direct observation, maintenance logs, and production reports were used to gather data. In order to prioritize maintenance operations based on RPN thresholds and downtime frequency, PFMEA was used as the primary methodology to identify potential failure modes across key sewing machines and analyze their root causes and operational implications. To ensure the statistical validity of the quantitative data, a reliability analysis was conducted using SPSS, yielding excellent internal consistency across the instrument scales with Cronbach's Alpha values exceeding 0.90. Statistical correlation tests confirmed significant positive relationships among the dimensions, revealing that higher failure occurrences were heavily driven by weak maintenance detection ($r = 0.897$, $p < 0.01$), which directly escalated production losses ($r=0.867$, $p<0.01$). The linear regression analysis further validated the predictive power of the model ($F= 228.925$, $p = 0.000$), indicating that systematic risk management and maintenance control strategies account heavily for the variance in operational outcomes. The empirical results showed that severe bottlenecks resulted from the inadequacy of conventional, reactive time-based maintenance procedures. An integrated structured PM framework was created and put into use based on the PFMEA risk prioritization. This framework integrated specific checklists designed for machine operators, technicians, and maintenance record formats with clear maintenance cycles (such as inspection, small maintenance, medium, and overhauls). According to the investigation, the lack of PM systems led to significant machine downtime, frequent malfunctions, poor maintenance planning, and insufficient inspection procedures. The study showed that combining PFMEA with PMP offers a practical method for lowering equipment failures, enhancing machine dependability, and promoting continuous production performance.

Keywords: *PMP, PFMEA, sewing machines, machine reliability, Risk Priority Number, garment industry, downtime reduction.*

LIST OF ABBREVIATIONS

CM……Corrective Maintenance

DNCS……Double Needle Chain stitch

FOM……Feed off the Arm Machine

KPI……Key Performance Indicator

MTBF……Mean Time between Failures

MTTR……Mean Time to Repair

OEE……Overall Equipment Efficiency

PFMEA……..Process Failure Mode and Effect Analysis

PLC……Private Limited Company

PM…….Preventive Maintenance

PPM……..Planned Preventive Maintenance

RCM…….Reliability Centered Maintenance

RPN…….Risk Priority Number

SNLS……Single Needle Lock Stitch Machine

SPSS……Statistical Package for the Social Science

TPM……Total Productive Maintenance

WIP……Work In Progress

Table of contents

ACKNOWLEDGMENT v

ABSTRACT vi

LIST OF ABBREVIATIONS vii

LIST OF TABLE xii

LIST OF FIGURE xiii

CHAPTER ONE 1

1. INTRODUCTION 1

1.1. Background and Justification of the Study 1

1.2. Statement of Problem 4

1.3. Research Questions 5

1.4. Objectives of the Study 5

1.4.1. General Objective 5

1.4.2. Specific Objective 5

1.5. Scope of the Study 6

1.6. Significance of the Study 6

1.7. Limitation of the Study 7

1.8. Organization of the Study 7

CHAPTER TWO 8

2. LITERATURE REVIEW 8

2.1. Introduction 8

2.2. Maintenance Management in Garment Manufacturing 8

2.3. Technical Classification of Preventive Maintenance Operations 9

2.4. Overview of Garment Manufacturing Processes 11

2.5. Types of Maintenance Systems 13

2.5.1. Comparisons of maintenance strategies 14

2.5.2. Corrective versus Preventive Paradigms 15

2.6. The Concept of Preventive Maintenance 16
2.6.1. Productivity Performance in the Absence of PM 16
2.6.2. Common preventive maintenance activities in sewing machines 17
2.6.3. Challenges in Implementing Preventive Maintenance 18
2.6.4. Operational Impact of Machine Downtime 19
2.6.5. Effects of machine downtime on machine life time in garment manufacturing 19
2.6.6. Reliability in Manufacturing Systems 20
2.7. Failure Mode and Effect Analysis (FMEA) 21
2.7.1. Definition and Historical Development of FMEA 21
2.7.2. Types of Failure Mode and Effect Analysis 22
2.8. Process Failure Mode and Effect Analysis (PFMEA) 22
2.8.1. PFMEA system explanation and Risk Priority Number (RPN) 23
2.8.2. The integration of PFMEA and preventive maintenance 24
2.9. Application of PFMEA in Preventive Maintenance Planning 25
2.9.1. Role of PFMEA in Maintenance Decision-Making 25
2.9.2. Long-Term Sustainability and Competitive Advantage 26
2.10. Research gap 28
2.11. Conceptual Framework of the Study 29

CHAPTER THREE 30

3. METHODOLOGY OF THE STUDY 30

3.1. Introduction 30
3.2. Study Area 30
3.3. Research Approach and Design 31
3.4. Sources of Data 33
3.5. Target Population and Sampling 33
3.5.1. Target Population 33
3.5.2. Determination of sample size 33
3.6. Methods of Data Collection 34
3.6.1. Questionnaires 34
3.6.2. Semi-structured interviews 35

3.6.3. Direct production Observations 35
3.7. Structure of the Questionnaire 35
3.8. Validity and Reliability 36
3.8.1. Validity of the Study 36
3.8.2. Reliability of the Study 36
3.8.3. Pilot Testing and Reliability Analysis 37
3.9. PFMEA Implementation Methodology 38
3.9.1. PFMEA Procedure and Risk Evaluation 38
3.9.2. Risk Priority Number (RPN) Calculation 40
3.9.3. RPN Values of Risk Classifications 40
3.10. Development of Proposed Preventive Maintenance Framework 40
3.10.1. Development Procedure of the PM Program 42
3.10.2. Maintenance Prioritization Logic 43
3.11. Data Analysis and presentation Techniques 43
3.12. Ethical Considerations 44

CHAPTER FOUR 45

4. RESULT AND DISCUSSION 45

4.1. Introduction 45
4.2. Existing Maintenance Practice of Senmul garment 45
4.3. Data Analysis from Questionnaires 46
4.3.1. Demographic Characteristics of Respondents 46
4.3.2. Response of Questionnaires 47
4.4. Reliability and Statistical Analysis 49
4.5. Interview and Observation Data Analysis 53
4.6. PFMEA Analysis and Critical Failure Modes Identification 58
4.6.1. Risk Priority Number Analysis and Maintenance Prioritization 59
4.6.2. Development of PFMEA-Based Preventive Maintenance Plan 60
4.6.3. General PM schedules for all sewing machines and maintenance cycle 61
4.7. Implementation of PM for the Critical & the whole Sewing Machines 68
4.7.1. Introducing the plan in to the production team 69

4.7.2. Production Performance Improvement after PM Implementation..... 72
4.8. Evaluation of Results..... 77
4.9. Integrated Discussion of Finding..... 78
CHAPTER FIVE..... 79
5. CONCLUSION AND RECOMMENDATION..... 79
5.1. Conclusion..... 79
5.2. Recommendation..... 80
5.3. Future Research Work..... 81
REFERENCE..... 82
APPENDICES..... 89
Appendices: A..... 89
Appendices: B..... 94
Appendices: C..... 97
Appendices: D..... 104
Appendices: E..... 108
Appendices: F..... 111

LIST OF TABLE

Table 2-1: Literature gap of the study 26
Table 3-1: Alpha Value Of Pilot Test Result 37
Table 3-2: Severity Rating Criteria 38
Table 3-3: Occurrence Rating Criteria 39
Table 3-4: Detection Rating Criteria 39
Table 3-5: Risk Priority Number values 40
Table 3-6: Maintenance Prioritization Logic 43
Table 4-1: Demographic characteristics of respondents 46
Table 4-2: Descriptive Statistics of Likert Scale Responses (n = 83) 47
Table 4-3: Construct Summary 49
Table 4-4: Reliability Analysis 49
Table 4-5: Correlation Analyses 50
Table 4-6 Regression model 51
Table 4-7: Regression Coefficients 52
Table 4-8: Machine failure recorded data 55
Table 4-9: Critical machines identification 56
Table 4-10: Maintenance schedule cycle and activity classification 62
Table 4-11: Sewing machine codes 63
Table 4-12: Annual machine maintenance cycle 63
Table 4-13: Sewing machines schedule for april 64
Table 4-14: Monthly PM execution and tracking sheet 65
Table 4-15: PFMEA recording sheet 66
Table 4-16: Daily Machine Maintenance Record Sheets 66
Table 4-17: Daily care checklists (performed by operators) 67
Table 4-18: Visual Control System Cards and Required Action 68
Table 4-19: PFMEA based maintenance implementation prioritization 71
Table 4-20: Conducted maintenance activities based on risk level 72
Table 4-21: Productivity improvement comparision before and after 73
Table 4-22: Results Before and After Implementation 76

LIST OF FIGURE

Figure 2.1: Conceptual Framework 29
Figure 3.1: Sewing Production 30
Figure 3.2: Research methodology schematic flow diagrams 32
Figure 3.3: Proposed PM Framework. 42
Figure 4.1: Machine downtime percentage 57
Figure 4.2: Distributions of machine failure modes 58
Figure 4.3: Implemented visual control system cards in line 68
Figure 4.4: Creating Awareness of PMP for sewing production team 70
Figure 4.5: Machine cleaning and repairing process 70
Figure 4.6: Production pieces and achivement percentage before 74
Figure 4.7: Productivity and achivement percentage after 75

CHAPTER ONE

1. INTRODUCTION

This paper studied how frequent sewing machine failures and the absence of PMP affect production performance, machine availability and operational efficiency. This section introduces the background, problem statement, objectives, significance, and scope of the study related to sewing machine maintenance in senmul garment plc. It also presents the application of process failure mode and effect analysis as systematic approach to identify critical machine failures and develop an effective integrated preventive maintenance plan for the sewing machines.

1.1. Background and Justification of the Study

The global apparel industry remains one of the largest and most dynamic manufacturing sectors, playing a critical role in economic development, employment generation, and international trade (Kounina et al.,2024). In 2024, the global textile and garment market was valued at approximately $1.7 trillion, with projections indicating continued growth driven by fast fashion, e-commerce, and rising consumer demand in emerging economies (Sustainable et al., 2022).

However, the industry operates under intense pressure characterized by short lead times, fluctuating order volumes, and stringent quality requirements, making operational efficiency and equipment reliability paramount for competitiveness (Bristy et al., 2025).

Garment manufacturing is a labor-intensive and process-oriented industry that converts raw fabrics into finished garments through sequential operations such as cutting, sewing, assembling, and finishing (Ltebo, 2022). The sector plays a significant role in developing economies by generating employment opportunities, supporting export earnings, and promoting industrialization (Agustina, 2019). On the other hand, production performance in garment factories is highly dependent on the reliability and availability of machinery, particularly sewing and finishing equipment (Díaz-Reza et al., 2019). And also frequent machine breakdowns and inadequate maintenance planning disrupt workflow, reduce production efficiency, and increase operational costs. Many factories rely on reactive maintenance strategies, addressing equipment failures only after breakdowns occur, which lead to repeated stoppages and unpredictable

downtime (Sahoo, 2021). As global market competition intensifies, adopting structured preventive and risk-based maintenance approaches has become essential to ensure stable production performance and cost control (Psarommatis et al., 2023).

Productivity and sustainability in garment industries are directly influenced by equipment performance and process synchronization. Garment production involves multiple interconnected operations performed by operators at different workstations. Effective coordination and uninterrupted machine operation are necessary to maintain line balancing and achieve targeted output levels (Jadhav et al., 2017). Equipment failures interrupt this synchronization, leading to bottlenecks and reduced overall system efficiency.

In developing economies, the garment sector is frequently prioritized as a strategic driver for industrialization due to its relatively low capital entry requirements and high labor absorption capacity (Ltebo, 2022). For Ethiopia, the textile and apparel industry has been identified as a cornerstone of the national Growth and Transformation Plan, aimed at diversifying exports away from agricultural commodities & creating employment opportunities, particularly for women (Rundassa et al., 2019). The Ethiopian government has established industrial parks, such as Hawassa and Bole Lemi, to attract foreign direct investment and integrate the country into global supply chain (Legesse & Singh, 2014).

Maintenance defined as the functional checking, repairing, or replacing of essential machinery. In garment manufacturing, where production systems rely heavily on sewing machines, unplanned failures disrupt workflow, reduce line efficiency, and significantly increase operational costs (Kar, M. K. 2016). While many factories still rely on reactive "breakdown" maintenance, preventive maintenance (PM) programs are essential for improving equipment availability and reliability (Agustina, 2019).

Maintenance has become considered one of the important strategic decisions in operations management (Agustina, 2019). Unplanned machine failures disrupt production flow, reduce operational efficiency, and significantly increase maintenance and operational costs (Ltebo, 2022). Unlike reactive maintenance, which addresses failures after they occur, preventive maintenance emphasizes inspection, lubrication, cleaning, adjustment, and timely component replacement to avoid breakdowns (Stamatis, 2019). Empirical studies indicate that structured

preventive maintenance programs improve equipment availability, reliability, and overall operational performance in manufacturing industries (Sahoo, 2021).

This study utilizes Process FMEA, According to Stamatis, D. H. (2019), a systematic risk assessment technique, to identify potential failure modes and prioritize corrective actions through the Risk Priority Number. By integrating PFMEA into the maintenance planning for Senmul Garment Manufacturing Industrial Plc, this research aims to transition the facility from a reactive to a proactive, risk-based maintenance strategy. Integrating PFMEA into preventive maintenance planning enhances decision-making and supports risk-based maintenance strategies in manufacturing systems (Psarommatis et al., 2023).

FMEA is a general risk assessment tool applicable to both product and process analysis, but PFMEA is specifically concerned with process-related failures. In this study, PFMEA is employed to analyze sewing machine failures and maintenance practices, enabling the identification of critical failure modes and the development of a risk-based preventive maintenance strategy (Ila et al., 2016).

Process FMEA serves as a proactive analytical tool for identifying, analyzing, and preventing potential failures in equipment and processes before they occur. By evaluating failures based on severity, occurrence, and detection, FMEA prioritizes risks using the Risk Priority Number (RPN) (Stamatis, 2019). When integrated with preventive maintenance planning, Process FMEA supports a transition from reactive to risk-based maintenance systems, resulting in reduced downtime, improved machine reliability, and enhanced operational competitiveness (Psarommatis et al., 2023).

At Senmul Garment Manufacturing Industrial Plc, located in Addis Ababa, frequent machine breakdowns have become a barrier to meeting delivery performance. Currently, the facility lacks a structured preventive plan, leading to repeated stoppages and unpredictable downtime (Sahoo, 2021). Traditional time-based maintenance often fails to address high-risk failure points effectively (Psarommatis et al., 2023).

1.2. Statement of Problem

Garment industries play a significant role in employment generation, industrial development, and export growth, particularly in developing countries (Sharma et al., 2025). However, production performance in garment manufacturing is highly dependent on machine reliability, availability, and effective maintenance practices (Bristy et al., 2025). Preventive maintenance (PM) has been reported to reduce machine downtime and improve equipment reliability by ensuring early detection and prevention of failures (Mojumder & Saad, 2025). In contrast, reactive maintenance practices often result in frequent machine breakdowns, production interruptions, and reduced operational efficiency (Psarommatis et al., 2023).

In the case of Senmul Garment PLC, the sewing section currently operates without a structured preventive maintenance program (PMP), resulting in low production efficiency of approximately 49%. The low performance is associated not only with the absence of systematic preventive maintenance but also with operational challenges such as operator absenteeism, delayed maintenance response, inadequate maintenance data recording, and limited failure analysis practices. Production records indicate that sewing machine breakdowns contribute to more than 1,800 minutes of monthly downtime, affecting production continuity and machine availability.

Machine-level analysis at Senmul Garment PLC indicates that Single Needle Lock Stitch (SNLS) machines contribute the highest proportion of cumulative downtime (approximately 30%) due to frequent minor failures, while button attach machines contribute about 25% because of their high production impact. Other machines, including button hole, edge cutter, DNCS, feed-off-the-arm, and overlock machines, also contribute significant downtime.

Although these machines have different failure characteristics and operational consequences, the existing maintenance system does not prioritize maintenance activities according to machine criticality, failure risk, and production impact. Consequently, machine availability remains below the commonly reported industrial benchmark of 85-90% (Zhang et al., 2025). Previous studies have investigated machine downtime and maintenance challenges in garment manufacturing industries (Koç, 2025). However, many studies have focused on general productivity improvement rather than machine-level failure analysis and risk-based maintenance planning in sewing operations.

Furthermore, PFMEA has mainly been applied for defect reduction in sewing processes (Tsegaye, 2023). and maintenance analysis of other textile machinery such as weaving equipment (Shamsuzzaman & Das, 2023). Its application for developing a PFMEA-based preventive maintenance program in sewing sections of garment industries, particularly in developing countries, remains limited. Therefore, this study aims to develop and implement a PFMEA-based preventive maintenance program that prioritizes critical sewing machine failures, reduces downtime, and improves production performance at Senmul Garment PLC.

1.3. Research Questions

This study addresses the following research questions in relation to Senmul garment plc.

- Which sewing - machine failure modes are most critical, and what are their root causes and operational impacts as determined by PFMEA**?**
- How do failure occurrence factors particularly weak maintenance detection relate to downtime and production losses in the sewing production process?
- To what extent does the PFMEA - based PMP predict and improve operational outcomes, compared with conventional reactive, time based maintenance?

1.4. Objectives of the Study

1.4.1. General Objective

- To develop and implement a PFMEA-based Preventive Maintenance Program (PMP) for sewing machines to reduce failure occurrences, minimize prolonged downtime, and improve production performance.

1.4.2. Specific Objective

- To identify the key failure modes of critical sewing machines and their root causes using PFMEA.
- To prioritize maintenance actions by ranking PFMEA risks using RPN thresholds and downtime frequency.

- To develop and implement a structured PFMEA-based preventive maintenance program (PMP) with defined maintenance cycles (inspection, small maintenance, medium, and overhauls) and role-based checklists/maintenance records.
- To evaluate the effect of the PFMEA-based PMP on machine dependability by analyzing relationships between failure occurrences, downtime/production losses, and maintenance control effectiveness.

1.5. Scope of the Study

This study focused on developing and implementing a PFMEA-based Preventive Maintenance Program (PMP) for sewing machines in the sewing section of Senmul Garment PLC, located in Akaki Kality Sub-City, Addis Ababa, Ethiopia. The study was limited to the sewing section because machine failures in this department directly affect production continuity, product quality, and operational performance.

The study identified critical sewing machine failure modes, evaluated their risks using PFMEA and Risk Priority Number (RPN), and developed a structured preventive maintenance program including inspection, small maintenance, medium maintenance, and overhaul activities. A convergent mixed-methods case study design was employed using questionnaires, interviews, field observations, maintenance records, production reports, and machine downtime data.

The developed PMP was implemented and evaluated over a three-week period to assess its effect on machine downtime and production performance. The study excluded the cutting, finishing, packaging, and administrative departments, as well as other maintenance approaches such as predictive maintenance, reliability-centered maintenance, and total productive maintenance.

1.6. Significance of the Study

This study contributes to improving maintenance management in garment manufacturing by developing and implementing a PFMEA-based Preventive Maintenance Program (PMP) for sewing machines at Senmul Garment PLC. The findings provide a systematic approach for identifying critical machine failure modes, prioritizing maintenance activities using the Risk Priority Number (RPN), and improving maintenance planning.

For Senmul Garment PLC, the developed PMP supports the transition from reactive to preventive maintenance, helping to reduce machine breakdowns, minimize production interruptions, improve equipment reliability, and enhance production performance. The proposed maintenance framework can also serve as a practical reference for other garment manufacturing companies with similar production systems.

In addition, the study contributes to the existing body of knowledge by demonstrating the application of PFMEA in preventive maintenance planning within the Ethiopian garment industry. It also provides a useful foundation for future research on machine reliability, risk-based maintenance, and production performance improvement.

1.7. Limitation of the Study

During data collection there was a number of difficulties in which supervisors, maintenance technicians, and machine operators' heavy production burden caused the data collecting difficult to collect. Due to their strict production deadlines & performance goals, completed questionnaires were not returned on time. Follow-up had to be ongoing in order to resolve this problem and guarantee a sufficient reaction time. With the intent of make possible the completion and collecting of the questionnaires, this involved setting up appropriate times during non peak production hours, lunch time & end time, by communicating directly with respondents.

1.8. Organization of the Study

This study is organized into five sections, each section designed to uphold a clear & logical sequence of information. Chapter one presents the primary issues tackled in the research and details the study objectives and aim. Chapter two gives the literature review, addressing the concept of maintenance systems, associated terms, & the significance of PM in enhancing overall equipment efficiency. Chapter three outlines the research methods employed in the study. It outlines the research structure, methods for data collection & the complete procedure used to carry out the study. Chapter Four emphasizes the analysis of data and the findings. Chapter Five presents the conclusion and suggestions derived from the research outcomes. It outlines the main findings and provides actionable recommendations for enhancing preventive maintenance strategies within the organization.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter reviews the theoretical and empirical literature related to preventive maintenance, maintenance management, sewing machine reliability, and Process Failure Mode and Effect Analysis (PFMEA) in garment manufacturing. It examines the impact of machine failures on production performance, equipment reliability, and overall operational effectiveness, while highlighting the transition from reactive to preventive maintenance systems. The chapter also discusses the technical classification of preventive maintenance activities, including inspection, minor maintenance, medium maintenance, and overhaul, as well as the application of PFMEA in identifying critical failure modes, evaluating maintenance risks, and prioritizing preventive maintenance actions. Furthermore, it synthesizes findings from previous studies, identifies existing research gaps, and provides the theoretical foundation and conceptual framework that support the research objectives and guide the present study.

2.2. Maintenance Management in Garment Manufacturing

Textile & garment companies continue to experience machine failures, downtime, & productivity losses due to inadequate maintenance planning and insufficient PM implementation. For keeping machines reliable & running smoothly maintenance management is important in manufacturing industries (Mojumder & Saad, 2025). It helps make sure that production keeps going and that everything runs efficiently. In factories good maintenance management helps machines run well through regular checks, servicing & repairs (Abdeen et al., 2019). These mean machines were less likely to break down & when they do they can be fixed quickly. As a result machines last longer & production become better overall in the garment industry, because production depends on sewing machines (Ighravwe, 2022).

These machines run constantly at speeds & were prone to problems like vibration, friction and dust buildup which can cause them to fail. Common issues with these machines include needles, misaligned timing, uneven thread tension, oil leaks and too much vibration. The breakdown of

sewing machines disrupts the production line, reduced efficiency & causes delays. This ultimately affects how efficiently garments were produced and deliver (Ghorbani et al., 2020).

There are two main types of maintenance in the manufacturing sector, this were corrective & preventive. Corrective maintenance fixes machine problems after breakdown (Amrina et al., 2022). This maintenance may seem easier in the term but in the garment industry it often leads to unexpected downtime, production interruption & higher repair costs (Stahre, 2020). On the other hand preventive maintenance involves regular checking and maintaining machines to prevent them from breaking down in the first place. This includes cleaning, lubricating, adjusting & replacing worn out parts (Sahoo, 2021).

Compared to reactive maintenance PM reduces downtime improves the quality of sewing stabilize production & make machines more reliable. Therefore better PM is critical for improving machine performance, efficiency & overall productivity in the garment industry (Mehmeti&Sejdiu, 2022). Maintenance activities can be scheduled to prevent problems, which help machines run better and last longer. In addition it's important for keeping production running and ensuring that garments were made efficiently. By taking care of machines factories can reduce the likelihood of breakdowns and keep production on track. This means that garments can be produced quickly with better quality, which is good, for both the factory & the customers (Adaramola et al., 2022).

The reviewed literature indicates that effective maintenance management is essential for ensuring machine reliability, minimizing downtime, and improving production efficiency in garment manufacturing. While corrective maintenance remains common in many factories, preventive maintenance provides a more systematic approach by reducing unexpected machine failures, extending equipment life, and enhancing overall production performance. Therefore, effective maintenance management provides the foundation for developing a structured preventive maintenance program for sewing machines.

2.3. Technical Classification of Preventive Maintenance Operations

Preventive maintenance activities for sewing machines were grouped in to levels based on the situation of the machine & the complication of the maintenance. In the garment manufacturing industries this levels of maintenance are called inspection, small maintenance, medium

maintenance and overhaul maintenance (Kafiabad, 2021). This technique of grouping helps to organize the maintenance work & use resources in a way. Those levels were defined as follows;

Inspection is a check to found out any signs of wear or potential problems before the machine breakdown. This check include looking at the machine, listening to any abnormal noises or vibration, checking the lubrication & making sure machines were clean. For sewing machines the inspection focuses on the condition of the belt, the needle, vibration of the machine, oil level, timing and if there is any lint buildup (Antosz & Ratnayake, 2019). Doing this inspection on a basis helps to find problems early and reduces the time the machine is not working.

Also small maintenance is the work that is done every day or every week to keep the machine in good condition. This work includes cleaning the machine lubricating it replacing the needle tightening any parts and making small adjustments (Soliman et al., 2023). It is very important to eliminate lint, dust and thread pieces from the machine because if they build up they can cause more friction reduce how well the machine works and make it wear out faster.

Medium maintenance is the planned work that needs to be done to keep the machine working. This work is usually done every month or every quarter. Includes taking the machine apart a little calibrating it and replacing any parts that are worn out (Stadnicka et al., 2024). This type of maintenance involves adjusting the timing correcting the alignment replacing the belt and spring adjusting the feed mechanism and cleaning the inside of the machine. This level restores machine performance and ensures stable production efficiency.

Overhaul (major) maintenance is the highest level of preventive maintenance and involves complete machine restoration through extensive inspection, disassembly, repair, and replacement of major machine components (Keller & Owen, 2025). Overhaul activities are normally performed during planned factory shutdown periods because they require significant maintenance time and technical resources. In sewing machines, overhaul maintenance includes replacement of major mechanical parts such as shafts, bearings, bushings, cams, and internal drive components. It may also involve replacement of electrical systems, lubrication lines, and damaged structural components. Although overhaul maintenance requires high maintenance cost and labor, it improves machine lifespan, restores machine performance, & reduces the risk of severe machine failure during production operations (Kafiabad, 2021).

2.4. Overview of Garment Manufacturing Processes

The garment and textile industry in Ethiopia's is contributing to the economy, and providing employment opportunities, especially for women. However, manufacturers face challenges in ensuring high efficiency in production processes, especially in the sewing section (Rundassa,& Berhan, E 2019). The efficiency of sewing is impacted by a lot of factors such as skill of the operators, use of machines, line balancing as well as physical arrangement of the production and mode of loading on the work (Islam & Liang, 2020). Garment manufacturing involves a series of interrelated technical and managerial activities that transform fabric in to finished apparel products meeting predefined quality, cost, and delivery requirements. It also includes fabric cutting, sewing, assembling, finishing, pressing, and packaging. These processes rely heavily on machine performance and coordination. Any disruption in machine operation can affect production flow, delivery schedules, and product quality. Therefore, effective maintenance is essential for sustaining continuous garment production (Kiisa, M., & Kapur, S. 2021).

Merchandising: Receive orders and specifications from buyers, develop production schedules and plans based on customer requirements, and collaborate with the design and development team to finalize product designs (Aus et al., 2021). Trims and Accessories Store: Inspect and receive trims and accessories such as buttons, zippers, labels, etc, Organize and store trims and accessories based on type, color, and style, Issue required trims and accessories to the production floor as per the production plan.

Fabrics Store: Inspect and receive fabric rolls from suppliers, organize and store fabrics based on type, color, and design and issue fabrics to the cutting section according to the cutting plan (Aus et al., 2021). Cutting: Cutting is the process of separating fabric into garment components according to marker layouts. This stage involves Receive approved patterns and marker plans, Lay out fabric layers based on the marker plans, Cut fabric pieces using cutting machines or manual methods, Inspect and sort the cut fabric pieces for further processing. Accurateness in cutting is important to make sure that the assembly is done correctly when sewing. If there are mistakes in cutting it can cause delays in production & more items can be rejected (Faruque et al., 2023).

Sewing is the part of making clothes, the fabric pieces that have been cut and assemble them into clothes according to the instructions. The quality of the sewing can be checked to make sure the stitches are good and the pieces are aligned properly. And also add things like trim, labels & other accessories as needed (Journal of Applied Research and Technology, 2022). Sewing machines were used to put the fabric pieces together into complete clothes. Because sewing is a process that involves steps & if one machine is not working it can stop the whole process. After sewing the clothes go through a finishing process, where any threads or extra fabric, from the clothes iron them to get rid of wrinkles & check the quality one last time to make sure everything is good. This finishing process makes the clothes look better and makes sure they meet the requirements of the people who are buying them (Faruque et al., 2023). After that finished garments were folded, labeled, packed into cartons, and prepared for shipment according to customer requirement. Accurate packing and documentation are essential to meet export standards and delivery timelines (Faruque et al., 2023).

Common Machines Used in the Garment manufacturing & their Typical Failures

Garment industries utilize various type of key machinery in cutting, sewing and finishing section. section Straight Knife Cutting Machine, Band Knife Cutting Machine, Computerized/CNC Cutting Machine, Laser Cutting Machine, Fabric Spreading Machine and Fabric Relaxation Machine (Y. Xu, 2020).

Sewing section machines are, single needle lock stitch (SNLS) machine, over lock machine (3/4/5 thread), button hole machine, button attaching machine, bar tack machine, feed-off-the-arm machine and double chain stitch machine (Silva, S. K. P. N., & Samarasinghe, G. D. 2012). Finishing, ironing/steam press machine, fusing machine, thread sucking/trimming machine, fabric inspection machine, metal detector machine and other department machines. These machines operate for long hours and are subject wear and tear, making them prone to mechanical, electrical and operational failures (Ali et al., 2021).

The most common technical problems observed in high-speed industrial sewing machines such as button attach, button hole, single-needle lockstitch, over lock, flat lock, feed-off-arm, and edge cutter machines (Hashem & Islam, 2020). Problems include improper stitch formation (skipped stitches, uneven stitch length), thread breakage due to tension imbalance, needle

breakage, lopper timing mismatch, hook and feed dog wear, knife dullness in over lock/edge cutter machines, excessive vibration from shaft or bearing play, insufficient lubrication or oil leakage, corrosion of thread guides, accumulation of lint and dust in moving components, missing or loose screws (e.g., throat plate and tension assemblies), & motor overheating (Bheda, 2017).

These failures primarily arise from inadequate PM, high operating speeds, poor lubrication control, and improper machine adjustment, leading to increased downtime, reduced machine availability, and productivity loss in garment production systems (Sharma & Kumar, 2018). Equipment failure impacts garment production lead to under production targets and discrepancies in the quality grade of products, thereby reducing profits for the company.

Although some defective products can be rectified through rework, the existence of defects resulting from rework imposes additional costs on the company (Rukmana et al., 2024). Equipment failure in garment manufacturing leads to production downtime, increased defect rates, delayed order fulfillment, and higher operational costs. Frequent breakdowns also affect worker morale and may pose safety risks. Consequently, equipment reliability is directly linked to productivity, profitability, and customer satisfaction in the garment industry (Kipchumba & Chemweno, 2024).

The literature shows that garment manufacturing consists of interconnected processes in which sewing plays a critical role in determining production continuity and product quality. Since sewing operations depend heavily on machine reliability, failures in sewing machines can disrupt production flow, reduce productivity, and increase operational costs. These findings highlight the importance of implementing an effective preventive maintenance system to ensure continuous production and improved operational performance.

2.5. Types of Maintenance Systems

Maintenance systems were generally classified into breakdown maintenance, preventive maintenance, predictive or condition based maintenance, total productive maintenance, and reliability-centered maintenance (Gackowiec, 2019). CM repairing equipment only after failure occur and it usually associated with high down time and cost. it is the most commonly used maintenance approach, equipment failure often causes unexpected production downtime, may

damage other related parts, and can become costly especially when major components or entire machines need replacement (Design et al., 2016). It is often most expensive not only can worn equipment damage other parts and cause multiple damage, but consequential repair and replacement costs and loss of revenues due to down time during overhaul can be significant (Hamasha et al., 2023).

Predictive maintenance: Relies on monitoring equipment condition to predict failures uses sensors to monitor key parameters within a machine and uses this data in conjunction with analyzed historical trends to continuously evaluate the system health and predict a breakdown before it happens. This strategy allows maintenance to be performed more efficiently, since more up-to-date data is obtained about how close the product is to failure. More recently, advances in sensing and computing technology have given rise to predictive maintenance (Mohammad M. Hamasha et al., 2023).

Preventive maintenance (PM): It's also a maintenance activity performed at predetermined intervals to reduce the probability of equipment failure and maintain assets in optimal working condition (Agustina, 2019). Additionally it's time-based or run-based periodically inspecting, servicing cleaning, or replacing parts to prevent sudden failure system.

Total productive maintenance emphasizes operator involvement and continuous improvement, is a highly structured approach, and careful and efficient planning and preparation are keys to successful company-wide implementation of TPM (Igbokwe et al., 2021). Reliability-centered maintenance is a strategic framework designed to ensure assets continue to operate as intended within their specific environment, rather than applying a "one-size-fits-all" approach, it tailors maintenance based on the criticality of the equipment and the consequences of its failure (Singh & Tewari, 2023).

2.5.1. Comparisons of maintenance strategies

Different maintenance strategies vary in terms of cost, effectiveness, & complexity. Breakdown maintenance is simple but risky and costs were significantly higher due to the unpredictability of equipment failures, leading to urgent responses and additional costs associated with downtime (Keller, S., & Owen, A. 2025). PM reduces failure frequency but requires systematic planning and resources. The average annual cost of PM activities was found to be 20% lower than that of

CM. This reduction is attributed to the planned nature of PM, which allows for bulk purchasing of parts and reduced labor costs through regular scheduling (Keller, S., & Owen, A. 2025).

Predictive maintenance offers higher accuracy but depends on advanced technology and skilled personnel (Karim, 2025). TPM is a system of maintaining and improving the integrity of production and quality systems through the machines, equipment, processes, and employees that add business value to an organization TPM enhance equipment effectiveness but demands strong organizational culture (Khosroniya et al., 2024).

2.5.2. Corrective versus Preventive Paradigms

While Corrective Maintenance remains the most common approach in developing countries due to its low initial cost, scholars such as Hamasha et al. (2023), argue that this "run-to-failure" model is the most expensive in the long term. They contend that consequential repair costs and revenue losses from downtime far outweigh the savings of avoiding routine checks. In contrast, Sahoo (2021), demonstrates through empirical data that structured PM programs improve equipment reliability significantly, though critics point out that over-maintenance can lead to "maintenance-induced failures" if not properly scheduled.

Sahoo (2021), found that in the textile sector, the improvements are often marginal due to poor implementation & a lack of skilled technicians. This suggests that industry context specifically the labor-intensive nature of garment manufacturing significantly affects how maintenance theory translates into practice.

Compared with corrective maintenance, PM provides better equipment reliability & operational performance. It reduces machine failures & downtime, increases production output, lowers maintenance costs, improves spare part control & enables early detection of potential failures before they cause breakdowns (Igbokwe et al., 2021). The cost comparisons of PM and CM, showed that, the average annual cost of PM activities was found to be 20% lower than the cost of CM. This reduction is attributed to the planned nature of PM, which allows for bulk purchasing of parts and reduced labor costs through regular scheduling.

Corrective Maintenance Costs: CM costs were significantly higher due to the unpredictability of equipment failures, leading to urgent responses and additional costs associated with downtime. Downtime Reduction: A critical finding was the significant reduction in equipment downtime

associated with PM. Analysis showed that organizations implementing PM experienced an average downtime reduction of 25%, translating into increased operational throughput (Keller, S., & Owen, A.2025) .

Previous studies demonstrate that preventive maintenance outperforms corrective maintenance by reducing failures, downtime, and maintenance costs. Therefore, this study adopts preventive maintenance instead of reactive maintenance.

2.6. The Concept of Preventive Maintenance

Preventive maintenance activities were carried out at predetermined intervals to reduce the likelihood of equipment failures. It involves routine, cleaning, lubrication, adjustment, and replacement of worn parts. PM can be time-based or usage-based and it's designed to maintain equipment in optimal operating condition (Todmal et al., 2023).

A well structured PMP enables organizations to anticipate failure & take corrective actions before breakdowns occur. Preventive maintenance is to detect the machine failure before breakdown occurs. The main role of preventive maintenance is routine attention, routine examination, preventive replacement, and inspection measurements (Domeika, A 2018).

2.6.1. Productivity Performance in the Absence of PM

Productivity performance in garment manufacturing largely depends on machine reliability, equipment availability, and uninterrupted production flow.

In production line operations, machine breakdowns disrupt workflow balance, reduce operator utilization, & increase idle time, thereby negatively affecting overall production efficiency (Diaz-Reza et al., 2019).

Several studies have shown that ineffective maintenance practices significantly reduce production throughput & operational stability in manufacturing industries (Bokrantz et al., 2020). Machine availability, defined as the ratio of operating time to premeditated production time it's also critical determinant of productivity performance (ISO, 2017). In the lack of structured PM, firms often experience unplanned downtime rating from 10-20% of scheduled production time (Alsyouf et al., 2020). Such interruptions reduce production capacity & lower resource

utilization. In garment companies globally line efficiency under stable condition commonly ranges between 85% & 90% (Jadhav et al., 2017).

However, reactive maintenance environments characterized by frequent machine failures & micro stoppages often reduce line efficiency approximately 70-75% & under (Psarommatis et al., 2023). This efficiency level goes under this number in developing countries local manufacturing companies. Studies point out organizations operating under reactive maintenance commonly experience OEE between 60% & 70%, while well maintained production systems achieve between 75% to 85% (Bokrantz et al., 2020). Furthermore inadequately maintained sewing machines contribute to stitching defects, thread breakage, inconsistent seam quality & rework, leading to additional production losses estimated 3%-8% in garment manufacturing (Diaz-Reza et al., 2019).

2.6.2. Common preventive maintenance activities in sewing machines

PM in the clothing industry refers to regularly scheduled procedures meant to preserve the efficiency of sewing machines & prevent unforeseen breakdowns. Essential elements of this strategy include timely lubrication of moving parts, appropriate cleaning, and routine inspections. Al-Turki (2014), asserts that putting PM into practice can greatly increase the longevity and dependability of machines, resulting in fewer disruptions to operations.

Because the sewing department had numerous machines operating continuously, regular maintenance is essential to preserving equipment reliability, boosting productivity, and ensuring uniform stitch quality (Teknologi et al., 2024). Routine upkeep duties, such as:

Machine cleaning: Cleaning in apparel manufacture is one of the most fundamental PM jobs. During sewing operations, lint, dust, broken threads, & fabric particles accumulate around machine components such as the throat plate, feed dog, bobbin case, & thread guides (Ramzan et al., 2022). This accumulation can affect stitch formation, slow down machine action, and cause friction between moving elements. Frequent cleaning aids in the removal of these impurities and guards against mechanical issues like thread breakage & skipped stitches. In order to maintain sewing quality & ensure smooth operation, personnel in clothing factories are typically in charge of cleaning the machines at the conclusion of each production shift (Godley,A.2023).

Machine lubrication: Another crucial PM procedure that lowers friction between moving machine parts is lubrication. For sewing machines to operate smoothly, a number of spinning and sliding components, including shafts, bearings, needle bars, and feed mechanisms, need to be well lubricated. Overheating, excessive wear, and ultimately machine failure can result from poor lubrication (Ramzan et al., 2022). Frequent oiling of sewing machines guarantees the smooth operation of mechanical components, lowers noise and vibration, and enhances the equipment's overall performance. Depending on the type of machine and usage level, machine lubrication schedules were usually implemented either daily or weekly in the apparel manufacturing industries (Mazari, 2025).

Machine Adjustment: Machine adjustment is necessary to ensure appropriate sewing performance and product quality. For sewing machines, a variety of factors need to be frequently changed, such as thread tension, needle placement, stitch length, presser foot pressure, and machine time. Inadequate corrections can result in sewing defects such as skipped stitches, uneven stitching, cloth puckering, or thread breaking. Regular machine component inspection & adjustment guarantees accurate stitch creation and proper alignment. Maintenance personnel typically make these adjustments during routine maintenance checks to keep equipment operating within the advised parameters (Eladly, 2020).

Replacement of spare parts: Machine components such as feed dogs, belts, springs, bearings, loppers, and needles ultimately wear out due to continuous use. If worn parts were not replaced immediately, they may cause poor stitch quality, machine failure, or complete breaking. Replacing essential spare components before they break is an essential maintenance strategy in the apparel manufacturing sector (Sharma et al., 2025).

Regular inspections of machine components allow maintenance technicians to promptly replace worn or damaged parts, preventing unplanned machine stoppages and maintaining consistent production efficiency (Geitner, F. K., & Bloch, H. P. 2019).

2.6.3. Challenges in Implementing Preventive Maintenance

Despite its benefits, PM had a number of implementation issues, particularly in poor nations. Inadequate maintenance planning, a shortage of qualified maintenance staff, inadequate maintenance documentation, a shortage of spare parts, & inadequate management assistance are

some of these issues. Due to production pressure & financial considerations, PM frequently disregarded in the apparel industry, which resulted in frequent malfunctions & inefficiencies (Hubbard, E. M. 2017).

PPM may not always guarantee the best possible use of equipment parts, which lowers cost-effectiveness. PPM may result in the needless and early replacement of parts before they reach the end of their usable lives. Additionally, it was noted that there is still little and conflicting empirical data to support the general efficacy of planned preventive maintenance (Ali, A. S., & Chua, S. J. L. 2016).

2.6.4. Operational Impact of Machine Downtime

Machine downtime is widely recognized as primary cause of production delay, but its impact varies by region and methodology of study. Studies in Bangladesh Ahmed et al. (2019), reported that machine downtime contributes approximately 30% of all production disruption. However many studies like (Agustina, 2019), use general descriptive statistics to report downtime. This research identified a gap, most studies fail to perform a quantitative breakdown (machine-wise failure), which is necessary to move from identifying that a problem exists to understanding why specific machines, like the Over Lock or Buttonhole machines, fail more frequently.

In any business, machine downtime is an operational loss or a time when a system is unavailable. This typically occurs when an unforeseen circumstance causes the system to malfunction (Alauddin, 2018). According to a recent study, factory maintenance costs account for 25-30% of total production costs (Agustina, 2019).

Despite the fact that maintenance costs are a significant portion of the operational budget of manufacturing organizations, the significance of maintenance services had grown due to their role in maintaining and increasing the availability, product quantity, and safety standards (Rivera-Gómez et al., 2021).

2.6.5. Effects of machine downtime on machine life time in garment manufacturing

The longevity, dependability, & performance of manufacturing equipment are all significantly impacted by machine downtime. Poor maintenance procedures, inconsistent service, and postponed repairs are frequently linked to frequent machine downtime, which can hasten

mechanical deterioration and component wear (Kafiabad, 2021). Inadequate maintenance can lead to minor problems in machines developing into major ones, putting more stress on mechanical components and reducing the equipment's lifespan.

Studies in industrial maintenance management have shown that uncontrolled downtime promotes equipment degradation & ultimately reduces machine reliability (Singh & Tewari, 2023). Additionally, during malfunction periods, critical components like bearings, motors, gears, and feeding mechanisms were subjected to unpredictable loading conditions & operational stress; frequent malfunctions & prolonged downtime can shorten the life of a machine. In production environments, machines that stop and restart frequently put more mechanical strain on their components, weakening them over time and increasing the risk of future failures. Effective maintenance techniques, particularly PMP are essential to reduce downtime and extend equipment service life (Wireman, 2019).

And also machine downtime affects the equipment's economic lifespan by increasing maintenance costs and reducing productive use. When machines sit idle for long periods of time due to problems, production schedules were disrupted and emergency repairs were needed. The effective operational life of machinery is further decreased by these unexpected maintenance procedures, which are frequently more expensive and could not address the underlying reasons of breakdowns. Industrial machinery longevity and performance can be greatly increased by using structured maintenance methods like PM & reliability-centered maintenance (Ben-Daya, Kumar, & Murthy, 2020).

2.6.6. Reliability in Manufacturing Systems

In the present manufacturing scenario, the challenging issues such as cost, quality, agility and mass customized goods make enormous demand on reliability and availability of the systems and their elements in the manufacturing plants, System functions play a crucial role (Loganathan, M. K., & Gandhi, O. P. 2017).

Reliability refers to the probability of a product operating without failure over a specified time and under predetermined conditions. It is a mathematical concept that requires improving the efficiency of tools, people and processes. The reliability of each device is measured by its reliability function. In maintenance engineering, reliability is often evaluated using indicators

such as mean time between failures, MTTR, & equipment availability. High reliability ensures stable production & reduced maintenance costs (Singh & Tewari, 2023).

Recent studies agree that preventive maintenance improves machine availability, production efficiency, and equipment life. However, conventional preventive maintenance often lacks risk prioritization, creating the need for PFMEA-based maintenance planning.

2.7. Failure Mode and Effect Analysis (FMEA)

2.7.1. Definition and Historical Development of FMEA

In the apparel and Textile industry to meet the high product quality demand of customers, organizations use systematic tools like failure mode & effects analysis. This helps them proactively prevent defects, improve equipment reliability, and lower manufacturing costs. While FMEA was originally developed for military & aerospace uses, it was widely adopted by the automotive industry in the 1970s and 1980s as a standard tool for managing operational risks (Anal et al., 2014).

Today, FMEA is recognized as a structured & preventive analytical method used across various industries to identify potential failure modes, evaluate their severity, occurrence, and detection levels, and prioritize improvement actions to enhance system reliability and operational performance (X. Xu & Chen, 2020). Process FMEA is also known as bottom-up inductive system analysis, which analyzes potential errors, including finding the root cause and how the error occurs (Hock et al., 2024).

The aims of PFMEA is to keep the customer satisfaction at highest point and to enhance the image of company at that point, to provide competitive superiority by minimizing the costs from production failures and improving the production efficiency.

The Failure Mode and Effects Analysis is a technique used for eliminating the release of unsuccessful products which may harm to company (Anal et al., 2014). Although FMEA method is employed to proactively address the technical aspects of risk reduction. Unlike other reliability management tools, FMEA serves as a proactive method to prevent system failures (Rukmana et al., 2024).

The industry faces challenges such as increasing quality demands from customers, the necessary cost optimization of products and processes, higher complexity, and product liability imposed by legislation. Therefore, the PFMEA method is employed to proactively address the technical aspects of risk reduction. Unlike other reliability management tools, PFMEA serves as a proactive method to prevent system failures, rather than an after-the-fact analysis method (Rukmana et al., 2024).

2.7.2. Types of Failure Mode and Effect Analysis

The most common types of FMEAs are System FMEA, Design FMEA and Process FMEA. System FMEA: is focus on system-related deficiencies, including system safety, system integration, interactions between subsystems or with other systems, interactions with the surrounding environment, human interaction, service, and other issues that could cause the overall system not to work as intended. In System FMEAs, the focus is on functions and relationships that were unique to the system as a whole (Carlson, 2014).

Design FMEA this type of FMEA had the purpose of identification and prevention of failure modes of products, which are related to their design. The most important function of this type of FMEA is the identification in the early stages of design development of the potential failure modes in order to eliminate their effects, select the optimal design variant and develop a documentary base to support future designs in order to minimize the risks that faulty products reach the customers (Demirkaya, 2022). PFMEA, it focuses on potential failure modes of the process that are caused by manufacturing or assembly process deficiencies. (Sharma, K. D., & Srivastava, S. 2018).

The literature shows that FMEA is an effective tool for systematically identifying potential failure modes, assessing their effects, and prioritizing risks before failures occur. It therefore provides the theoretical foundation for applying PFMEA in developing a preventive maintenance program for sewing machines in this study.

2.8. Process Failure Mode and Effect Analysis (PFMEA)

Process Failure Mode and Effect Analysis is a proactive risk management tool used to systematically identify potential failures in manufacturing processes, evaluate their causes and effects, and prioritize preventive actions based on risk level (Ta, 2018).

In garment manufacturing, PFMEA improves process stability by reducing defects, minimizing downtime, and supporting effective preventive maintenance planning. As a result, it contributes to higher machine availability, improved production efficiency, and better product quality (Parsana & Patel, 2014).

2.8.1. PFMEA system explanation and Risk Priority Number (RPN)

Failure mode refers to the manner in which a machine or process fails to perform its intended function within specified operating conditions. It may involve complete functional failure, reduced performance, or inability to meet required operational standards (Dedimas & Gebeyehu, 2019). Failure effect is the consequence of the failure on the manufacturing process, machine operation, or end user, particularly at the production and assembly level in PFMEA applications (Pazireh et al., 2017). Failure causes are the specific reasons responsible for the occurrence of the failure mode and identified through root-cause analysis of machine (Carlson, 2014).

Risk Priority Number (RPN) is a risk evaluation method used in PFMEA to identify and prioritize critical failure modes requiring maintenance attention. It is calculated by multiplying Severity (S), Occurrence (O), and Detection (D) ratings, with scores ranging from 1(absolute best) to 1000 (absolute worst), (Gatot Basuki, 2018). Higher RPN values indicate higher operational risk and greater maintenance priority.

Based on industrial PFMEA practice & garment manufacturing operational conditions, failure modes with RPN values above 250 were classified as very high risk and required immediate preventive action. RPN values between 150-250 were considered high risk, values between 80-149 were treated as medium risk, while values below 80 were classified as low risk and managed through routine inspection (AIAG 2019). These classifications were adapted to the operational conditions of sewing machines considering production interruption, machine reliability, and maintenance criticality within the sewing section (Demir & Sabır, 2024).

Probability of Failure Occurrence (O) indicates how frequently a specific failure cause is expected to occur within the process or machine system. It is evaluated using a rating scale from 1 to 10, where higher scores represent greater likelihood of failure occurrence (Ridho et al., 2020). Severity of Failure (S) represents the seriousness of the effect caused by a failure mode on machine operation, production performance, or product quality. Severity is also evaluated on a

scale of 1 to 10, where higher scores indicate more critical operational impact (Ridho et al., 2020).

Detection (D) represents the ability of the existing control system to identify or detect potential failure causes before the failure occurs. Detection is assessed using a scale from 1 to 10, where lower detectability results in a higher detection rating (Sari, 2023). PFMEA and RPN provide a systematic approach for identifying, analyzing, and prioritizing machine-related risks within manufacturing systems.

PFMEA identified potential failure modes and their causes, while RPN quantifies the level of risk based on severity, occurrence, and detection ratings, enabling maintenance teams to prioritize critical machine problems affecting equipment reliability and production performance (Ta, 2018). In garment manufacturing industries, particularly within sequential sewing operations, failure of a single machine can interrupt the entire production flow. Therefore, PFMEA integrated with RPN serves as an effective tool for prioritizing PM activities, reducing machine downtime, improving equipment availability, and supporting continuous improvement through risk-based maintenance decision-making (Ciani et al., 2019).

2.8.2. The integration of PFMEA and preventive maintenance

The integration of PFMEA with PM is a fundamental shift from time-based maintenance strategies to risk-based decision-making approaches. Conventional PM systems typically rely on fixed intervals, treating all equipment equally regardless of their failure criticality (Muthalib et al., 2019). While such approaches provide routine control, they often result in inefficient resource allocation, as a low risk components may receive excessive attention, where as high risk failures remain insufficiently addressed (Stamatis, 2019).

In contrast, PFMEA introduces a systematic and analytical framework that prioritizes maintenance activities based on risk evaluation criteria. This enables maintenance managers and technicians to focus on the most critical failures (Krynke et al., 2014). Compared to traditional approaches, PFMEA-driven maintenance ensures that interventions are both targeted & data-driven, enhancing maintenance effectiveness (Certa & Galante, 2018). According performance perspective, the integration of PFMEA had been shown to produce measurable improvements in key reliability indicators, such as Mean Time between Failures and Mean Time to Repair. Unlike

routine maintenance, which may not address underlying failure causes, PFMEA-based planning identified root causes and addresses them proactively (M Piechowski et al., 2018).

Traditional maintenance strategies often distribute resources uniformly, leading to unnecessary maintenance actions and increased operational costs (Wannawiset & Tangjitsitcharoen 2019). In contrast, Process FMEA enables risk-based resource allocation, ensuring that maintenance efforts are concentrated on high-risk components & failure modes. This targeted approach minimizes redundant maintenance activities while preventing costly failures, thereby reducing total maintenance expenditure without compromising equipment reliability or efficiency (Anal et al., 2014).

Overall, the integration of PFMEA with PM provides a comparative advantage over conventional approaches by enhancing availability and optimizing maintenance costs. This makes it a highly suitable strategy for improving maintenance performance in resource-constrained and production-intensive environments such as the garment manufacturing industry (Ila et al., 2016). This integration significantly improves overall equipment effectiveness, which is influenced by availability and performance (Nagaraj et al., 2019).

Previous studies demonstrate that PFMEA effectively prioritizes machine failures using Risk Priority Numbers. However, limited studies have applied PFMEA to sewing-machine maintenance in Ethiopian garment industries.

2.9. Application of PFMEA in Preventive Maintenance Planning

2.9.1. Role of PFMEA in Maintenance Decision-Making

Preventive maintenance traditionally focuses on planned activities such as inspection, lubrication, adjustment, and replacement of machine components. However, conventional PM systems often apply uniform maintenance schedules across all machines without considering individual failure risk, which limits their effectiveness in complex manufacturing environments (Dedimas & Gebeyehu, 2019).

To address this limitation, Process Failure Mode & Effect Analysis can be integrated into PMP to support risk-based decision-making. PFMEA enables systematic identification of potential failure modes, evaluation of their effects on production, and assessment of associated risks using

the RPN. In this approach, maintenance activities are prioritized based on risk level rather than fixed time intervals, ensuring that critical failures receive higher maintenance attention (Farouk & Youssef, 2025).

The integration process begins with machine selection, followed by identification of failure modes and their effects. Subsequently, severity (S), occurrence (O), and detection (D) ratings were assigned to each failure mode, and the RPN is calculated to determine risk priority levels (Ta, 2018). Based on these results, high-RPN failure modes were prioritized for immediate preventive actions. These are then translated into specific maintenance tasks such as inspection, servicing, adjustment, or component replacement (M Piechowski et al., 2018).

Finally, continuous monitoring is required after implementation to evaluate system performance and reduce recurrence of failures. This integrated PFMEA-based approach ensures that preventive maintenance becomes data-driven, risk-focused, and more effective compared to conventional time-based maintenance systems (Parsana & Patel, 2014).

2.9.2. Long-Term Sustainability and Competitive Advantage

In highly competitive garment manufacturing environments, timely delivery and quality are critical success factors. PFMEA-based PM enhances operational stability, reduced variability, & strengthens production reliability. This contributes to Improved customer satisfaction, better on-time delivery performance, sustainable operational growth, enhanced competitive positioning (Kipchumba & Chemweno, 2024).

Furthermore, PM contributes to sustainable manufacturing practices by extending equipment lifespan and minimizing material waste caused by machine failures. Properly maintained equipment operates more efficiently, leading to lower operational costs. In addition, maintenance-driven reliability improvements can enhance worker safety and operational stability in industrial environments (Gomaa, 2025).

Existing studies show that integrating PFMEA with preventive maintenance improves maintenance planning and machine reliability. Nevertheless, few studies have implemented and evaluated such systems in garment manufacturing, justifying the present study.

Table 2-1: Literature gap of the study

Thematic Area	Authors and Years	Identified Gaps / Limitations	Methodology Adopted in This Study
Preventive vs. Reactive Maintenance	Sahoo (2021); Keller & Owen (2025); Thomas & Weiss (2020)	Maintenance in developing countries remains largely reactive (70-80%). PM programs are poorly implemented and sometimes lead to over-maintenance.	A risk-based PM system is developed using PFMEA. Machines are prioritized based on RPN values, & maintenance is scheduled as daily, weekly, monthly, & quarterly tasks to replace reactive practices.
Risk of Over-Maintenance	Keller & Owen (2025)	Over-maintenance may lead to unnecessary interventions and maintenance-induced failures.	RPN thresholds are introduced to classify failures into very high, high, medium, & low risk. Based on that machines get prioritization.
FMEA in Textile & Garment Industry	Dedimas & Gebeyehu (2019); Anal et al. (2014)	FMEA is mainly used for defect and rework reduction, not for structured maintenance planning, especially in sewing sections.	PFMEA is applied specifically for maintenance planning in sewing operations, linking failure modes directly to preventive maintenance actions.
Application in Developing Countries (Ethiopia)	Rundassa, Azene & Berhan (2019); Legesse & Singh (2014)	Limited studies in Ethiopia apply PFMEA to garment sewing sections; most focus on Lean or productivity tools rather than machine reliability.	This study provides a case study of Ethiopian garment industry, applying PFMEA to develop a practical maintenance plan for sewing machines.
Maintenance Performance Evaluation	Bokrantz et al. (2020); Psarommatis et al. (2023)	Few studies evaluate the effect of PFMEA-based PM on productivity, machine reliability, and downtime in garment manufacturing.	Evaluated the impact of the developed PM plan on machine downtime reduction, and production achievement.

2.10. Research gap

While a lot of research exists, there are still several critical gaps that this study addresses. Much of the existing literature many studies focus on general production improvement rather than maintenance planning for sewing machines. Research on garment manufacturing had mainly applied improvement tools to reduce defects, waste, and improve productivity, rather than focusing on machine maintenance strategies in the sewing section (Mulugeta, 2020).

Several studies have applied maintenance analysis using FMEA in other textile machinery such as knitting and weaving machines (Dedimas & Gebeyehu, 2019). But the application of this method to sewing machine maintenance in garment factories remains limited.

Existing research indicates that FMEA had been used mainly to identify failure modes and downtime in textile equipment, and only a few studies have developed practical PM strategies based on those results (Anal et al., 2014). Many garment factories, especially in developing countries, like Senmul garment still rely on corrective maintenance, where machines are repaired only after failure occurs that leads to frequent breakdowns, production delays, & reduced machine reliability (Defiatri & Damayanti, 2023).

Despite the proven effectiveness of PFMEA, a significant research gap remains in applying risk-based PM to sewing sections. Most existing studies lack a systematic framework for prioritizing sewing machine failures using RPN. Therefore, research integrating Process FMEA with PM is critically needed to transition from reactive to proactive maintenance (Farouk & Youssef, 2025).

2.11. Conceptual Framework of the Study

The conceptual framework of the study illustrates the relationship between machine failures, PFMEA analysis, PMP, & performance outcomes in the Senmul garment. Below figure 2.1 conceptual framework diagram (Textual Representation).

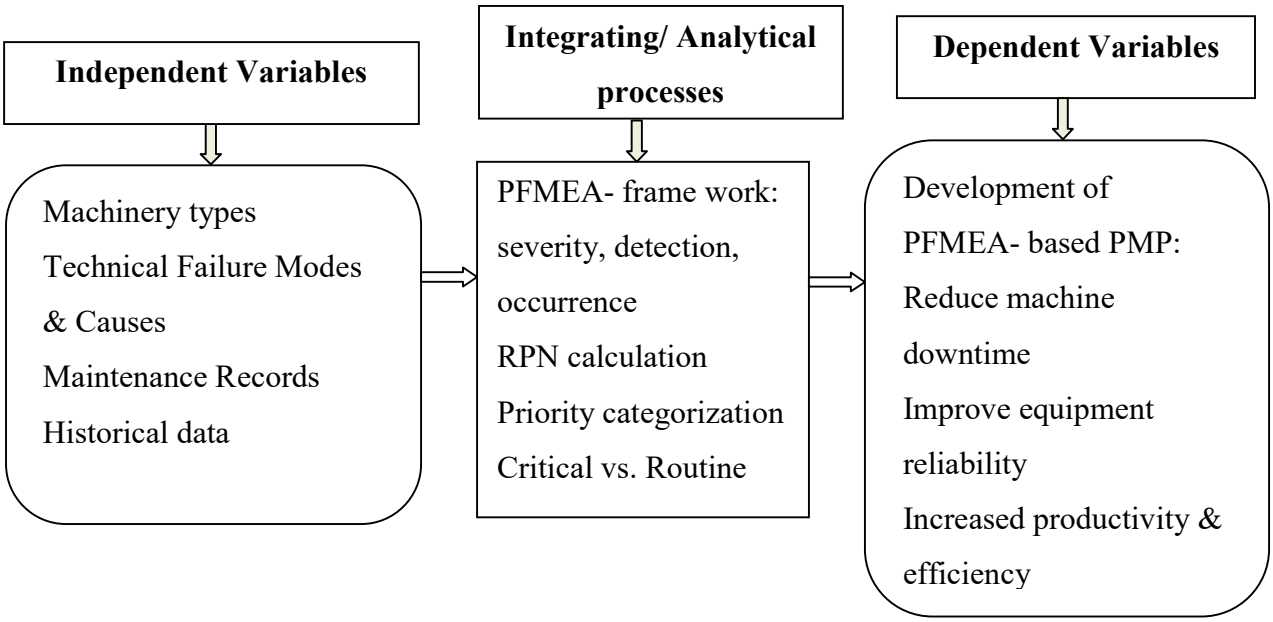


Figure 2.1: Conceptual Framework

CHAPTER THREE

3. METHODOLOGY OF THE STUDY

3.1. Introduction

This chapter presents the research methodology used to develop an integrated preventive maintenance system for sewing machines in the sewing section of Senmul Garment Plc. The chapter includes research design, data collection methods, PFMEA procedures, machine criticality evaluation, and the development of the proposed preventive maintenance framework. The methodology was designed to identify critical machine failures, evaluate machine risks, and develop a maintenance prioritization system that improved machine reliability & production continuity.

3.2. Study Area

In this study Senmul Garment Plc was the case company located in Akaki Kality Sub- City, Addis Ababa, Ethiopia. It's a private male & female shirt manufacturing company that was founded in 2004 EC and incorporated in Addis Ababa, Ethiopia. Variety of shirts for males and females were produced by the company for domestic markets and industrial consumers, operating within the apparel and ready-made garment industry. This research was conducted from January, 2026 up to May 2026. Figure below 3.1 showed Senmul sewing production area.



Figure 3.1: Sewing Production

3.3. Research Approach and Design

This study used a convergent mixed-methods design within a case study framework to assess machine maintenance and failure conditions in the sewing section of Senmul Garment Plc. This approach combines qualitative and quantitative methods for a full understanding of the problem. The qualitative part focused on machine failure causes, operator practices, maintenance activities, and workplace conditions using interviews and direct observation. The quantitative part analyzed machine downtime, breakdown frequency, questionnaire data, and PFMEA results to measure maintenance performance. Both methods were integrated to improve the reliability and completeness of the findings. PFMEA was used to link the two by converting qualitative failure data into quantitative RPN for prioritizing critical machine failures.

In this study, PFMEA was chosen because the sewing section of Senmul Garment PLC experienced frequent machine failures without a structured preventive maintenance program. PFMEA helped identify the most critical failure modes, prioritize them based on risk, and develop a preventive maintenance plan to reduce downtime and improve production performance. It also provided a structured way to identify failure modes, analyze causes & effects, & prioritize risks in garment production where machine failures directly affect productivity, quality, and continuity.

The combination provided both measurement and explanation. The sewing section was selected because it was the core production area where machine failures directly disrupt the entire line, making it ideal for studying maintenance problems. Senmul Garment Plc was chosen due to frequent machine breakdowns, high downtime, and reliance on corrective maintenance, making it suitable for developing a PFMEA-based preventive maintenance system (Chandra Sheel, 2025). Figure below showed research flow diagram.

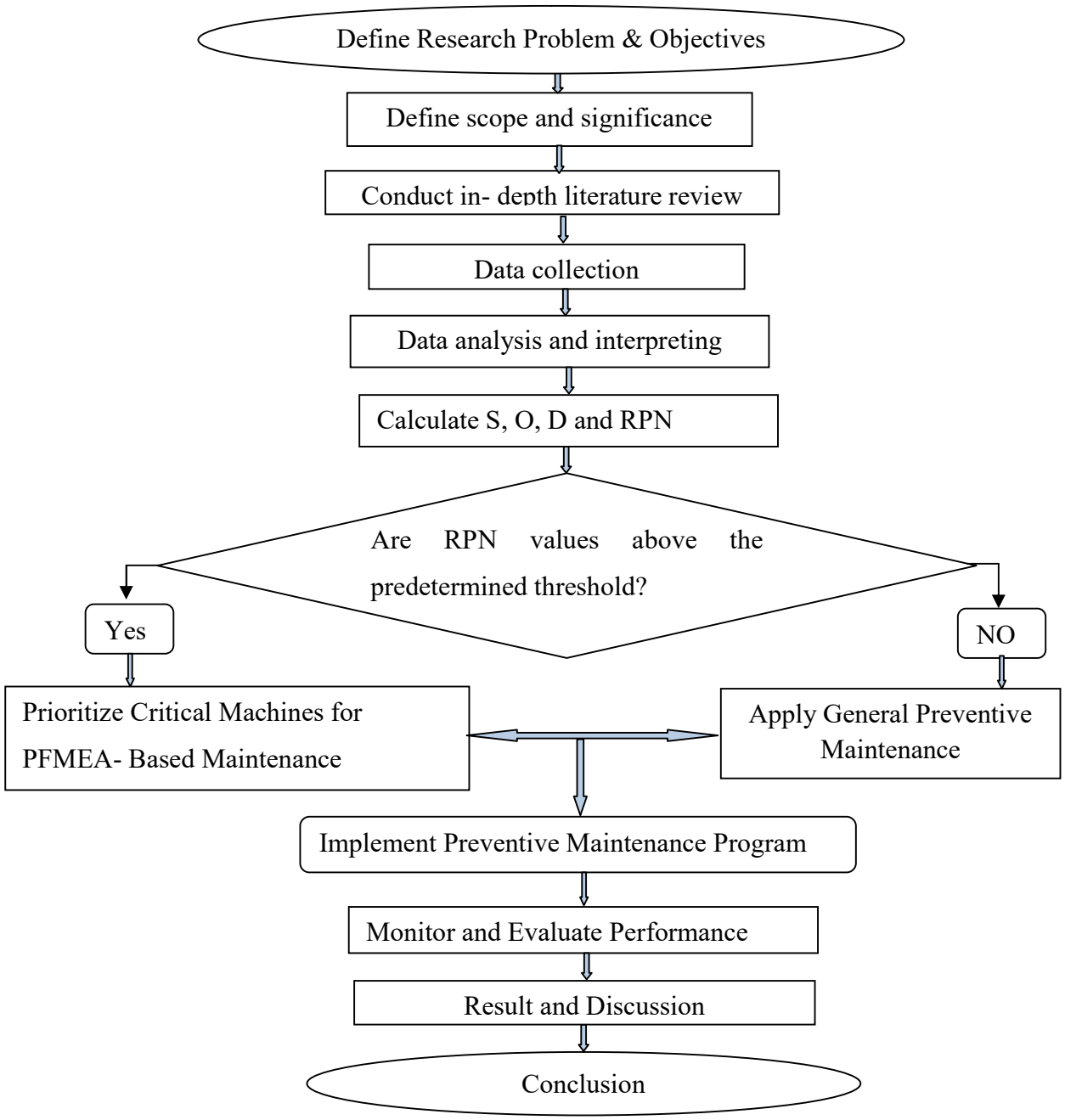


Figure 3.2: Research methodology schematic flow diagrams

3.4. Sources of Data

In this study primary and secondary data source was used. The primary data referred to information collected directly from sources related to the research problem. The data include observation, survey questionnaires, interviews, photos.

Secondary data: is information that had already been collected, analyzed or published by others can be obtained from relevant books, journals, articles, by using internets in different website like Google scholar and company records. Together these types and sources provide a comprehensive foundation for understanding the research problem and supporting evidence based conclusion.

3.5. Target Population and Sampling

3.5.1. Target Population

The target population of the study employed working in the sewing production of Senmul Garment Plc, including machine operators, maintenance technicians, production supervisors, quality supervisors, checkers, production executives, production managers and other concerned personnel. From this population respondents were selected for the study using mixed quantitative and qualitative approaches. Among them, 76.85% respondents participated in quantitative data collection through questionnaires, while 23.15% participants were involved in interviews.

A combined purposive & stratified random sampling approach was employed. Purposive sampling targeted key personnel maintenance technicians, supervisors, and managers who have direct experience with machine maintenance and failure identification.

Stratified random sampling was applied to sewing machine operators across different production lines to ensure proportional representation of various machine types and operational sections. This combination allowed the collection of both expert-informed and representative data, enhancing the reliability and validity of the study findings (Quarcoo & Akomaning, 2022).

3.5.2. Determination of sample size

The sampling frame was being a list of employed working in the garment factories at Senmul Garment Industry. This list can be obtained from the human resources department of each

factory. Determining the sample size depends on the total number of employed in the garment factories at Senmul and other Garment Industries. A common rule of thumb is to use a sample size calculator to ensure a confidence level of 95% and a margin of error of 5%. There were 148 total populations by excluding employed not concerned with the study; a sample size of around 108 would be needed. The calculation was done by using Yamane formula.

By using Yamane formula $n = \frac{N}{1+N(e)^2} = \frac{148}{1+148(0.05)^2} = \frac{148}{1.375} = 108.03 \approx 108$

Where: n= sample size N= Population and e= constant error term (0.05) (Louangrath, 2018). The required sample size was calculated using the Yamane formula, resulting in 108 participants. This method ensured accuracy and representativeness while accounting for population variability and optimizing cost-effectiveness in data collection (Yamane, 1967) .

3.6. Methods of Data Collection

Data for the study were collected using direct observation, interviews, maintenance records, and production reports from the sewing section.

3.6.1. Questionnaires

To effectively address the research objectives, structured questionnaires were employed as a primary data collection instrument. These questionnaires were specifically designed to identify operational failures & challenges hindering the implementation of PMP at Senmul Garment Plc to improve the productivity & to minimize machine failures. The targeted items in the questionnaire were designed to assess perceived obstacles affecting maintenance performance and production efficiency in garment manufacturing. These obstacles include frequent machine breakdowns, reduced production output, increased product defects, reliance on corrective maintenance, inadequate preventive maintenance practices (such as poor cleaning and lubrication), and weak maintenance documentation systems. The respondents were asked to respond to each of the statements in terms of five degrees. The responded in one of the following ways: 1= Strongly Disagree, 2= Disagree, 3= Neutral, 4= Agree and 5= Strongly Agree.

3.6.2. Semi-structured interviews

Qualitative data were collected through semi-structured interviews to examine the influence of maintenance management practices and supervisory approaches on machine reliability and production performance within the garment manufacturing environment. The interviews facilitated an in-depth exploration of participants, perceptions, and operational challenges related to machine breakdowns, PM implementation, and maintenance response systems.

A thematic analysis approach was employed to systematically identify recurring patterns, root causes of failures, and gaps in existing maintenance practices. Furthermore, the qualitative findings provided contextual and explanatory insights that supported the interpretation of quantitative results and informed the development of a risk-based preventive maintenance framework. This integrative approach enhanced the overall validity and robustness of the study.

3.6.3. Direct production Observations

Direct observation was conducted in the sewing section to identify machine failure conditions, machine operating practices, and maintenance activities. During the observation, machine breakdown conditions, maintenance responses, downtime duration, and production interruptions were systematically recorded by PFMEA recording sheet. This firsthand look helped gather practical details about the companies' actual working conditions and any maintenance aspects in play. Photographs were also captured to document these observations, offering insights that might not come up in interviews or surveys.

3.7. Structure of the Questionnaire

The questionnaire is designed to comprehensively assess factors related to machine operation, maintenance practices, and their impact on production performance. It begins with a section for demographic information, collecting details such as age, job role, & years of experience. The main section includes closed-ended questions to capture participants' perceptions of machine reliability, maintenance procedures, workload, and management support.

Likert scale items were used to measure participants' perceptions, experiences, and attitudes regarding three main aspects related to sewing machines and production. Open-ended questions were included to gather qualitative feedback on personal experiences, challenges faced, and

suggestions for improving preventive maintenance. This mixed-method approach ensures a complete understanding of how maintenance practices affect both machine performance and employed productivity within the sewing section.

3.8. Validity and Reliability

Ensuring the reliability and validity of research findings is critical for ensuring the accuracy, consistency, and credibility of the study's results. The following sections outline how these two essential components were addressed in this study.

3.8.1. Validity of the Study

The validity of this study was ensured through the use of appropriate data collection & analysis methods aligned with the research objectives. Questionnaires and interviews were reviewed by experts and advisors before data collection. Triangulation techniques were used to compare information obtained from different sources for consistency and accuracy. A pilot test was conducted to enhance the clarity and reliability of the research instruments. Both quantitative & qualitative data were systematically analyzed using standard statistical and thematic analysis methods. These procedures contributed to improving the credibility & accuracy of the study's findings.

3.8.2. Reliability of the Study

Several methodological controls were put in place to guarantee the reliability of the study's conclusions. First, an initial pilot test that reduced answer error and removed item ambiguity proved content validity and clarity. Second, to confirm the survey instruments' internal consistency & dependability in assessing the target maintenance constructs, Cronbach's Alpha coefficients were computed. Additionally, by using a systematic sample design throughout the Senmul Garment workforce and keeping a consistent period for data collection, selection and temporal biases were reduced. When taken as a whole, these stringent data-cleansing and design validation procedures guarantee a solid empirical basis for creating the suggested preventive maintenance framework.

To establish the reliability, the researcher was employed the test of Cronbach's alpha value using SPSS version 23 software. Many studies agree that a Cronbach's alpha coefficient of 0.7 is good

enough measure of an instrument of internal consistency (Taber, 2018). According to Wong et al., (2022) an alpha coefficient below 0.5 is unacceptable but from 0.5 up to (but not including) 0.6 is poor, from 0.6 up to (but not including) 0.7 is questionable; from 0.7 up to (but not including) 0.8 is acceptable, from 0.8 up to (but not including) 0.9 is good, & an alpha of 0.9 or higher is excellent.

3.8.3. Pilot Testing and Reliability Analysis

A two-step validation procedure was used to ensure the validity and reliability of the data collection instruments. First, the questionnaire was reviewed by the research adviser to assess its content validity, clarity, and relevance to the operational context of Senmul Garment PLC. Based on the feedback, necessary revisions were made. Second, a pilot test was conducted with 25 employees of Senmul Garment PLC to identify ambiguities, evaluate the questionnaire's practicality, and improve its reliability. Feedback from the pilot study was used to refine the instrument before the main data collection.

Table 3-1: Alpha Value Of Pilot Test Result

Variable group	Cronbach's Alpha values	N of Items	N of Items
Machine Failure Causes (A)	.943	5	Excellent
Maintenance Practices and System Effectiveness (B)	.956	6	Excellent
Production Performance Impact (C)	.894	4	Good

Above Table 3.1 presents the reliability analysis using Cronbach's Alpha. All coefficients exceeded the recommended threshold of 0.70, indicating strong internal consistency. Therefore, the questionnaire was considered reliable and suitable for statistical analysis.

3.9. PFMEA Implementation Methodology

3.9.1. PFMEA Procedure and Risk Evaluation

PFMEA was used to identify potential failure modes, their causes, and their effects on production performance. Each failure mode was evaluated using Severity, Occurrence, and Detection ratings on a standardized 1-10 scale based on maintenance records, production observations, machine conditions, and expert judgment. The Risk Priority Number (RPN) was then calculated to rank failure modes according to their maintenance priority and risk level. (Dedimas & Gebeyehu, 2019).

Severity (S); In this study severity was mainly evaluated based on the level of production disruption & machine downtime caused by the failure. Higher severity ratings indicate failures that create greater production interruption & loss of target output (Rahmawati et al., 2023).

Table 3-2: Severity Rating Criteria

Downtime Duration	Severity Rating	Interpretation
< 5 minutes	4	Minor disruption with negligible impact on production
5 - 15 minutes	5- 6	Moderate disruption with limited production loss
15 - 30 minutes	7- 8	Significant disruption affecting production efficiency
> 30 minutes	9 -10	Critical disruption causing major production loss

Source: (Choudhary et al., 2018)

Occurrences (O); It is measured based on the observed number of failures per machine per day. A higher occurrence rating indicates that the failure happens more frequently and poses a greater risk to production continuity.

Table 3-3: Occurrence Rating Criteria

Failure Frequency	Occurrence (O)	Interpretation
≥ 5 times/day	10	Very high (almost constant)
3-4 times/day	9	Extremely frequent
2 times/day	8	Very frequent
1 time/day	7	Frequent
1 time every 2 days	6	Moderately frequent
1 time per week	5	Occasional
1 time per 2 weeks	4	Low frequency
1 time per month	3	Rare
1 time per 3 months	2	Very rare
< 1 time per 3 months	1	Almost never

Source: (Kipchumba & Chemweno, 2024).

Detection (D); It's the ability of existing control mechanisms to identify a failure before it occurs or before it affects production (Choudhary et al., 2018).

Table 3-4: Detection Rating Criteria

Detection Capability	Detection (D)	Interpretation
Almost certain detection	1	Failure was almost always be detected
Very high chance of detection	2	Detected with minimal effort
High chance of detection	3	Easily detected by operators
Moderately high detection	4	Detected under normal inspection
Moderate detection	5	Sometimes detected
Low detection	6	Often missed
Very low detection	7	Rarely detected
Remote detection	8	Very difficult to detect
Very remote detection	9	Almost impossible to detect
No detection method available	10	Failure cannot be detected

3.9.2. Risk Priority Number (RPN) Calculation

The Risk Priority Number (RPN) is a quantitative metric used in PFMEA to assess and prioritize potential failure modes based on their risk (Parsana & Patel, 2014). It is calculated by combining the three risk parameters: RPN=S×O×D

Where: S = Severity of the failure mode

O = Likelihood of occurrence

D = Ability to detect the failure before it occurs

The resulting RPN value provides a numerical representation of the overall risk, with higher values indicating failure modes that are more critical and require immediate attention. By ranking failure modes according to their RPN values, the most significant risks can be identified, and preventive maintenance actions can be prioritized accordingly (Pazireh et al., 2017).

3.9.3. RPN Values of Risk Classifications

This classification system was adapted to the operational conditions of garment manufacturing sewing machines, considering machine downtime severity, production interruption, & maintenance criticality within the sewing department (Agustina, 2019). To prioritize maintenance activities, RPN values were categorized into four risk levels as follows:

Table 3-5: Risk Priority Number values

No	RPN value	Risk level	Action taken
1	> 250	Very High	Immediate preventive & corrective action required
2	150-250	High	Prioritized PM & increased inspection frequency
3	80-149	Medium	Scheduled maintenance & regular monitoring
4	< 80	Low	Routine inspection & normal maintenance activities

3.10. Development of Proposed Preventive Maintenance Framework

The proposed PM framework integrates PFMEA with a preventive maintenance program (PMP) for sewing machines. Failure data were collected through observations, maintenance records, and production reports. PFMEA was then applied to identify failure modes, assess their risks, and

prioritize critical machines for structured, risk-based maintenance (Antosz et al., 2021). Based on the PFMEA results the PM framework was developed using two maintenance approaches.

The first approach is PFMEA based priority, where machines that have high production impact & high RPN values receive priority of PM attention. These critical machines were assigned frequent inspections, planned replacement of worn components, adjustments, lubrication, & closer follow up to reduce work interruptions (Parsana & Patel, 2014).

The second strategy applies a general PM cycle to all sewing machines, irrespective of the degree of risk. To maintain overall machine condition and lower common operational failures, this standardized maintenance system includes routine inspection, cleaning, lubrication, and basic machine adjustment tasks (Krynke et al., 2022). The integration of PFMEA based priority maintenance with the general PM cycle helps direct maintenance efforts toward high risk machine failures while maintaining the operational condition of all sewing machines within the production system. Below figure 3.3 showed proposed PM framework.

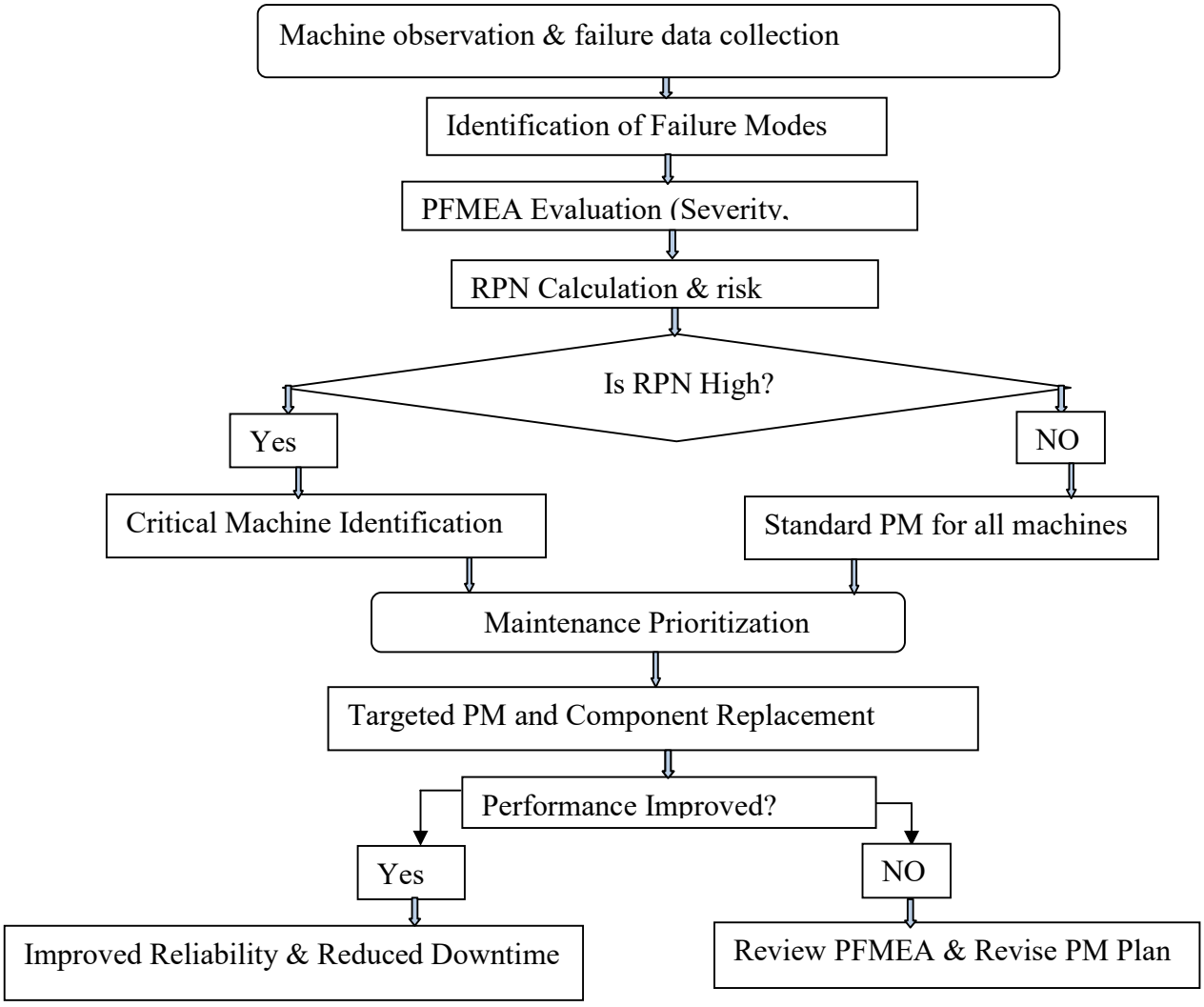


Figure 3.3: Proposed PM Framework.

3.10.1. Development Procedure of the PM Program

Collection of failure data; Machine failure, downtime, and maintenance data were collected through observations, maintenance records, interviews, and questionnaires.

PFMEA analysis; PFMEA was applied to identify potential failure modes, determine their causes and effects, and evaluate associated risks.

RPN ranking; Risk Priority Numbers (RPNs) were calculated and ranked to prioritize failure modes according to their risk levels.

Identification of critical machines; Machines with the highest RPN values were identified as critical and selected for priority maintenance actions.

Development of maintenance schedules; Preventive maintenance schedules were developed based on machine criticality, failure characteristics, and recommended maintenance intervals.

3.10.2. Maintenance Prioritization Logic

It's a systematic, data-driven decision framework used to determine which equipment or failure modes receive immediate resources and which can be scheduled later. In an industrial sewing section, it prevents maintenance teams from falling into a purely reactive firefighting loop by objectively categorizing urgency.

Table 3-6: Maintenance Prioritization Logic

RPN Level	Risk Level	Card Color	Maintenance Decision
>250	Very High	Red	Immediate PM & corrective action
150-250	High	Yellow	Prioritized PM and close monitoring
<150	Medium/Low	Green	Routine PM

3.11. Data Analysis and presentation Techniques

Quantitative data were analyzed using descriptive statistics, including frequencies and percentages to summarize operational trends and failure occurrences. Correlation analysis was also conducted to explore relationships between maintenance practices and machine reliability (Mcbeath, December 2020). For systematic processing, the quantitative data were initially organized and cleaned in Microsoft Excel before being imported into SPSS for advanced statistical analysis, including trend identification and hypothesis testing (Arkkelin, 2014). Qualitative data obtained from interviews were analyzed using thematic analysis to identify recurring patterns, root causes of machine failures, and operational challenges (Levitt et al., 2018).

And observations data analyzed in, tables, pie chart & graphs. Results of the observation & interviews were integrated with quantitative results through triangulation, enhancing the validity of the findings and supporting the development of a risk-based PM framework (Peters & Fàbregues, 2024). This combined approach ensured that the analysis captured both statistical trends and contextual insights, enabling informed decision-making and prioritization of PM interventions in the garment production process.

3.12. Ethical Considerations

After receiving formal permission to conduct this study from the management of Senmul garment plc prior to data collection. The purpose, scope, and academic nature of the research were clearly explained to ensure transparency and institutional cooperation (Roshaidai & Arifin, 2018). Participants were also informed of their right to decline or withdraw from the study at any stage without any negative consequences. According to Arifin, S. R. M. (2018), the protection of human subjects through the application of appropriate ethical principles is important in all research study. Data were collected and reported honestly, without fabrication, falsification, or misrepresentation of information.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

This chapter presents the analysis of collected data, machine failure assessment, PFMEA evaluation results, development of the PM framework, & implementation outcomes. The chapter also discusses machine downtime analysis, risk prioritization, and improvements achieved after applying the developed PM system.

4.2. Existing Maintenance Practice of Senmul garment

The findings of the study revealed that maintenance activities within the sewing section of Senmul Garment Plc were primarily reactive in nature. Machines were commonly repaired only after breakdown occurrence, while structured PM activities such as scheduled inspection, lubrication, calibration, and preventive spare-part replacement were inconsistently practiced. Observation results further showed inadequate maintenance documentation systems, irregular machine cleaning practices, and limited operator participation in basic maintenance activities.

This maintenance condition contributed to repeated machine failures, unstable production flow, and increasing machine downtime within the sewing section. The result supports the literature discussed under preventive versus reactive maintenance, where Sahoo (2021), and Keller & Owen (2025), explained that garment industries in developing countries continue to depend heavily on breakdown maintenance systems due to production pressure and limited maintenance planning. Similarly, Hbbard (2017), stated that preventive maintenance is often neglected in garment industries because management prioritizes immediate production output over long-term machine reliability.

The observed maintenance condition at Senmul Garment Plc confirms that lack of structured maintenance systems directly reduced equipment reliability and production continuity. Furthermore, the study findings indicate that insufficient machine cleaning and lubrication accelerated component wear, resulting in timing problems, thread breakage, excessive vibration, and unstable stitch quality.

This supports the explanation provided by Ramzan et al., (2022), who emphasized that improper lubrication and accumulation of lint & dust significantly increase friction and wear in sewing machines, thereby increasing operational failures and machine downtime. Therefore, the current findings demonstrate that the absence of systematic PM practices significantly contributed to poor machine reliability and inefficient production performance within the sewing section.

4.3. Data Analysis from Questionnaires

4.3.1. Demographic Characteristics of Respondents

The majority of respondents, 62 (74.7%), were aged between 20-29 years, while 68 (81.9%) were female. Regarding educational qualification, most respondents held a diploma 29 (34.9%) or bachelor's degree 27 (32.5%). In terms of job position, machine operators represented the largest group with 60 (72.5%) respondents, indicating that most participants were directly involved in sewing operations. Concerning work experience, 42 (50.6%) respondents had 6-10 years of experience, while 38 (45.8%) had less than five years of experience. This showed that the respondents had adequate practical experience related to garment production and machine maintenance activities.

The majority of respondents were machine operators, accounting for 72% of the total respondents, indicating that most participants were directly engaged in sewing production activities. The remaining respondents included checkers, maintenance technicians, quality supervisors, production managers, production supervisors, industrial engineers, and other staff with smaller proportions. This distribution showed that the study mainly focused on employed directly associated with garment production operations. Table below clearly showed;

Table 4-1: Demographic characteristics of respondents

Demographic characteristics		Frequency	Percent (%)
Age group	20-29	62	74.7
	30-39	15	18.1
	40-49	3	3.6
	50+	3	3.6
	Total	83	100

Gender	Male	15	18.1
	Female	68	81.9
	Total	83	100
Academic qualification	10+ and/or 12+	24	28.9
	Diploma	29	34.9
	Bachelor Degree	27	32.5
	Masters	3	3.6
	PhD	0	0.0
	Total	83	100
Position	Production manager	1	1.2
	Production supervisor	1	1.2
	Checker	4	4.8
	Maintenance technician	2	2.4
	Quality supervisor	2	2.4
	Machine operator	60	72.5
	Industrial Engineer	1	1.2
	Other	12	14.5
	Total	83	100
Years of experience	Less than 5	38	45.8
	6-10	42	50.6
	11-15	3	3.6
	16+	0	0.0
	Total	83	100

SPSS Result Output (2026).

4.3.2. Response of Questionnaires

The questionnaire survey was conducted to assess respondents' perceptions regarding sewing machine failures, existing maintenance practices, and the impact of machine problems on production performance. The collected Likert-scale data were analyzed using descriptive statistics, including frequency distribution, mean score, and interpretation. This analysis supports the identification of existing maintenance problems and contributes to answering the research questions related to machine failure causes and maintenance practices.

Table 4-2: Descriptive Statistics of Likert Scale Responses (n = 83)

No.	Questionnaire Item	SD	D	N	A	SA	Mean	Interpretation
1	Machine breakdowns often occur during production.	3	6	10	46	18	4.84	Agree
2	Breakdown of sewing machines frequently occurs during operations.	4	9	25	35	10	3.46	Agree
3	Lack of proper lubrication contributes to machine failures.	2	5	8	43	25	4.01	Agree
4	Inadequate cleaning of sewing machines leads to breakdowns.	1	2	5	30	45	4.40	Strongly Agree
5	Different machine failures significantly affect production performance.	2	4	10	48	19	3.94	Agree
6	Machines are inspected regularly in the sewing section.	6	18	27	24	8	3.12	Neutral
7	Sewing machines are cleaned regularly.	12	24	22	18	7	2.81	Neutral
8	Proper lubrication is consistently performed.	11	23	24	18	7	2.84	Neutral
9	Maintenance technicians respond quickly when machines fail.	7	16	25	27	8	3.16	Neutral
10	Maintenance records are properly documented.	13	25	21	17	7	2.76	Neutral
11	Preventive maintenance reduces repeated failures.	1	2	4	28	48	4.45	Strongly Agree
12	Machine failures reduce daily production targets.	4	8	24	36	11	3.51	Agree
13	Corrective maintenance causes production delays.	1	2	5	25	50	4.46	Strongly Agree
14	Machine problems can lead to garment defects.	2	5	9	46	21	3.95	Agree
15	Preventive maintenance improves production achievement.	1	2	4	26	50	4.47	Strongly Agree

Scale: SD = Strongly Disagree, D = Disagree, N = Neutral, A = Agree, SA = Strongly Agree.

Table 4-3: Construct Summary

Construct	Number of Items	Mean	Interpretation
Machine Failure Causes	5	4.13	Agree
Maintenance Practices	6	2.95	Neutral
Production Performance	4	4.10	Agree

The questionnaire responses from 83 participants were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree)**.** The descriptive analysis indicated that respondents generally agreed that machine failures frequently occur and significantly affect production performance (overall mean = 4.13). However, respondents expressed neutral perception**s** regarding the effectiveness of existing maintenance practices (overall mean = 2.95), suggesting weaknesses in inspection, lubrication, cleaning, maintenance response, and documentation systems. Respondents also agreed that preventive maintenance improves production performance and reduces repeated failures (overall mean = 4.10). These descriptive findings support the subsequent reliability, correlation, and regression analyses by providing an initial understanding of respondents' perceptions.

4.4. Reliability and Statistical Analysis

Reliability Analysis

To ensure the reliability of the questionnaire, Cronbach's Alpha coefficients were calculated for each of the three thematic scales. According to academic standards, a Cronbach's Alpha based on standardized items value above 0.70 is considered acceptable, while values above 0.90 indicate excellent reliability (Izah et al., 2024).

Table 4-4: Reliability Analysis

	No. of Items	Cronbach's Alpha	Interpretation
Failure Causes & Occurrence	5	.947	Excellent
Maintenance Detection Controls	6	.956	Excellent
Production Performance & Outcomes	4	.902	Excellent

SPSS Result Output (2026)

As shown above in the table 4.4 showed excellent internal consistency, with Cronbach's Alpha values above 0.90. Failure Causes & Occurrence (α = 0.947) showed high reliability in measuring machine breakdowns, operational failures, lubrication problem, cleaning deficiencies, & failure impacts. Maintenance detection controls (α = 0.956) reliably represented inspection practices, lubrication consistency, technician response, documentation, & PM effectiveness. Production Performance & Outcomes (α = 0.902) consistently measured production loss, maintenance delays, garment defects, and maintenance efficiency. Overall, the reliability analysis confirmed that the research instrument was highly reliable and suitable for further PFMEA analysis, RPN calculation, and PMP development.

Correlation Analyses

All correlation coefficients were positive & statically significant at $p < 0.01$, indicating strong relationships among the three PFMEA dimensions. Failure causes & occurrence showed a very strong positive correlation with maintenance detection controls (r = 0.897), suggesting that increased machine failures were associated with weak maintenance responses and detection practices.

Table 4-5: Correlation Analyses

Construct Pair		Failure Causes & Occurrence	Maintenance Detection Controls	Production Performance & Outcomes	Interpretation
Failure Causes & Occurrence (A)	Pearson Correlation	1	.897	.867	Strong, positive, significant
	Sig. (2-tailed)		.000	.000	
	N	83	83	83	
Maintenance Detection Controls (B)	Pearson Correlation	.897	1	.917	Strong, positive, significant
	Sig. (2-tailed)	.000		.000	
	N	83	83	83	
Production Performance & Outcomes (C)	Pearson Correlation	.867	.917	1	Very Strong, positive, significant
	Sig. (2-tailed)	.000	.000		
	N	83	83	83	

SPSS Result Output (2026).

As shown in the table 4.5 above failure causes & Occurrence also had a strong positive correlation with Production Performance & Outcomes (r = 0.867), indicating that higher machine failures lead to greater production losses, delays, and garment defects. The strongest relationship was observed between maintenance detection control & production performance and outcomes (r= 0.917), confirming that effective maintenance practices are closely linked to improved production performance & reduced failure severity. Overall the strong & significant correlations validate the PFMEA framework applied in this study & support the calculation of RPN & the development of a PMP for the sewing machines of Senmul garment.

Analysis of Variance (ANOVA)

The ANOVA table tests show that overall significance of the regression model whether the independent variables collectively predict the dependent variable better than the mean.

Table 4-6 Regression model

Model		Sum of Square	Df	Mean Square	F	Sig.
1	Regression	867.916	2	433.958	228.925	.000[b]
	Residual	151.650	80	1.896		
	Total	1019.566	82			

SPSS Result Output (2026)

The ANOVA table test above 4.6 shows that the overall regression model is a good fit for the data collected at the factory. The calculated F-statistic, F-value is 228.925, which is quite high, suggesting the model had a significant predictive power. Significance level, the “Sig.” value is .000; which is well below the standard threshold of 0.05. This confirms that the relationship between the PFMEA factors & the maintenance outcome is statistically significant & did not occur by chance.

Regression Coefficient

The coefficient table below provides the individual role of each independent variable to the regression model. It includes unstandardized coefficients (B), standardized coefficients (Beta), & t-statistic & significance value.

Table 4-7: Regression Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.378	.522		2.641	.010
	A	.169	.073	.226	2.316	.023
	B	.443	.061	.714	7.310	.000

SPSS Result Output (2026).

The coefficients table 4.7 allows seeing the specific contribution of each factor (A&B) to the maintenance plans success. Variable impact B showed a stronger influence on the outcome than factor A, with a standardized beta of .714 compared to A's .226. Predictive strength, both predictors were statistically significant, as their individual p-values (Sig.) are .023 & .000, respectively. And the regression equation, based on the unstandardized coefficients (B), the predictive model for the research can be expressed as: C = 1.378 + 0.169(A) + 0.443(B). A, B & C stands for (A) failure causes & Occurrence, (B) maintenance detection Controls, (C) production performance & outcomes.

PFMEA analysis was conducted to systematically identify sewing machine failure modes, their causes, effects, and risk levels. Severity, Occurrence, and Detection ratings were assigned, and the Risk Priority Number (RPN) was calculated to prioritize critical failures requiring preventive maintenance actions. This analysis addresses the objective of identifying critical machine failures and developing a risk-based preventive maintenance program.

4.5. Interview and Observation Data Analysis

Open Ended Interviews

The qualitative data was gathered through semi structured interviews & observations conducted between March 4, 2026 and April 27, 2026, at Senmul garment. The investigation follow a thematic approach to spot frequent pattern regarding develop PMP. Interviews were conducted with twenty five respondents of Senmul garment maintenance technicians, production managers, quality team, production supervisors, executives and senior machine operators in the sewing section of Senmul Garment Plc to assess the existing maintenance practices and machine failure conditions.

The people who were interviewed said that the way things are done now to keep the machines working is not very good. They only fix the machines when they break down of doing things to prevent them from breaking down in the first place. The interview analysis showed that maintenance is mainly done after something goes wrong than before. The people who were interviewed said that this is because there is no schedule for checking the machines to make sure they were working properly and there is no list of things to check. The sewing machine maintenance is a problem.

The people who were interviewed said that the machines break down a lot because they are not taken care of properly. They said that the machines are not lubricated enough and that dirt and lint build up inside them. The common problems with the sewing machines are when the needles break, when the thread gets tangled, when the timing is off when the motor comes loose and when the parts wear out. The people who were interviewed also said that sometimes the machines break down in ways that're hard to notice like when the bearings or motor go bad. This means that the machines can break down completely before anyone realizes there is a problem and it takes a time to fix them.

The analysis of the interviews also showed that the people in charge of maintaining the machines do not have a system for checking to see if the machines are working properly. They only check the machines when they break down of doing regular checks to make sure everything is okay. This means that problems with the machines can get worse and worse before anyone notices and it makes it harder to fix them. The people who were interviewed said that this is a problem because it affects the quality of the repairs how well the machines work, the quality of the stitching and how much work gets done. The interview results also showed that when the machines break down a lot it causes a lot of problems. The production line gets. It is hard to get everything done on time.

The people who were interviewed said that this costs a lot of money & that it would be better if they had a plan in place to prevent the machines from breaking down in the place. They said that if they had a plan for maintaining the machines they could fix problems before they get serious & everything would work better. The people who were interviewed thought that using a kind of plan called a PFMEA-based preventive maintenance plan could help them prioritize what needs to be fixed and make a schedule, for maintaining the machines. They thought this could help reduce downtime and make the production line work better.

Close Ended Interviews

The survey results show that the company mostly does corrective maintenance reported by 85% of respondents is the dominant practice and the remaining answers other. This means the company mostly waits for things to break before fixing them of trying to stop them from breaking in the first place. When it comes to who does the maintenance 94% of the people who answered the survey said that technicians are in charge of maintenance. 5% said that operators do the maintenance and 1% said that external technicians do it.

As for taking care of the machines 55% of the people who answered the survey said that they only clean and lubricate the machines after they break down. Some people, 25% said they do this every week. Fewer people, 15% said they do it every day and 5% said they do it every month. This showed that the company is not very good at taking care of the machines to prevent problems. The Single Needle Lockstitch machines were the ones that break down the most. The Button Attach machines break down rarely but it had a big impact, on production. This is what the survey found out about the machines. The company needs to pay attention to the SNLS and buttons attach machines to prevent breakdowns and keep production continuing.

Analysis of Observation and Recorded Data

In the shop floor with the sewing machines to see what was going wrong & how it was affecting production. To keep track of things like what kind of machine was being used what was going wrong with it & how long it was not working. This information helps us understand what is really happening on the shop floor. It was help us do more research using special techniques, like PFMEA to come up with a good plan to stop problems before they happen.

Based on the identified high-risk failure modes from the PFMEA analysis, a preventive maintenance program was developed. Maintenance activities, frequencies, and responsible

personnel were assigned according to failure criticality to ensure that the developed program directly addresses the major causes of machine downtime.

Table 4-8: Machine failure recorded data

Machine type	Failure mode	Effect	Root cause	Downtime	Severity	occurrence	detection	RPN
Button hole/ 01S0203	Increased friction and overheating	Created by absence of lubrication	Create high WIP	35	9	5	4	180
Button Attach/ 01S0503	Sensor failure	High WIP lead to over time	Dust, electrical fault	25	10	3	10	300
SNLS/ 01S0128	Thread breakage	Minor stoppage	Poor threading, lint	15	1	9	4	36
Button attach/01S0601	Fabric not feeding smoothly	Dirt accumulation, poor lubrication	Uneven button holes,	10	3	5	7	105

As shown in the above table 4.8 RPN value can be calculated as RPN= S×O×D; First row of table 4.8 showed RPN value = 5×8×4=180, (150-250) indicates high (prioritized PM & increased inspection frequency).Second row of table 4.8 showed RPN value = 10×3×10=300, (>250) indicating very high (immediate preventive & corrective action required). Third rows of table 4.8 showed RPN value =1×9×4= 36, (<80) indicating low risk (routine inspection & normal maintenance activities). Fourth rows of table 4.7 showed RPN value = 3×5×7=105, (80-149) indicating medium risk (schedule maintenance and regular monitoring). The full recorded data placed in the Appendices C.

Table 4-9: Critical machines identification

Rank	Machine Type	Observation
1	SNLS	Highest failure frequency and repeated stoppages
2	Button Attach	Highest production impact
3	Button Hole	High quality-related defects
4	DNCS	Moderate failures affecting seam quality
5	Edge Cutter	Wear-related issues, cutting inconsistency problems causing trimming quality issues & downtime.
6	FOA	Feeding problems and fabric slippage frequently affected seam consistency and machine performance
7	Over lock	Moderate level of thread breakage, uneven stitching, and knife wear problems causing intermittent stoppages.

Recorded data result (2026)

Based on the data collected from Senmul Garment Plc, SNLS machines contributed the highest frequency of cumulative machine failures and button attach is the highest production downtime among all sewing machines. The big problems were with threads breaking, needles breaking and issues with timing, feeding & tension on the machines. All these problems stopped production a lot. Meant the machines in the sewing section was not available to use. This is what Hashem & Islam (2020), found out it.

They said that problems with thread tension and timing were reasons why sewing machines break down in the garment industry. when machines are not working it causes a loss in production and makes things less efficient (Alauddin, 2018). The Button Attach machine was the biggest problem. It often had problems with the clamps, sensors, timing and parts coming loose. Other machines, like the DNCS, Button Hole, Edge Cutter, FOA and Overlock machines had problems compared to the others.

Critical Machine Analysis

Critical machine analysis based on the total downtime revealed that large usage machine is responsible for the vast majority of lost production time. This helps visually justify the focus on the PMP. Figure below showed of machine downtime (Process FMEA).

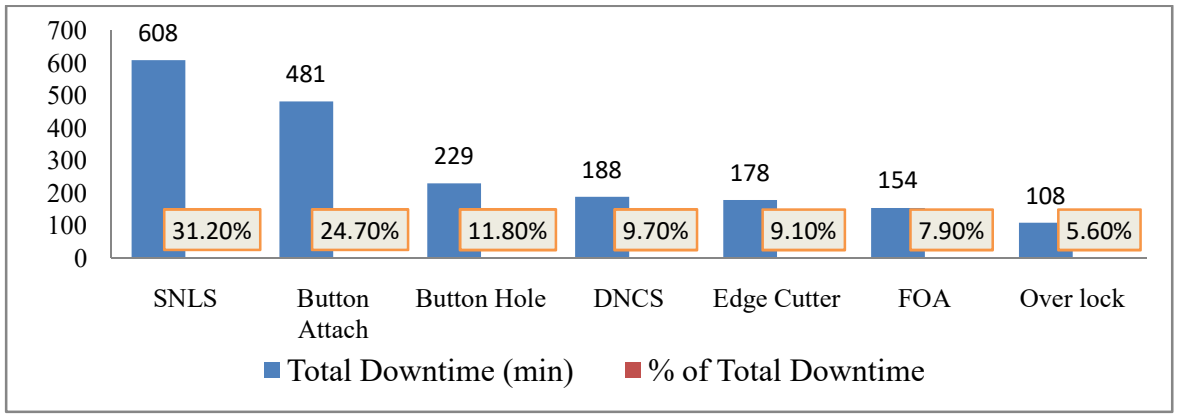


Figure 4.1: Machine downtime percentage

The figure above 4.1 showed that SNLS machines had the downtime. It was 608 minutes, which's 31.2% of the total. This was mainly because of problems, like thread breaking; timing issues skipped stitches and tension failures that happened during production. These issues kept happening with SNLS machines. Button Attach machines recorded the second highest downtime with 481 minutes (24.7%), mainly because of clamp failures, sensor faults, and loose mechanical parts. Button Hole, DNCS, & Edge Cutter machines accounted for 11.8%, 9.7%, and 9.1% of total downtime respectively, while FOA and over lock machines contributed comparatively lower downtime at 7.9% and 5.6%.

The total recorded downtime of 1,946 minutes indicates that SNLS and Button Attach machines was the major contributors to production interruption & therefore require higher maintenance priority. This finding agrees with Hashem & Islam (2020), who identified timing mismatch and thread tension failure as major causes of sewing machine interruption in garment industries. The result further indicates that lack of PM significantly affected machine reliability and production continuity within the sewing section. Figure below 6 showed major failure mode distribution of machines.

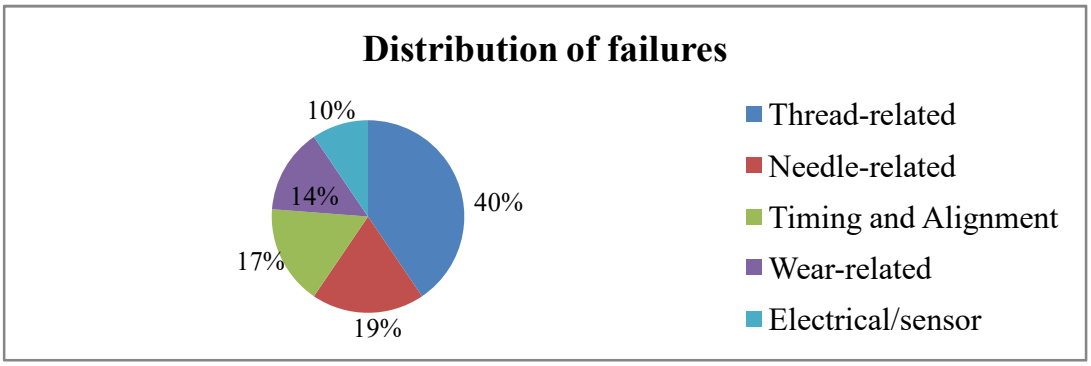


Figure 4.2: Distributions of machine failure modes

As shown in the above figure 4.2, the PFMEA analysis identified timing problems, thread breakage, skipped stitches, and lubrication failure as critical sewing machine failure modes affect production continuity. This finding supports Ta (2018), who explained that PFMEA systematically identified operational failures before complete breakdown occurs. Similarly, Carlson (2014), stated that machine-related process failures significantly affect manufacturing reliability & production performance.

4.6. PFMEA Analysis and Critical Failure Modes Identification

The PFMEA analysis identified several critical sewing machine failure modes within the sewing section, including timing problems, thread breakage, needle failure, skipped stitches, excessive vibration, lubrication failure, and feed mechanism malfunction. These failure modes negatively affected sewing quality, machine stability, and production continuity. The analysis further revealed that several machine failures received high occurrence ratings because the same failures repeatedly occurred during daily production operations.

What the research says was also seen in the other research conducted, in which it states that if a machine had major issues, those were rated by severity where the major issues cause failure to produce or reduce quality and caused or caused total machine failure, this made a lot of sense and links with what was described in section 2.8 of the literature review, this described process FMEA and stated that it could also be used to help make decisions on which machines and areas in the manufacturing process were risky.

The findings were also consistent with Ta (2018), who confirmed that PFMEA improved process stability & machine reliability by identify potential failure modes & evaluating possible failure modes & evaluating their operational consequences. Similarly the current findings agree with Carlson (2014), who confirmed that malfunction causes in Process FMEA were directly related to manufacturing equipment conditions and operational deficiencies.

The present study concluded that improper handling of the machine, poor lubrication, delay of replacement of the new spare parts, and non-preventive inspection are the fundamental reasons for multiple machine failures. The results from the FMEA concluded also that failures are often discovered late because, since the inspection and the structured monitoring of a factory, failures rates could be found in their early stage, which caused for several failure modes of late stage for detection ratings of a given number. The results are similar to those of Sari (2023), who mentioned weak problem detection systems increase the risk of things going wrong, because the problems will only be identified when the machine has failed. Therefore, the PFMEA results shows that by having an analysis of machine failures and looking at it analytically creates a very solid technical base to identify machine problems and decide on their order of priority in the maintenance system of the garment industry.

4.6.1. Risk Priority Number Analysis and Maintenance Prioritization

In this study the RPN analysis are important to systematically prioritize sewing machine failures based on operational risk level. Due to the combination of high severity, frequent occurrence, & inadequate detection capability, the results showed that SNLS & button attach machines had the highest RPN values. Machine failures with RPN values more than 250 were classified as extremely high risk and necessitated prompt preventive maintenance intervention according to the RPN classification system used in the study. Regular preventive inspection and monitoring efforts were planned for medium-risk failures. The results corroborate in the literature reviewed by Gatot Basuki (2018), described RPN as a quantitative method for identifying critical machine faults that need priority maintenance attention.

Similarly, AIAG (2019),emphasized that RPN classification improved maintenance effectiveness by enabling industries to focus maintenance resources on the most critical operational risks. The study findings also strongly support the theoretical integration of PFMEA

and PM described in the literature that PFMEA-based system created in this study prioritized maintenance tasks based on actual operational risk circumstances, in contrast to traditional time-based maintenance systems where all machines receive equal maintenance attention.

This outcome is consistent with Stamatis (2019), explanation that PFMEA converts routine scheduling of PM into risk-based maintenance decision-making. In a similar vein, Piechowski et al., (2018), stressed that by proactively addressing root causes, PFMEA-based maintenance increases mean time between failures and decreases maintenance inefficiencies. As a result, the RPN-based prioritizing approach created in this study greatly increased the efficacy of maintenance planning and facilitated the proper distribution of maintenance resources within the sewing department.

4.6.2. Development of PFMEA-Based Preventive Maintenance Plan

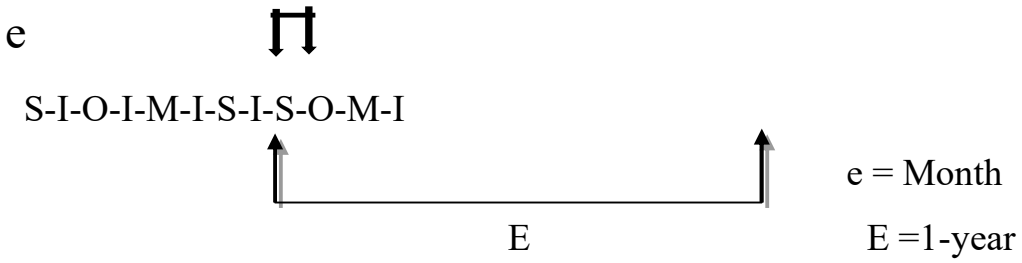
A structured PM was created for Senmul Garment Plc's sewing section machines based on the PFMEA findings and RPN prioritization results. Based on machine condition & operational criticality, the established maintenance plan divided maintenance tasks into four categories: inspection, small maintenance, medium maintenance, & overhaul maintenance. The research gaps noted in Section 2.10 of the literature evaluation were immediately addressed by the established framework. While little study had created useful PM frameworks specifically for sewing section machines within Ethiopian garment industry, prior studies had mostly concentrated on improving overall productivity and reducing defects.

The results provide significant support for the literature on the combination of PFMEA and PM. Muthalib et al., (2019), indicated that risk-based maintenance systems enhance maintenance effectiveness by ranking machine failures based on operational criticality. In a similar layer, PFMEA-driven maintenance planning improved loyalty & lowers unscheduled downtime when compared to traditional maintenance systems, according to Certa & Galante (2019).

The study demonstrates that PFMEA based maintenance planning is effective approach for improving maintenance performance in resource constrained garment manufacturing environments.

4.6.3. General PM schedules for all sewing machines and maintenance cycle

Maintenance cycle is the predetermined sequence of maintenance activities performed on a machine at specified intervals within a given period to ensure reliable operation, reduce breakdowns, & extend machine life (Domeika A 2018).



While the lower arrow (E) depicts the entire yearly maintenance cycle, the upper sequence shows the order in which maintenance tasks are completed throughout the maintenance plan. The one-year cycle's start and finish are indicated by the vertical arrows. The monthly maintenance interval that is used to schedule and repeat the maintenance tasks is indicated by the symbol e.

I, refers to (Inspection), S, (Small Maintenance), M. (Medium Maintenance), O, (overhaul Maintenance). Each machine and equipment was going through maintenance steps at different times. The cycle of maintaining machines and the schedule for the year and month are, fully described in the appendix.

Table 4-10: Maintenance schedule cycle and activity classification

Maintenance Level	Maintenance Cycle	Maintenance Activities	Responsible Person
Inspection (Basic PM)	Daily	Clean lint, dust, and thread waste from machine body and working area. Check needle condition, thread path, and bobbin case. Inspect machine sound and vibration before operation. Ensure proper lubrication level and smooth running condition.	Machine Operator & technician
Small Repair (Minor Maintenance)	Weekly	Tighten loose screws and mechanical parts. Adjust thread tension and stitch quality. Clean internal accessible parts. Check belt condition and minor alignment issues. Replace damaged needles and minor consumable parts.	Technician
Medium maintenance	Monthly	Inspect & adjust the timing system, feed mechanism, & machine calibration. Check & replace worn components, including belts, pressure feet, & needle plates. Verify machine performance after maintenance & correct any abnormalities.	Maintenance technicians
Overhaul Maintenance	Annual / As required	Complete dismantling & deep inspection of machine. Replace major components (hook, assembly, bearings & timing system parts). Full lubrication system service & oil replacement electrical system inspection (motor, wiring, sensors for button attach machines) (Agustina, 2019).	Maintenance Engineer / Technical Team

Sewing Machine coding

Machine coding system was developed to provide unique identification of each machine to facilitating maintenance planning, failure recording & preventive maintenance scheduling. For more check Appendices, B.

Table 4-11: Sewing machine codes

Machine location	Machine description	Location of machine	Machine type	Machine no	Code of each machine
Sewing Room	SNLS	01	S01	01-63	01S0101
	Button hole	01	S02	01-03	01S0201
	Over lock	01	S03	01-02	01S0301
	DNCS	01	S04	01-04	01S0401
	Feed off arm	01	S05	01-03	01S0501
	Button attach	01	S06	01-03	01S0601
	Edge cutter	01	S07	01-03	01S0701

Annual machine maintenance cycle

The table below 4.12 presents the annual maintenance cycle developed for sewing machines based on the PM. The schedule specifies the timing of inspection (I), small maintenance (S), medium maintenance (M) & overhaul (O) maintenance activities throughout the year. For more please check the full table in the Appendices, D.

Table 4-12: Annual machine maintenance cycle

M/C code	Month											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
01S0102	I	S	I	O	I	M	I	S	I	S	O	M
01S0103	S	I	S	I	O	I	M	I	S	I	S	O
01S0104	M	S	I	S	I	O	I	M	I	S	I	S

Monthly sewing machine schedule for April

April was selected as the implementation month because it was the first month after completing data collection, PFMEA analysis, and development of the preventive maintenance plan. Therefore, the April schedule represents the initial implementation phase of the developed PFMEA-based preventive maintenance program. The schedule can be adjusted and continued for subsequent months based on the company's production requirements and maintenance conditions. Table 4.12 presents the detailed monthly PM schedule for April, including the

maintenance activities assigned to each machine and their planned execution periods. Different maintenance dates were assigned to avoid simultaneous shutdown of multiple machines and to ensure efficient utilization of maintenance personnel without significantly affecting the production flow. For more check appendices, E.

Table 4-13: Sewing machines schedule for april

M/c code	Week 1						Week 2						Week 3						Week 4					
	M	TU	W	TH	F	S	M	TU	W	TH	F	S	M	T	W	TH	F	S	M	T	W	TH	F	S
01S0101	S																							
01S0102								I																
01S0103															M									
01S0104																						O		

Preventive Maintenance checklist

A maintenance checklist is a structured list of inspection, cleaning, lubrication, and adjustment tasks used to ensure that equipment operates safely and efficiently. It provides a standardized guide for maintenance activities so that required tasks were performed consistently and no critical steps were missed (Delgado-romero et al., 2025). This PM checklist is a general maintenance tracking tool developed to record and monitor all maintenance activities carried out on equipment. It is linked with PFMEA results to ensure that maintenance actions were prioritized by depending on RPN, failure mode, & machine criticality.

Monthly PM execution and tracking sheet

The monthly PM execution and tracking sheet was developed to document and monitor the implementation of scheduled maintenance activities. It records maintenance tasks, responsible personnel, validation, and future maintenance schedules to ensure that preventive maintenance activities are carried out consistently and effectively.

Table 4-14: Monthly PM execution and tracking sheet

Name of Equipment: Sewing Machine	Manufacturer: JUKI	Contact Details: _____	Date of Purchase: _____
Label: _____	Serial Number: _____	Person Responsible: Maintenance Technician	Date Put into Service: _____

Date	Maintenance Description	Maintenance Performed By	Date of Validation Before Put into Service	Validation Performed By	Next Maintenance Planned on Date	Remark
06/09/18	Small maintenance (Lubrication)	Maintenance Technician	06/09/18	Maintenance Supervisor	13/09/18	Machine functioning properly
13/09/18	Machine cleaning and thread path inspection	Maintenance Technician	13/09/18	Maintenance Supervisor	20/09/18	No abnormality observed
20/09/18	Needle replacement and thread tension adjustment	Maintenance Technician	20/09/18	Maintenance Supervisor	27/09/18	Stitch quality improved
27/09/18	Belt inspection and screw tightening	Maintenance Technician	27/09/18	Maintenance Supervisor	04/10/18	Machine operating normally

Process failure mode and effect analysis recording sheet

This checklist outlines the PM activities, inspection frequency, & responsible personnel for maintaining sewing machine reliability and reducing unexpected failures.

Table 4-15: PFMEA recording sheet

Machine type	Failure mode	Effect	Root cause	Downtime minute	severity	occurrence	detection	RPN

The above table 4.15 showed PFMEA based PM checklist was designed as a recording & analyzed tool used to document weekly, monthly, & annual PM activities. The checklist supports maintenance tracking, validation, scheduling, and implementation of PFMEA-based maintenance actions.

Daily machine maintenance recording sheet

This sheet records daily machine maintenance activities, identified problems, downtime & technician details to ensure proper implementation and tracking of PM activities.

Table 4-16: Daily Machine Maintenance Record Sheets

Date	Machine ID	Machine type	Problem identified	Performed PM	Downtime (min)	Technician name	Signature
25/08/18	01S0401	DNCS	Cutter problem	Adjust cutter	15min	S.D	

Daily care checklist

The daily care checklist was developed to support operator involvement in preventive maintenance activities. Since operators continuously operate sewing machines, their routine inspection and care activities help detect early failure symptoms and maintain machine performance. Table 4.17 presents the daily maintenance activities performed by operators as part of the developed preventive maintenance program.

Table 4-17: Daily care checklists (performed by operators)

No	Activity	Before lunch	End shift	Remark
1.	Clean machine surface			
2.	Remove lint and dust			
3.	Check oil level			
4.	Inspect needle condition			
5.	Check thread tension			
6.	Report abnormal sound			
7.	Verify stitching quality			

Maintenance Visual Control System

This control system is based on something called PFMEA, which helps figure out what maintenance needs to be done to prevent problems. The green cards are for machines that are working fine and just need the usual checks like cleaning and oiling.

The yellow cards are for machines that might have some problems and need to be watched closely. The red cards were given for machines that were actually broken & need to be fixed right away.

These systems were also helping the workers converse to each other better. The operators, supervisors and maintenance technicians can all see what is going on with the machines & fix problems faster. They can also keep track of what they had done to the machines and what still needs to be done (Tejada et al., 2025). It is also helping to keep track of the machines & make sure they are running smoothly. Table below 4.18, gives more clarity for the actions that can be taken.

Table 4-18: Visual Control System Cards and Required Action

Card Color	Machine Condition	Maintenance Urgency	Monitoring Level	Action Required
Green	Normal	Routine	Daily operator check	Standard PM
Yellow	Moderate abnormality	Scheduled attention	Technician follow-up	Inspection & adjustment
Red	Critical	Immediate action	Continuous monitoring	Urgent PM & repair

The implementation process of visual green, yellow & red cards on sewing machines were performed successfully to show the machine condition as showed below the figure.



Figure 4.3: Implemented visual control system cards in line

The developed preventive maintenance program was implemented to evaluate its practical effectiveness. The evaluation was conducted by comparing machine downtime, production achievement, and other performance indicators before and after implementation.

4.7. Implementation of PM for the Critical & the whole Sewing Machines

The proposed PM was implemented in the sewing section, combining PFMEA-based maintenance for certain critical machines with standardized PM for all sewing machines. In order to maintain overall machine condition & lower common failures throughout the production line, the general PM concentrated on routine tasks such cleaning, lubrication, inspection, tightening, and adjustment (Agustina, 2019). Machines with increased downtime contributions & elevated RPN values were identified using PFMEA results (Dedimas & Gebeyehu, 2019).

The implementation ranked critical failure types based on their operational criticality, severity, recurrence, and impact on downtime. While less serious problems were handled by the

conventional preventive maintenance system, high-impact failures that significantly disrupted production were addressed by improved PM. Cleaning, lubrication, component tightening, timing adjustment, hook & sensor inspection, alignment correction, part replacement, calibration, & regular condition monitoring were among the maintenance tasks.

Compared to machines undergoing routine preventive maintenance, those with higher RPN values were inspected more frequently and closely monitored. A visual maintenance control system using red, yellow, and green cards was also applied to support machine condition monitoring and maintenance prioritization. Overall, the implementation aimed to improve machine reliability, reduce downtime, & strengthen maintenance decision making through the integration of general PM and PFMEA based prioritization.

4.7.1. Introducing the plan in to the production team

The PMP plan was introduced to the production line according to the schedule to perform the given maintenance tasks. Machine coding was assigned to facilitate machine identification & maintenance tracking. Daily, weekly, monthly, & overhaul maintenance activities were scheduled & documented using maintenance checklists. Maintenance personnel performed inspections, cleaning, lubrication, adjustments, & replacement of worn components based on the established maintenance procedures with the integration of operators & visual cards.

Creating of Awareness Activities for the production team

Awareness was provided to machine operators & maintenance technicians regarding the importance of PM & how they are performed. The awareness emphasized appropriate machine cleaning practices, early identification of machine abnormalities,

And the responsibilities of operators in maintaining machine condition. The objective was to build up a maintenance culture that supports machine consistency & production improvement.





Figure 4.4: Creating Awareness of PMP for sewing production team

Execution of Maintenance Tasks

The maintenance tasks were executed according to the PM schedule. Daily cleaning activities were carried out by machine operators, while technical inspections, lubrication, adjustments & component replacements were performed by maintenance technicians during weekly & monthly maintenance periods. Maintenance records were completed after each activity to monitor maintenance performance & ensure compliance with the PMP.



Before and after machine cleaning oil before cleaning



Oil cleanness after during maintaining

Figure 4.5: Machine cleaning and repairing process

Table 4-19: PFMEA based maintenance implementation prioritization

Group	Priority Level	Machines Included with Codes	Failure Characteristics	Maintenance Strategy	Implementation Type	Monitoring	Card
A	Immediate Critical	Button Attach (01S0602, 01S0603), FOA (01S0502), Buttonhole (01S0203), DNCS (01S0403), Edge Cutter (01S0703)	High RPN, production stoppage, repeated breakdowns	Enhanced PM (corrective & preventive actions)	Full implementation on selected machine	Continuous / Daily inspection	Red
B	High Priority	SNLS (01S0161, 01S0142), Button Attach (01S0601), DNCS (01S0401)	Frequent failures, moderate downtime, early warning issues	Scheduled PM (inspection & adjustment)	Partial implementation	Weekly / Daily monitoring	Yellow
C	Routine Control	SNLS (01S0128), FOA (01S0501), Buttonhole (01S0201)	Low severity, operational issues, operator-controlled failures	Standard PM (cleaning, lubrication, basic adjustment)	Routine system-wide PM	Daily operator check	Green

Based on the above table 4.19 the maintenance implementation was structured into three priority levels based on PFMEA results. Category A machines required immediate PM due to high production impact, while Category B machines were managed through scheduled PM with close monitoring. Category C machines were controlled using routine PM activities to maintain basic machine condition and prevent minor failures.

The RPN analysis revealed that SNLS and button attach machines had the highest operational risk because of high severity, occurrence, and limited failure detection capability. This findings chains Stamatis (2019), who explained that process FMEA improved maintenance prioritization by focusing on machines that had high production impact. This result also agrees with AIAG (2019), which stated higher failure impact machines need to had immediate maintenance intervention.

Table 4-20: Conducted maintenance activities based on risk level

Date	Activity	Machine code	Machines Covered	Status
21/08/18	Inspection	01S0602,01S0161, and 01S0128 (A,B,C)	All selected machines	Completed
24/08/18	Small Maintenance	01S0603, 01S0142, (A,B)	Critical and high-priority machines	Completed
30/08/18	Small Maintenance	01S0502 , 01S0601 (A, B)	Critical & high-priority machines	Completed
03/09/18	Medium Maintenance	01S0203 ,(A)	Critical machines	Completed
06/09/18	Small Maintenance	01S0403 , 01S0401 (A, B)	Critical and high-priority machines	Completed
10/09/18	Overhaul Maintenance	01S0603,(A)	Selected critical machine	Completed
12/09/18	Small Maintenance	01S0703,01S0161 ,(A, B)	Critical and high-priority machines	Completed
14/09/18	Medium Maintenance	01S0602,(A)	Critical machines	Completed

The monitoring criteria of these machines can be done daily, weekly, monthly monitoring needs by operators & maintenance technicians. The rest of machines were get the routine and other PM activities based on the schedule.

4.7.2. Production Performance Improvement after PM Implementation

With an emphasis on breakdown frequency, downtime, production disruption, and machine reliability, a comparative analysis was carried out to determine the effect of the PFMEA-based

preventive maintenance framework on machine performance and production stability in the sewing sector. Prior to installation, a reactive maintenance approach that fixed machines after breakdowns caused frequent machine failures and unscheduled stoppages in the sewing department.

This resulted in frequent production disruptions and decreased productivity; the machines that caused the most downtime were SNLS, Button Attach, Button Hole, DNCS, and FOA. Following installation, machine stability was enhanced by the PM framework and PFMEA-based prioritization, which decreased recurring failures and guaranteed prompt maintenance of key machines based on RPN values. Additionally, monitoring and reaction times to new problems were enhanced using visual control tools (red, yellow, and green cards). As a result, production productivity raised, downtime decreased, & breakdown frequency & reaction time improved. This attests to increased productivity and machine dependability.

The results confirm that Keller and Owen (2025), claim that, in contrast to reactive systems, PM increases equipment availability. Furthermore, Diaz-Reza et al., (2019), highlighted that workflow stability and production efficiency are directly improved by machine reliability. The results showed that basic preventive maintenance tasks like cleaning, lubrication, inspection, and adjustment can yield quantifiable improvements in clothing production systems, even when the gain is modest. As a result, combining PFMEA with PM greatly enhances production performance and equipment constancy.

Table 4-21: Productivity improvement comparision before and after

Day on February	Produced pieces before PM implementation	Output achievement % before implementation of PM	Day	Production pieces after implementation	Output achievement (%) After implementation
02/06/18	482	48.2%	21/08/18	525	52.5%
03/06/18	495	49.5%	22/08/18	518	51.8%
04/06/18	471	47.1%	24/08/18	542	54.2%
05/06/18	503	50.3%	26/08/18	528	52.8%
06/06/18	488	48.8%	28/08/18	537	53.7%
09/06/18	490	49.0%	29/08/18	521	52.1%

10/06/18	478	47.8%	30/08/18	548	54.8%
11/06/18	512	51.2%	01/09/18	526	52.6%
12/06/18	484	48.4%	03/09/18	535	53.5%
13/06/18	499	49.9%	04/09/18	532	53.2%
14/06/18	475	47.5%	05/09/18	541	54.1%
16/06/18	501	50.1%	06/09/18	523	52.3%
17/06/18	487	48.7%	07/09/18	546	54.6%
18/06/18	494	49.4%	08/09/18	527	52.7%
19/06/18	486	48.6%	10/09/18	534	53.4%
20/06/18	493	49.3%	11/09/18	529	52.9%
21/06/18	489	48.9%	12/09/18	538	53.8%
22/06/18	496	49.6%	13/09/18	531	53.1%
14/06/18	485	48.5%	14/09/18	536	53.6%
25/06/18	492	49.2%	15/09/18	544	54.4%
Average	490	49.0%	Average	528.1	52.81% ≈ 53%

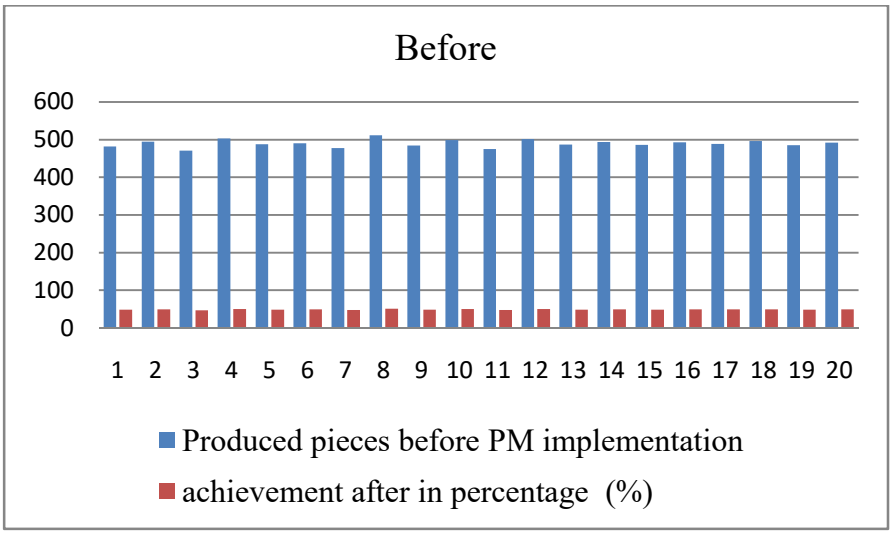


Figure 4.6: Production pieces and achivement percentage before

Figure above 4.6 showed that daily production performance before PM implementation. The average production efficiency was 49 %. Variations in daily production indicate the presence of machine failure and operational interruptions that affected production performance.

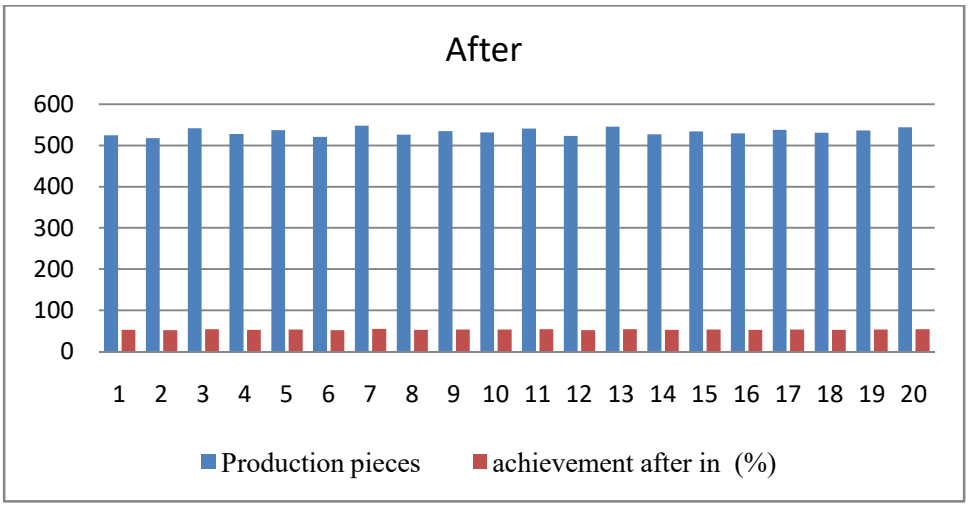


Figure 4.7: Productivity and achivement percentage after

The above figure 4.7 showed that daily production performance after PM implementation. The average production achievement increased to 53.0%. The resulted indicate improved machine reliability & production performance following the implementation of PFMEA based PMP.

Productivity 49% → 53%

When explained mathematically;

$$production\ achivement\ before = \frac{produced\ pieces}{planned\ pieces} \times 100$$

Daily planning of senmul garment before and after = 1000 pieces

Actual pieces of production per day before = 490 pieces

$$production\ achivement = \frac{490}{1000} \times 100 = 49\%$$

Actual pieces of production per day before = 530 pieces

$$production\ achivement = \frac{530}{1000} \times 100 = 53\%$$

Table 4-22: Results Before and After Implementation

Indicator	Before Implementation	After Implementation	Improvement results
Machine downtime (minutes)	1946 min	1166 min	780 min
Machine Breakdowns	88 cases	47 cases	41 failures
Average Response Time	20 min	17 min	3 minute
Machine Availability	84.4%	90.65%	6%
Output improvement	49%	52.81% ≈53%	3.81% ≈4%

The implementation measurement was conducted over a three-week period, therefore, the observed improvements represent short-term operational performance changes after implementation of the PM system. Downtime reduction confirmed improved machine availability & operational reliability after PM implementation. This finding supports Keller & Owen (2025), who reported that structured PM systems significantly improve production continuity & equipment reliability compared to corrective maintenance practices.

Down time reduction in minute = before – after, 1946 –1166 = 780min

Breakdown frequency reduction: The number of machine failure incidents recorded in production. Before implementation initially, the sewing section record 88 breakdown cases. Frequent failures were mainly observed in SNLS and Button Attach machines. After implementing regular inspection, cleaning, lubrication, & maintenance follow-up, breakdown cases reduced to 47 breakdown cases

Maintenance Response Time: Refers to the average time required for maintenance technicians to respond to machine failures after being reported. Before implementation, the average maintenance response time was twenty minutes. This delay was caused by lack of maintenance prioritization and weak communication between operators and maintenance personnel. But after implementation following the introduction of the visual maintenance control system and maintenance scheduling, response time improved to 17 minutes.

$$\text{Response time improvement } = 20 - 17 = 3\text{min}$$

Machine availability: Machine availability measures the percentage of planned production time during which machines were available and operating properly.

$$\text{Availability (\%)} = \frac{\text{operating time}}{\text{planned production time}} \times 100$$

Planned production time before = 480 minutes/day and Downtime = 74.8 minutes

Operating time:

480 −74.8=405.2 minutes

$$\text{Availability Before (\%)} = \frac{405}{480} \times 100 = 84.4\%$$

$$\text{Availability after (\%)} = \frac{\text{operating time}}{\text{planned production time}} \times 100$$

Planned production time after = 480 minutes/day and downtime per day = 44.8minutes

Operating time:

480−44.8=435 minutes

$$\text{Availability after (\%)} = \frac{435}{480} \times 100 = 90.65\%$$

4.8. Evaluation of Results

The evaluation of the implemented PM framework was carried out by comparing machine performance & production stability before & after implementation. The production line showed discernible improvements upon execution. Due to focused maintenance measures and enhanced inspection procedures, machines classified as critical under PFMEA analysis demonstrated decreased failure recurrence. Improved PM efforts helped identify and fix any issues before they became serious malfunctions.

The maintenance response was also enhanced by the implementation of an organized maintenance prioritization system. While common problems were handled through planned preventive maintenance, high-risk machinery received prompt attention. On the shop floor, the visual control system also facilitated quicker communication and machine status monitoring. Overall, the findings show that the PFMEA-based PM framework reinforced maintenance decision-making in the sewing department, decreased unscheduled downtime, and increased machine dependability.

4.9. Integrated Discussion of Finding

The lack of an organized PM system is the biggest issue in the sewing department, according to the combined results of PFMEA analysis, quantitative data, qualitative interviews, & field observations. The reactive nature of the current maintenance procedures led to frequent machine failures, production disruptions, and erratic machine performance. Production output & overall operational performance were shown to be impacted by maintenance-related issues as well as operational factors such operator absenteeism, differences in operator efficiency, incorrect machine handling & production pressure.

Based on RPN values, PFMEA results successfully identified important machines and high-risk failure modes that matched observed downtime trends and interview replies. Based on RPN values, PFMEA results successfully identified important machines and high-risk failure modes that matched observed downtime trends and interview replies. The success of the PFMEA prioritization approach in identifying maintenance-critical locations was confirmed by the fact that machines with higher RPN values were also the most commonly reported during field observation.

Both common operational failures and high-impact technical breakdowns were successfully addressed by combining general PM with PFMEA-based maintenance prioritizing. While enhanced preventive maintenance concentrated on major failures that seriously impacted production continuity and machine reliability, general preventive maintenance actions managed typical machine issues through cleaning, lubrication, inspection, and small adjustments.

The results also show that organized risk assessment, as opposed to reactive responses following machine failure, enhances maintenance effectiveness. Overall, the study demonstrates that PFMEA-based PM is a suitable strategy for enhancing machine dependability, cutting downtime, and promoting production stability in settings related to clothing manufacturing.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The main objective of this study was to reduce operational losses at Senmul Garment Manufacturing Plc caused by unscheduled sewing machine breakdowns through the development and implementation of a risk-based Preventive Maintenance Plan (PMP) using Process Failure Mode and Effects Analysis (PFMEA). The study found that the sewing section was operating under a reactive maintenance system, which resulted in frequent machine failures, high downtime, production interruptions, and low production achievement. Before improvement, the average production achievement level was 49%, showing the negative impact of unreliable machine performance on production efficiency.

The study identified critical machine failure modes and their root causes through PFMEA analysis. The results showed that SNLS and button attach machines contributed the highest downtime due to their high production impact. Major failure causes included timing errors, broken needles and threads, skipped stitches, insufficient lubrication, and irregular inspection. PFMEA-based Risk Priority Number (RPN) analysis helped prioritize high-risk machines and develop appropriate preventive maintenance activities.

The developed preventive maintenance plan was implemented in the sewing section, and its effectiveness was evaluated. The implementation reduced machine downtime by 780 minutes and improved production achievement from 49% to 53%. These results demonstrate that a shift from reactive maintenance to a proactive, risk-based maintenance approach can improve machine reliability and production performance.

Overall, the study concludes that integrating PFMEA with preventive maintenance planning provides a systematic approach for identifying machine risks, prioritizing maintenance actions, reducing unexpected breakdowns, and improving production continuity. The developed PMP can serve as a practical framework for enhancing maintenance effectiveness and machine dependability in garment manufacturing industries.

5.2. Recommendation

Based on the findings of this study, the following recommendations are proposed for Senmul Garment Manufacturing Plc management and technical teams to sustain the improvements achieved through the PFMEA-based Preventive Maintenance Plan (PMP).

Institutionalize the PFMEA-based Preventive Maintenance System;

The company should formally integrate the developed preventive maintenance program into its regular maintenance practices. Daily, weekly, monthly, and annual maintenance activities should be consistently implemented according to the identified maintenance levels, including operator-level inspections, cleaning, lubrication, minor adjustments, medium repairs, and major overhauls during planned shutdown periods.

Strengthen Operator Involvement in Autonomous Maintenance;

Operators should be trained and encouraged to perform basic daily maintenance activities, including machine cleaning, needle alignment checks, lubrication monitoring, and early identification of abnormal machine conditions. This practice can help prevent minor problems from developing into major failures and reduce high-risk failure occurrences.

Improve Spare Parts and Maintenance Resource Management;

The company should link PFMEA results with spare parts inventory management. Critical components associated with high-risk failure modes, such as needles, tension components, belts, and machine lubricants, should be available to minimize delays during corrective and preventive maintenance activities.

Establish Effective Maintenance Data Management;

The company should implement standardized preventive maintenance checklists, machine history records, and breakdown reporting systems. Proper documentation of maintenance activities and failure history will support future analysis, decision-making, and continuous improvement.

Conduct Periodic PFMEA Review and Continuous Improvement;

A cross-functional team involving production supervisors, maintenance technicians, and quality personnel should periodically review and update the PFMEA analysis. RPN values should be reassessed regularly to reflect changes in failure frequency, maintenance effectiveness, and emerging operational risks.

Consider Human and Operational Factors in Production Improvement;

In addition to machine-related improvements, management should address operational factors such as operator skill variation, absenteeism, and production pressure. Providing continuous operator training, improving workforce management, and maintaining proper line balance will further enhance production performance and sustain the benefits of the preventive maintenance program.

5.3. Future Research Work

Predictive Maintenance: Predictive maintenance should also explore into the research of machine condition monitoring, sensor, vibration analysis and real time machine health data so that it'll possible to prevent the machinery from failure before it happen.

Explore to other garment sections: As the above PFMEA study concentrates on only on stitching machine so it can be extended to utilize for other sections such as cutting, embroidery, washing, finishing and packing to optimize machine maintenance practices in the overall factory.

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APPENDICES

Appendices: A

FDRE TVT Institute

Faculty of Textile and Apparel Fashion Technology

Department of Garment Technology

Dear respondent, you are kindly invited to participate in this academic study entitled: "Developing a preventive maintenance plan for Senmul garment plc sewing machines using process failure mode and effect analysis." This research is conducted in partial fulfillment of the requirements for the masters of Science degree in garment technology. The primary objective of this study is to develop a risk based PMP to enhance the operational reliability of sewing machines at senmul garment plc. Your honest responses are vital to the success of this study and provide significant insights into strengthening maintenance practices. If you want to require further clarification contact me at any time through the following addresses:

Asnakew Eshetie Alemu: Phone: +251927600844

Email: asnake19eshetie@gmail.com

General Direction

- ❖ No need to write your name.
- ❖ Please put a tick ☑ mark in the box for your answer and the number of your choice for the alternatives given.

Part I. Demographics

1. Age group ☐ 20-29 ☐ 30-39☐ 40-49 ☐ 50+
2. Gender ☐ Male ☐ Female
3. Academic qualification ☐ 10+ and/or 12+ ☐ Diploma ☐ Bachelor Degree ☐ Masters ☐ PhD and/or Above
4. Position ☐ Production manager ☐ Production supervisor ☐ checker ☐ Maintenance technician ☐ Quality supervisor ☐ Machine operator ☐ Industrial Engineer ☐ Other

5. Years of experience ☐ Less than 5 ☐ 6-10 ☐ 11-15 16+ ☐

Part II. Questionnaires

Please try to answer all items. You can skip the question if an item is irrelevant, or if you are not sure or you do not know the answer. Where: 1= Strongly Disagree, 2= Disagree, 3= Neutral, 4= Agree and 5= Strongly Agree

No	Description	Scale				
		1	2	3	4	5
A. Machine Failure Causes & that support failure identification and Occurrence in FMEA.						
1.	Machine breakdowns often occur during production.					
2.	Breakdown of sewing machines frequently occurs during operations.					
3.	Lack of proper lubrication contributes to machine failures.					
4.	Inadequate cleaning of sewing machines leads to breakdowns.					
5.	Different types of machine failures significantly impact production performance.					
B. Maintenance Practices & System Effectiveness that supports Detection & control mechanisms in FMEA.						
6.	Machines are inspected regularly in the sewing section.					
7.	Sewing machines are cleaned regularly.					
8.	Proper lubrication is consistently performed on sewing machines					
9.	Maintenance technicians respond quickly when machines fail.					
10.	Maintenance records are properly documented and maintained.					
11.	Preventive maintenance reduces repeated machine failures.					
C. Production Performance Outcomes that supports Severity in FMEA.						
12.	Machine failures reduce daily production targets.					
13.	Corrective (breakdown) maintenance causes production delays.					
14.	Machine problems can lead to garment defects.					
15.	Preventive maintenance improves overall production achievement.					

Part II interview questions (close ended)

1. What type of maintenance is most commonly practiced? ☐ Preventive maintenance ☐ Corrective maintenance ☐ Predictive maintenance ☐ Total productive maintenance
2. Who typically performs maintenance on the machine? ☐ Operators ☐ Maintenance technicians ☐ External technicians ☐ Operators and technicians
3. How often is your machine cleaned and lubricated? ☐ Daily ☐ Weekly ☐ Monthly ☐ Only when breakdown occurs
4. What is the average downtime when a machine fails? ☐ Less than 10 min ☐ 10-30 min ☐ 30-60 min ☐ More than 1 hour
5. What is the most common cause of machine failures? ☐ Needle breakage ☐ Thread breakage ☐ Timing issue ☐ Loose stitch ☐ Mechanical wear ☐ Other
6. Do you know about Failure Mode and Effect Analysis? ☐ Yes ☐ No
7. How often does your machine experience breakdown? ☐ Daily ☐ Weekly ☐ Monthly ☐ Rarely
8. Which sewing machine tends to break most often? ☐ Single needle lock stitch ☐ Over lock ☐ Button attach ☐ Button hole ☐ Feed off the arm ☐ Edge cutter ☐ Double needle chain stitch

❖ **Open ended Interview questions**, please provide concise and clear explanations.

9. In your own words, how would you describe the way maintenance is currently handled at Senmul Garment PLC.?
10. Based on your experience, what technical factors most commonly contribute to frequent machine failures in the sewing section?
11. How does unplanned machine downtime affect your daily work and the achievement of production targets?
12. What problems do you expect might occur when trying to implement a preventive maintenance system in your department?
13. In your experience, which machine components have the highest impact in terms of failure severity, frequency, or difficulty of detection? Please explain.

14. What is your view on the effectiveness of a PFMEA-based maintenance plan in reducing machine failures and production risks?

ለተሻለ ግልጽነት እና ለተሳታፊዎች ቀላል ግንዛቤ እንዲኖር፣ መጠይቆቹ በአማርኛ ተዘጋጅተዋል።

ተ.ቁ	መግለጫ	ደረጃ				
		1	2	3	4	5
A. በPFMEA ውስጥ የብልሽት መለየትን (Identification) እና የመከሰት ድግግሞሽን (Occurrence) የሚደግፉ የማሽን ብልሽት ምክንያቶች						
1.	በምርት ሂደት ውስጥ የማሽን ብልሽቶች ብዙ ጊዜ ይከሰታሉ።					
2.	የስፌት ማሽኖች ብልሽት በሥራ ሂደት ውስጥ በተደጋጋሚ ይከሰታል።					
3.	ተገቢ ቅባት (Lubrication) አለመደረግ ለማሽን ብልሽት ያስከትላል።					
4.	የስፌት ማሽኖችን በአግባቡ አለማጽዳት ወደ ብልሽት ያመራል።					
5.	የተለያዩ የማሽን ብልሽት አይነቶች በምርት አፈጻጸም ላይ ከፍተኛ ተጽእኖ ያሳድራሉ።					
B. በPFMEA ውስጥ የመለየት (Detection) እና የመቆጣጠር (Control) ስርዓቶችን የሚደግፉ የጥገና ልምዶች እና የስርዓት ውጤታማነት						
6.	በስፌት ክፍል ውስጥ ማሽኖች በመደበኛነት ይመረመራሉ።					
7.	የስፌት ማሽኖች በመደበኛነት ይጸዳሉ።					
8.	በስፌት ማሽኖች ላይ ተገቢ ቅባት በቋሚነት ይደረጋል።					
9.	ማሽኖች ሲበላሹ የጥገና ቴክኒሺያኖች በፍጥነት ምላሽ ይሰጣሉ።					
10.	የጥገና መዝገቦች በአግባቡ ተመዝግበው ይቀመጣሉ።					
11.	መከላከያ ጥገና (Preventive Maintenance) ተደጋጋሚ የማሽን ብልሽቶችን ይቀንሳል።					
C. በPFMEA ውስጥ የSeverity (የተጽእኖ ከባድነት) የሚደግፉ የምርት አፈጻጸም ውጤቶች						
12.	የማሽን ብልሽቶች የዕለታዊ ምርት ኢላማን ይቀንሳሉ።					
13.	የCorrective Maintenance በምርት ሂደት ውስጥ መዘግየትን ያስከትላል።					
14.	የማሽን ችግሮች በልብስ ምርቶች ላይ የጥራት ጉድለት (Defects) ሊያስከትሉ ይችላሉ።					
15.	መከላከያ ጥገና (Preventive Maintenance) አጠቃላይ የምርት ግብ አፈጻጸምን ያሻሽላል።					

ክፍል II: የቃለ መጠይቅ ጥያቄዎች (ዝግ መልስ / Close-ended Questions)

1. በድርጅታችሁ በብዛት የሚተገበረው የጥገና ዓይነት የትኛው ነው? ☐ መከላከያ ጥገና ☐ የብልሽት ጥገና ☐ ትንበያ ጥገና ☐ ጠቅላላ ምርታማ ጥገና

2. በተለምዶ የማሽን ጥገናን ማን ያከናውናል?

☐ ኦፕሬተሮች ☐ የጥገና ቴክኒሺያኖች ☐ ከውጭ የሚመጡ ቴክኒሺያኖች ☐ ኦፕሬተሮች እና የጥገና ቴክኒሺያኖች

3. ማሽንዎ ምን ያህል ጊዜ ይጸዳል እና ቅባት ይደረግለታል? ☐ በ በየቀኑ ☐ በየሳምንቱ በየወሩ ☐ ብልሽት ሲያጋጥም ብቻ

4. ማሽን ሲበላሽ በአማካይ የሚፈጀው የቆመ ጊዜ (Downtime) ስንት ነው?

ከ10 ደቂቃ በታች ☐ 10 - 30 ደቂቃ ☐ 30 - 60 ደቂቃ☐ ከ1 ሰዓት በላይ

5. በብዛት የሚከሰተው የማሽን ብልሽት ምክንያት የትኛው ነው?

☐ የመርፌ መሰበር☐ የክር መቆረጥ☐ የታይሚንግ ችግር ☐ የላላ ስፌት☐ የሜካኒካል መልበስ ☐ ሌላ _____

6. ስለ Failure Mode and Effect Analysis ግንዛቤ አለዎት? ☐ አዎ ☐ የለኝም

7. ማሽንዎምን ያህል ጊዜ ብልሽት ያጋጥመዋል?☐ በየቀኑ☐ በየሳምንቱ በየወሩ☐ አልፎ አልፎ

8. ከሚከተሉት የስፌት ማሽኖች ውስጥ በብዛት ብልሽት የሚያጋጥመው የትኛው ነው?

☐ ሲንግል ኒድል ሎክ ስቲች ☐ ኦቨርሎክ ☐ የቁልፍ ማያያዣ) ☐ የቁልፍ ቀዳዳ ማሽን ☐ ፊድ አፍ ዘ አርም
☐ ኤጅ ካተር ☐ ድብል ኒድል ቼይን ስቲች

ክፍል III: ክፍት መልስ የቃለ መጠይቅ ጥያቄዎች (Open-ended Questions)

እባክዎ አጭር፣ ግልጽ እና በተቻለ መጠን ዝርዝር መልስ ይስጡ።

9. በእርስዎ አስተያየት፣ በሴንሙል ጋርመንት ኃ.የተ.የግ.ማ. ውስጥ የማሽን ጥገና በአሁኑ ጊዜ እንዴት እየተከናወነ እንዳለ ያብራሩ።

10. በእርስዎ ልምድ፣ በስፌት ክፍል ውስጥ ተደጋጋሚ የማሽን ብልሽቶችን በብዛት የሚያስከትሉ ቴክኒካዊ ምክንያቶች ምንድናቸው?

11. ያልታቀደ የማሽን መቆም (Unplanned Downtime) በዕለታዊ ሥራዎ እና በምርት ግብ አፈጻጸም ላይ ምን ተጽዕኖ ያሳድራል?

12. በክፍልዎ ውስጥ የመከላከያ ጥገና (Preventive Maintenance) ሥርዓት ለመተግበር ሲሞክር ምን ዓይነት ችግሮች ሊያጋጥሙ ይችላሉ ብለው ይጠብቃሉ?

13. በእርስዎ ልምድ፣ የትኞቹ የማሽን ክፍሎች ከብልሽት ከባድነት (Severity)፣ የመከሰት ድግግሞሽ (Occurrence) ወይም የመለየት አስቸጋሪነት (Detection) አንጻር ከፍተኛ ተጽዕኖ አላቸው? እባክዎ ያብራሩ።

14. PFMEA ላይ የተመሠረተ የጥገና ዕቅድ የማሽን ብልሽቶችን እና የምርት አደጋዎችን ለመቀነስ ውጤታማ ነው ብለው ያስባሉ? አስተያየትዎን ያብራሩ።

Appendices: B

Sewing machine codes

No	Machine location	Machine description	Location of machine	Machine type	Machine no	Code of each machine
1	Sewing room	SNLS	01	S01	01-63	01S0101
						01S0102
						01S0103
						01S0104
						01S0105
						01S0106
						01S0107
						01S0108
						01S0109
						01S0110
						01S0111
						01S0112
						01S0113
						01S0114
						01S0115
						01S0116
						01S0117
						01S0118
						01S0119
						01S0120
						01S0121
						01S0122
						01S0123
						01S0124
						01S0125
						01S0126

						01S0127
						01S0128
						01S0129
						01S0130
						01S0131
						01S0132
						01S0133
						01S0134
						01S0135
						01S0136
						01S0137
						01S0138
						01S0139
						01S0140
						01S0141
						01S0142
						01S0143
						01S0144
						01S0145
						01S0146
						01S0147
						01S0148
						01S0149
						01S0150
						01S0151
						01S0152
						01S0153
						01S0154
						01S0155
						01S0156
						01S0157
						01S0158

						01S0159
						01S0160
						01S0161
						01S0162
						01S0163
2		Button hole Sewing	01	S02	01-03	01S0201
						01S0202
						01S0203
3		Over lock	01	S03	01-02	01S0301
						01S0302
4		DNCS	01	S04	01-04	01S0401
						01S0402
						01S0403
						01S0404
5		Feed off the arm	01	S05	01-03	01S0501
						01S0502
						01S0503
6		Button attach	01	S06	01-03	01S0601
						01S0602
						01S0603
7		Edge cutter/finish	01	S07	01-03	01S0701
						01S0702
						01S0703

Appendices: C

Data of sewing machine failures based on PFMEA record sheet

Machine Type	Observed Failure Mode	Effect on Production	Root Cause	Downtime (min)	Severity	Occurrence	Detection	RPN =S*O*D
SNLS/ 01S0162	Thread breakage	Machine stoppage	Poor threading	10	5	8	4	160
Button hole/ 01S0203	Increased friction and overheating	Created by absence of lubrication	Create high WIP	35	9	5	4	180
Button Attach/ 01S0503	Sensor failure	High WIP lead to over time	Dust, electrical fault	25	10	3	10	300
SNLS/ 01S0128	Thread breakage	Minor stoppage	Poor threading, lint	15	1	9	4	36
Button attach/01S 0601	Fabric not feeding smoothly	Dirt accumulation, poor lubrication	Uneven button holes,	10	3	5	7	105
SNLS01S0 154	Thread looping under fabric	Rework needed	Tension imbalance	12	2	4	6	48
Over lock/01S03 02	Thread breakage	Frequent stoppage	Lint accumulation	20	3	7	4	84
SNLS/01S 0133	Needle breakage	Delay	Wrong needle size	17	2	6	5	60
Button Attach/01S 0601	Clamp failure	Button misalignment	Mechanical wear	62	8	2	7	112
SNLS/01S	Needle breakage	Short delay	Wrong needle	15	5	8	4	160

0122			size					
SNLS/01S 0117	Bobbin case problem	Machine stoppage	Worn component	22	5	4	6	120
Buttonhole/ 01S0201	Knife dullness	Damaged garment	Wear	58	8	2	6	96
SNLS/01S 0148	Bobbin case jam	Machine Stop	Lint	12	6	4	5	120
Button Attach/01S 0603	Thread looping	Defective stitch	Tension issue	25	8	6	5	240
SNLS/01S 0151	Skipping stitches	Defective seam	Timing issue	15	7	5	6	175
DNCS/01S 0401	Timing problem	Seam defect	Misalignment	55	7	5	6	210
Button Attach/01S 0603	Sensor failure	Line stoppage	Dust	55	9	2	9	162
SNLS/01S 0149	Feed dog not feeding	Production stop	Dirt, wear	21	5	3	6	90
SNLS/01S0 144	Thread breakage	Not stitching	Poor threading	10	5	9	4	180
Edge Cutter/01S 0702	Blade dullness	Poor cutting	Wear	32	5	5	5	125
SNLS/01S0 130	Needle breakage	Delay	Wrong needle position	12	3	7	5	105
SNLS/01S0 161	Bobbin case jam	Stop	Lint	15	6	8	5	240
Button Attach/01S 0602	Part loose	Line stop	Vibration & lack of pm	45	10	3	10	300
SNLS/01S0	Thread breakage	Stoppage	Poor threading	10	3	8	4	96

102								
DNCS/01S 0402	Needle collision	Machine damage	Poor setup	35	7	3	6	126
SNLS/01S0 123	Needle breakage	Delay	Needle and hook timing problem	16	5	4	5	100
FOA/01S0 501	Needle breakage	Machine stoppage	Fabric thickness	25	7	5	6	210
SNLS/01S0 108	Thread breakage	Frequent stoppage	Poor threading	12	2	9	4	72
DNCS/01S 0403	Stitch inconsistency	Defective garment	Timing issue, tension	41	9	6	5	270
SNLS/01S0 103	Needle plate breakage	Production delay	Material fatigue, impact	23	9	3	6	162
Edge Cutter/01S 0701	Uneven cutting	Poor finishing	Blade wear	30	6	6	5	180
SNLS/01S0 152	Feed mechanism jam	Defective stitch	Dust	8	6	4	7	168
Button Attach/01S 0603	Cable failure	Line stoppage	Dust/electrical	60	10	4	8	280
Over lock/01S03 02	Thread breakage	Stop	Improper threading	10	6	7	5	210
SNLS/01S0 142	Problem of bobbin case	Machine stoppage	Lint accumulation,	18	8	6	5	240
DNCS/01S 0403	Thread looping under the fabric	Poor seam quality	Incorrect threading	22	6	6	5	180
SNLS/01S0 137	Thread looping on top of fabric	Defective stitch	Tension imbalance	10	3	8	5	120

		formation						
Edge Cutter/01S0703	Fabric jamming	Downtime	Dirt, lack of cleaning	20	6	5	5	150
Over lock/01S0301	Uneven stitching	Poor seam quality	Lopper misalignment, dirt	25	6	6	6	216
SNLS/01S0128	Loud noise of machine	Reduced productivity	Loose parts, wear	11	5	7	6	210
SNLS/01S0158	Tension adjustment problem	Quality variation	Improper setting	8	6	8	5	240
SNLS/01S0143	Fabric puckering	Quality defect	Tension/feed issue	25	6	7	5	210
Over lock/01S0302	Knife wear	Cutting issue	Wear	20	6	6	5	180
Button Attach/01S0603	Clamp failure	Misalignment	Wear	75	10	4	9	360
SNLS/01S0101	Thread jam in hook	Machine stoppage	Lint accumulation	30	7	7	6	294
SNLS/01S0119	Tension problem	Quality variation	Poor adjustment	20	6	8	5	240
FOA/01S0502	Feeding issue	Uneven seam	Misalignment	25	6	4	6	144
SNLS/01S038	Thread looping	Defect	Tension issue	14	6	9	5	270
DNLS/01S0401	Needle misalignment	Poor seam	vibration	27	7	6	5	210
Edge cutter/01S0703	Thread breakage	Incorrect stitch	High thread tension	9	6	6	5	180

SNLS/01S0161	Needle over heating	Fabric damage	High speed & wrong needle	10	7	6	7	294
Button Hole/01S0202	Thread breakage	Production stoppage	Tension issue, poor thread	30	8	6	6	288
DNCS/01S0401	Needle breakage	Production delay	Wrong needle, wear	15	6	7	5	210
FOA/01S0502	Puller Assembly problem	Uneven Feed / Fabric Slippage	Mismatched panels.	14	7	8	6	336
SNLS/01S0155	Fabric puckering	Defective garment	Feed/tension imbalance	16	6	7	5	210
Button Hole/01S0203	Irregular / skipped stitch	Garment rejection, rework	Needle wear, misalignment	45	9	5	7	315
Over lock/01S0301	Wrong cut	Panel reject	Improper feeding	20	6	5	5	150
FOA/01S0501	Fabric slippage	Defective seam	Feed wear	35	7	6	6	252
Button Attach/01S0602	Skipping stitch	Defective button attachment	Timing issue, misalignment	12	8	6	6	288
SNLS/01S0128	Timing problem	Defective seam	Misalignment, poor adjustment	15	6	7	6	252
SNLS/01S0118	Damaged bobbin and bobbin case	Machine stoppage	Wear, mishandling	15	4	2	6	48
Over lock/01S0302	Thread breakage	Production interruption	High tension, lint	13	6	8	5	240
SNLS/01S0142	Feed dog not feeding fabric	Machine stoppage	Wear, dirt accumulation	9	8	4	6	192

FOA/01S0502	Feeding issue	Uneven seam	Misalignment	20	6	3	7	126
SNLS/01S0121	Thread looping under fabric	Defective seam, rework	Tension imbalance, poor threading	12	2	8	5	80
SNLS/01S0132	Feed mechanism jam	Machine stoppage	Dust, lint accumulation	20	5	4	8	160
Edge cutter/01S0702	Knife dullness	Poor trimming quality	Blade wear	25	6	7	6	252
Button Attach/01S0603	Button misplacement	Rework, rejection	Clamp looseness	30	8	6	7	336
SNLS/01S0131	Bobbin tension fault	Loose stitch	Spring looseness	11	2	8	5	80
SNLS/01S0120	Hook damage	Skipped stitches	Impact, poor maintenance	22	8	4	5	160
DNCS/01S0404	Needle misalignment	Uneven seam	Needle bar shift	18	7	6	6	252
Buttonhole/01S0201	Stitch density variation	Defective buttonhole	Setting error	20	7	6	6	252
SNLS/01S0113	Thread jam inside hook	Machine stoppage	Dirt build up, bobbin problem	18	3	6	8	144
Button attach/01S0601	Noise and vibration from feeder	Loose parts	Increased machine wear	15	4	3	5	60
SNLS/01S0108	Needle bent	Breakage risk	High-speed operation	10	4	7	7	196
Edge cutter/01S0703	Lopper misalignment	Poor seam	Timing shift	22	7	6	7	294

Button Attach/01S 0602	Timing problem	Incorrect button stitching	Gear wear, poor adjustment	42	9	6	5	270
SNLS/01S0 111	Feed dog wear	Uneven feeding	Continuous friction	16	6	4	7	168
Button attach/01S0 601	Button Clamp	Weak holding pressure	Button movement during stitching	15	7	5	6	210
SNLS/01S0 109	Thread guide damage	Thread breakage	Metal wear	14	9	3	7	189
FOA/01S0 502	Feeding problem	Uneven seam	Misalignment	20	7	5	7	245
Edge Cutter/01S 0701	Excessive cutter length	Damage scrap removal area,	lack of adjustment, operator error	40	7	6	6	252
SNLS/01S0 103	Needle hitting hook	Incorrect timing setting	Needle breakage & hook damage	20	8	6	5	240
FOA/01S0 502	Needle & Looper System	Skipped Stitches	Weak seam strength	15	2	4	5	40
SNLS/01S0 101	Fabric puckering	Quality defect	Feed/tension imbalance	15	6	3	3	36
DNCS/01S 0401	Differential feed fault	Fabric distortion	Improper setting	22	7	6	6	252
Button attach/01S0 601	Loose button attachment	poor stitch formation	Button fall-off during use	10	6	2	6	72

Appendices: D

Annual PMP schedule cycle for line one

M/C code	Month											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
01S0101	S	I	O	I	M	I	S	I	S	O	M	I
01S0102	I	S	I	O	I	M	I	S	I	S	O	M
01S0103	S	I	S	I	O	I	M	I	S	I	S	O
01S0104	M	S	I	S	I	O	I	M	I	S	I	S
01S0105	S	M	S	I	S	I	O	I	M	I	S	I
01S0106	I	S	M	S	I	S	I	O	I	M	I	S
01S0107	M	I	S	M	S	I	S	I	O	I	M	I
01S0108	I	M	I	S	M	S	I	S	I	O	I	M
01S0109	S	I	M	I	S	M	S	I	S	I	O	I
01S0110	I	S	I	M	I	S	M	S	I	S	I	O
01S0111	O	I	S	I	M	I	S	M	S	I	S	I
01S0112	I	O	I	S	I	M	I	S	M	S	I	S
01S0113	O	I	O	I	S	I	M	I	S	M	S	I
01S0114	M	O	I	O	I	S	I	M	I	S	M	S
01S0115	S	M	O	I	O	I	S	I	M	I	S	M
01S0116	M	S	M	O	I	O	I	S	I	M	I	S
01S0117	O	M	S	M	O	I	O	I	S	I	M	I
01S0118	M	O	M	S	M	O	I	O	I	S	I	M
01S0119	S	M	O	M	S	M	O	I	O	I	S	I
01S0120	I	S	M	O	I	S	M	O	I	O	I	S
01S0121	O	I	S	M	O	I	S	M	O	I	O	I
01S0122	I	O	I	S	M	O	I	S	M	O	I	O
01S0123	S	I	O	I	S	M	O	I	S	M	O	I
01S0124	M	S	I	O	I	S	M	O	I	S	M	O
01S0125	S	M	S	I	O	I	S	M	O	I	S	M
01S0126	O	S	M	S	I	O	I	S	M	O	I	S
01S0127	S	O	S	M	S	I	O	I	S	M	O	I

01S0128	M	S	O	S	M	S	I	O	I	S	M	O
01S0129	S	M	S	O	S	M	S	I	O	I	S	M
01S0130	I	S	M	S	M	S	M	S	I	O	I	S
01S0131	S	I	S	M	S	M	S	M	S	I	O	I
01S0132	O	S	I	S	M	S	M	S	M	S	I	O
01S0201	O	S	O	S	I	S	M	S	M	S	M	S
01S0202	S	O	S	O	S	I	S	M	S	M	S	M
01S0301	M	S	M	S	M	S	M	S	M	S	M	S
01S0401	S	M	S	M	S	M	S	M	S	M	S	M
01S0402	M	S	M	S	M	S	M	S	M	S	M	S
01S0501	S	M	S	M	S	M	S	M	S	M	S	M
01S0502	M	S	M	S	M	S	M	S	M	S	M	S
01S0601	S	M	S	M	S	M	S	M	S	M	S	M
01S0701	S	M	S	M	S	M	S	M	S	M	S	M
01S0702	M	S	M	S	M	S	M	S	M	S	M	S

Annual planned scheduled maintenance table for line 2

M/C code	Month											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
01S0133	S	I	O	I	M	I	S	I	S	O	M	I
01S0134	I	S	I	O	I	M	I	S	I	S	O	M
01S0135	S	I	S	I	O	I	M	I	S	I	S	O
01S0136	M	S	I	S	I	O	I	M	I	S	I	S
01S0137	S	M	S	I	S	I	O	I	M	I	S	I
01S0138	I	S	M	S	I	S	I	O	I	M	I	S
01S0139	M	I	S	M	S	I	S	I	O	I	M	I

01S0140	I	M	I	S	M	S	I	S	I	O	I	M
01S0141	S	I	M	I	S	M	S	I	S	I	O	I
01S0142	I	S	I	M	I	S	M	S	I	S	I	O
01S0143	O	I	S	I	M	I	S	M	S	I	S	I
01S0144	I	O	I	S	I	M	I	S	M	S	I	S
01S0145	O	I	O	I	S	I	M	I	S	M	S	I
01S0146	M	O	I	O	I	S	I	M	I	S	M	S
01S0147	S	M	O	I	O	I	S	I	M	I	S	M
01S0148	M	S	M	O	I	O	I	S	I	M	I	S
01S0149	O	M	S	M	O	I	O	I	S	I	M	I
01S0150	M	O	M	S	M	O	I	O	I	S	I	M
01S0151	S	M	O	M	S	M	O	I	O	I	S	I
01S0152	I	S	M	O	I	S	M	O	I	O	I	S
01S0153	O	I	S	M	O	I	S	M	O	I	O	I
01S0154	I	O	I	S	M	O	I	S	M	O	I	O
01S0155	S	I	O	I	S	M	O	I	S	M	O	I
01S0156	M	S	I	O	I	S	M	O	I	S	M	O
01S0157	S	M	S	I	O	I	S	M	O	I	S	M
01S0158	O	S	M	S	I	O	I	S	M	O	I	S
01S0159	S	O	S	M	S	I	O	I	S	M	O	I
01S0160	M	S	O	S	M	S	I	O	I	S	M	O

01S0161	S	M	S	O	S	M	S	I	O	I	S	M
01S0162	I	S	M	S	M	S	M	S	I	O	I	S
01S0163	S	I	S	M	S	M	S	M	S	I	O	I
01S0203	O	S	I	S	M	S	M	S	M	S	I	O
01S0302	S	O	S	I	S	M	S	M	S	M	S	I
01S0403	S	M	S	M	S	M	S	M	S	M	S	M
01S0404	M	S	M	S	M	S	M	S	M	S	M	S
01S0503	S	M	S	M	S	M	S	M	S	M	S	M
01S0602	M	S	M	S	M	S	M	S	M	S	M	S
01S0603	M	S	M	S	M	S	M	S	M	S	M	S
01S0702	S	M	S	M	S	M	S	M	S	M	S	M

Appendices: E

Monthly sewing machine scheduled for April

M/c code	WEEKS																							
	Week 1						Week 2						Week 3						Week 4					
	M	TU	W	TH	F	S	M	TU	W	TH	F	S	M	T	W	TH	F	S	M	T	W	TH	F	S
01S0101	S																							
01S0102								I																
01S0103															M									
01S0104																						O		
01S0105		S																						
01S0106									I															
01S0107																S								
01S0108																							O	
01S0109			M																					
01S0110										I														
01S0111																	M							
01S0112																								O
01S0113					M																			
01S0114											I													
01S0115																		S						
01S0116																								O
01S0117						S																		
01S0118												I												
01S0119																			M					
01S0120				I																				
01S0121							S																	
01S0122													I											
01S0123																				M				
01S0124			I																					
01S0125										S														
01S0126																	O							

01S0127																								S
01S0128				I																				
01S0129											M													
01S0130																		O						
01S0131																			M					
01S0132	I																							
01S0201													O											
01S0202																					S			
01S0301		M																						
01S0401								O																
01S0402														M										
01S0501																				S				
01S0502					I																			
01S0601									M															
01S0701															I									
01S0702																						S		
01S0133						I																		
01S0134										S														
01S0135																O								
01S0136																							M	
01S0137			I																					
01S0138												M												
01S0139																	O							
01S0140																								M
01S0141																I								
01S0142				O																				
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01S0163												O												
01S0203																	S							
01S0302																							M	
01S0403				O																				
01S0404							S																	
01S0503		S																						
01S0602								M																
01S0602															I									
01S0702																						O		

Appendices: F

Literature gap

Thematic Area	Authors and Years	Identified Gaps	Methodology Adopted in this Study
Machine-Level Failure Analysis	Ahmed et al. (2019); Agustina (2019)	The majority of studies report overall downtime statistics & do not analyze failures at the individual machine level.	Conducted machine-wise failure analysis & identified critical sewing machines using PFMEA & RPN.
Integration of PFMEA with Preventive Maintenance	Muthalib et al. (2019); Certa & Galante (2018); Farouk & Youssef (2025)	Existing studies discuss PFMEA &PM separately, with limited integration of PFMEA into PMP.	Integrated PFMEA with PM to establish a risk-based maintenance framework for sewing machines.
Maintenance Prioritization	Parsana & Patel (2014); Ciani et al. (2019)	Traditional PM treats all machines equally without considering their failure criticality and operational impact.	Prioritized machines based on Severity, Occurrence, Detection, and RPN values.
Ethiopian Garment Industry Context	Rundassa & Berhan (2019); Legesse & Singh (2014); Mulugeta (2020)	Research in Ethiopian garment industries mainly focuses on lean manufacturing & productivity improvement rather than machine reliability & PM.	Conducted a case study at Senmul Garment PLC & developed a practical PFMEA-based maintenance framework.
Practical Maintenance Tools	Anal et al. (2014); Farouk & Youssef (2025)	Most studies identify failure modes but do not provide practical maintenance schedules, checklists, or recording sheets.	Developed daily, weekly, monthly, and overhaul schedules, PFMEA sheets, checklists, and maintenance record forms.
Sewing Machine Reliability	Singh & Tewari (2023); Kipchumba & Chemweno (2024)	Limited studies investigate the relationship of sewing machine failures & production continuity.	Analyzed sewing machine failures & developed reliability-focused PM actions.