Lean Production System Analysis For Quality Maintenance

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Abstract: Waste is products, procedures, and activities in a company that is considered non-value-adding benefits. The Lean Production System aims to minimize waste while maximizing quality, productivity, and efficiency. Any business and company have lean waste that needs to be reduced or eliminated; accordingly, the researchers conducted a study in PMC Bottle King Solutions Services, Inc. to determine the highest value of waste in the company using qualitative and quantitative approaches, namely descriptive analysis, discussion, observations, and survey research methodologies. For the acquisition of data, survey questionnaires and unstructured interviews were administered to 22 participants. It was found that the highest value of waste in the company is Machine Breakdown; thus, the study focused on reducing breakdowns. A time study was also conducted for a week to determine the machine downtime. The data gathered were analyzed using different lean tools and techniques. The researchers identified the root causes and reasons for Machine Breakdown which are heating, sensor, and oil seal; and its effects on sales in the company to which they lose ₱ 25,385.83 daily. The current quality implementation of the company was also analyzed using different metrics of Incident Management Key Performance Indicator that indicates that the company takes longer to respond and resolve. With all the data gathered, the researchers proposed a Quality Maintenance Procedure that, if strictly implemented, could significantly reduce machine breakdowns.

Keywords: waste, waiting, PET plastic, machine breakdown, total production, maintenance

I. INTRODUCTION

"Seek perfection, continually improve quality, and eliminate waste"- Larry Rosborough, 2020

Waste refers to the products, substances, and services consumed, bought, and employed uselessly and not fully utilized or appreciated. It does not give an adequate return or total value [1]. In an industry, waste is considered an action or a step of the process that does not add any merit to the customer. It is the greatest enemy of profitability in a business [2].

The Lean Production System (LPS) is a systematic manufacturing method with tools and principles focused on eliminating waste while boosting productivity and efficiency [3].

According to the statistics presented during the 2020 Virtual Fenestration Canada meet, 60% of the majority of a company's activities are considered wasteful; 35% are necessary but have no value; and from the perspective of the customer, only 5% offer value-added benefits. The majority of the wasteful activities fall into the 8 Muda of Lean Production. Any one of these deadly lean wastes could cause the business to lose its efficiency and money. Identifying and eliminating them is the key to presenting and delivering value to the customers [4].

Maintenance. It is a profit center in any production environment that significantly impacts the company's ability to maximize production to achieve long-term objectives. It assists businesses in maintaining their resources while regulating time and costs to maximize the efficiency of the production process, utilities, and related facilities [5].

PET plastic bottles frequently replace bulky and delicate glass bottles in various items since they provide reusable packaging for beverages like mineral water. Compared to glass, PET bottles can reduce weight by up to 90%. The market for PET bottles was worth USD 84.3 billion in 2019 and is anticipated to reach USD 114.6 billion by 2025, registering a CAGR of 6.64% during the forecast period for 2020 to 2025

II. BACKGROUND OF THE STUDY

Total Productive Maintenance. From identifying the waste of lean management this study is done through the use of Total Productive Maintenance and its proactive approach. It aims to involve all organizational levels and functions to increase the overall efficiency of industrial machinery. By minimizing errors and mishaps, this technique fine-tunes already-existing procedures and machinery. Total Productive Maintenance (TPM) aims to incorporate staff members from all departments and levels, from the plant floor to senior executives, to ensure efficient equipment performance.

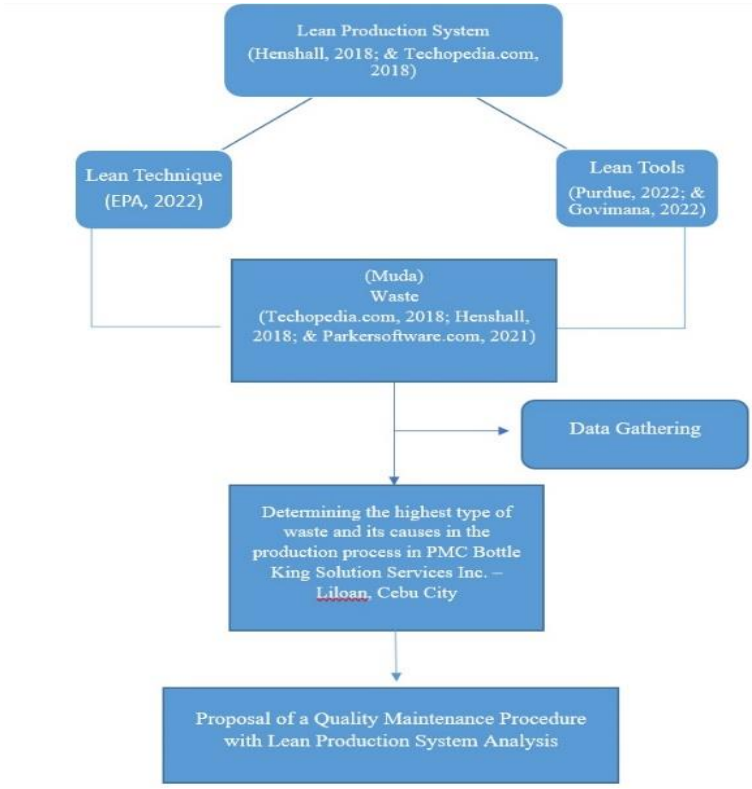

Fig. 1 Schematic presentation of the theoretical background of the study

Lean production's basic tenet is the detection and removal of waste. In order to help focus efforts in this area, lean practitioners created a list of eight wastes: defects, overproduction, transportation, processing, motion, waiting, unused talent, and inventory. These apply to processes involved in the creation of products or any activity that occurs in the normal course of business.

Defects. A defect is defined as anything that does not please customers in Lean, which has a unique focus on addressing customer needs.

Overproduction. Businesses that achieve success may overproduce their products, going too far ahead of market demand. This type of oversupply might result in additional expenditures for storing goods, among other concerns.

Transportation. Transportation issues are often the result of poorly planned processes. It can also refer to the time required to communicate necessary information to continue a procedure where the longer the transit route, the more time is spent.

Non-Value-Added Processing. A multitude of difficulties can result in activities that bring no value to the process e.g. poorly structured process, such as inadequate communication, overlapping areas of responsibility, and data duplication. In Lean, it is critical to evaluate each stage of a process to see if it adds value to the consumer.

Motion. Time wasted is money lost. This issue is frequently traced back to poorly organized workstations and work flow.

Waiting. Waiting can occur in a variety of ways during the manufacturing process. In most circumstances, it involves workers waiting for someone upstream to either provide them with the supplies or knowledge they require to do their tasks, or it entails a machine breakdown. Bottlenecks that form result in waiting and wasting time.

Inventory. Overproduction of resources or completed products, which must then be kept, can cause inventory issues. It can also involve ordering an excessive number of materials from suppliers and requiring a big amount of storage space to store them.

Unused Talent. To eliminate this waste, managers must do a thorough review of their employees' abilities and expertise, as well as how to put them to use to improve operations.

These wastes highlight the areas where the waste is most likely to occur. The secret to success when implementing lean techniques is to comprehensively understand these eight areas and prioritize process improvement efforts within each of them [6].

III. RELATED WORKS

A business should be efficient and sustainable to gain a competitive advantage in the increasingly competitive global market. This means having strategic planning and practices that allow the company to offer more products or services with less cost and resources. It also means minimizing waste and enhancing quality at the source.

The Japanese created the concept of Lean Production System Analysis in the 1980s to reduce waste in PET plastic bottle industries. This methodology suggests eliminating tasks that provide no value to the consumer, minimizing waste generated, and was adopted by many sectors due to its affordability, quality, and flexibility [7].

Lean manufacturing is a strategy used by industries to reduce and eliminate waste and increase productivity as a strategy to increase companies' competitiveness. Numerous studies have emphasized the positive relationship between lean implementation and business performance [8]. A continuous improvement techniques were implemented to preserve the company's levels of competitiveness and the satisfaction of its customers in terms of quality [9]. In general, companies must quickly adapt to market changes and implement policies of product innovation and standardization to improve weaving production.

On the investigation of wasteful activities in Kazakhstan, survey examined general understanding of wasteful activities and Lean methods to reduce non-value-adding tasks [10]. Lean Manufacturing enhances a company's operational excellence, which

gives it a competitive edge in terms of pricing, service quality, and on-time delivery. It also helps organizations increase their quality and response time to client demand, resulting in defects being decreased, customer value flows optimized, inventories being decreased, and delivery times being enhanced [11].

Lean manufacturing's primary goal is to manufacture finished goods with little to no waste in response to customer demand. Lean production as a multidimensional approach that combines several management techniques, such as just-in-time, quality control, work teams, cellular manufacturing, supplier management, etc., into one cohesive system [12]. This methodology has previously demonstrated its effectiveness in SMEs and large corporations, but studies on lean adoption in tiny businesses (VSBs) still need to be made available [13].

Lean manufacturing is the most effective production system of the 21st century, as it requires less investment and is suitable for practically all types of companies [14].

Lean manufacturing uses a variety of approaches and methodologies to eliminate every bit of waste in a specific sector [15]. Defective parts and products have an evident negative effect on the company's sustainable performance, so lean methodology and its tools were used to provide accurate information on what specific defects affect the production [16].

Local Small and medium-sized manufacturers (SMEs) experienced difficulties in competing on the global market with large industrial companies [17]. To address this, they used Lean Manufacturing methodologies to enhance system performance across their Plastic Injection Melding (PIM) operation.

Different quality management tools were used to evaluate and assess the quality of processed pet bottle production [18]. The Pareto-Lorenz diagram was used as a quantitative approach to the PET bottle quality issues, and the Ishikawa diagram was used to determine the most prevalent issue's likely causes. The machine should not be utilized for its full capacity, as it is mathematically impossible for a machine to be operational for more than the amount of time allowed [19]. The present investigation is aimed at addressing this gap statistically, specifically in the PET plastic bottle industry.

IV. METHODOLOGY

This study is a quantitative descriptive research that uses an observational and survey research design to provide analytic data and systematic details for the maintenance of PMC Bottle King Solutions Services Inc., a PET-plastic bottle firm at Cebu, Philippines, improve productivity and reduce waste, human effort, and inventory by utilizing several Lean Techniques and Tools to attain quality maintenance procedure regarding its Lean Production System. The researchers used Field Observation, Unstructured Interview and Discussion, and Highest Waste Survey Questionnaire to gather data. The researchers used statistical and lean tools to analyze and evaluate the acquired data, specifically using Percentage Frequency Distribution, Pareto Chart, and Incident Management Key Performance Indicator. The data collected also served as a guide in analyzing the current waste situation in the area, which can help improve the company's current state and quality management.

V. RESULTS AND DISCUSSIONS

PMC Bottle King Solution Services Inc. faces daily problems with the number of difficulties encountered during production that resulted in minutes of waiting, several rejections, and additional repair costs that hindered the company's efficiency, productivity, and total capacity.

This section presents the responses of the respondents to the Lean Waste survey questionnaire. The data shown in Figure 4 indicates the percentage of waste in the company analyzed using a percentage frequency distribution bar graph. The researcher's observation is also discussed in this section.

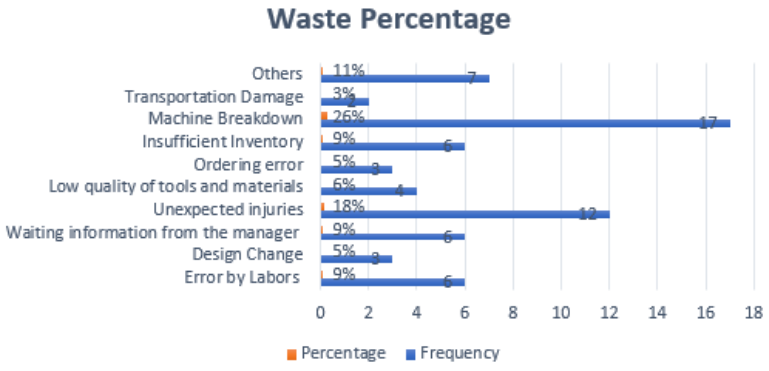

Fig 4. Waste produced in PMC Bottle King Solutions Services Inc.

Figure 4 shows the survey result on the waste within the company. The researchers found that the major contributor of waste in the company is the number and duration of Machine Breakdowns which accumulate 26% of the total waste. Further data and information gathered focused on identifying and reducing waste of machine downtime in accordance with Lean Concept. Machine Breakdown is among the waste in the production process that needs to be eliminated because of its negative impact on the company [20].

Table 2 Data Collection of Machine Breakdown for a week

Breakdown	in minutes						Average min/day	Average hr./day
	5-Dec-22	6-Dec-22	7-Dec-22	8-Dec-22	9-Dec-22	10-Dec-22		
Mechanical	200	270	95	105	80	412	193.67	3.23

Electrical	0	0	0	0	0	20	3.33	0.06
Total	200	270	95	105	80	432	197	3.28

Table 2 shows the Data Collection of Machine Breakdown. The target for breakdown/day of the company is only 30 minutes in every shift, but the current status of machine downtime in the industry exceeds the target.

The Breakdown Analysis is used to determine the root causes and reasons of the Machine Breakdowns. The analysis reveals the reasons and the primary cause of the breakdown in the production area.

Table 3 List of Breakdowns

No.	Breakdowns	Minutes
1	Heating	739
2	Nut detachment	50
3	Oil Seal	180
4	Sensor	239
5	Light	30
6	Motor-Chiller	143
7	Leaking	30
8	Electrical	20
	Total	1431

Table 3 shows the number, the type of breakdowns, and the minutes of the occurrence of the breakdowns in the company. There are 8 different types of breakdowns in the company, and each breakdown takes different machine downtime.

The highest type of machine breakdowns was identified through the use of a Pareto Diagram, and figure 6 depicts the major contributor to the breakdowns.

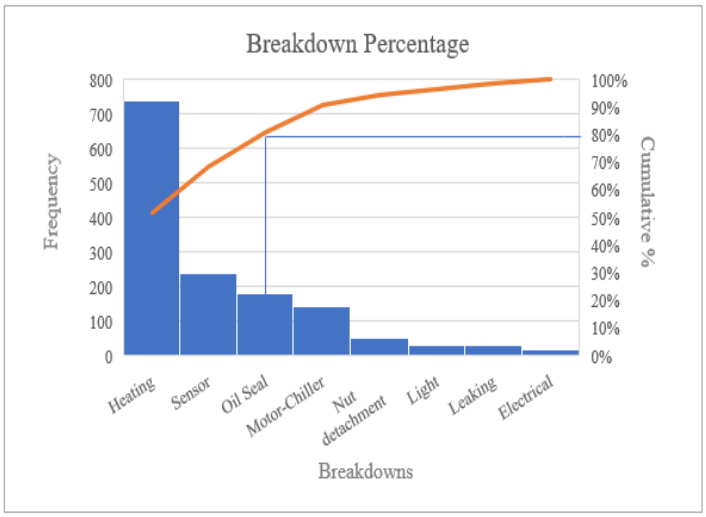

Fig 5. The Machine Breakdown Percentage

Following the 80/20 rule, the major contributor of breakdowns are as follows: Heating, Sensor, and Oil Seal.

The root cause and reasons for the breakdowns are stated in Table 4.

Table 4 The Root Cause and Reasons for Breakdown

No.	Breakdown	Root Cause	Reasons
1	Heating	Overuse	The machine running at total work and malfunctions of temperature setting
2	Sensor	Misalignment of device	Overexposure to high temperature, bearing failures, and seal failure
3	Oil Seal	Improper installation	Dust accumulation, not sufficiently lubricated, and stress by high pressure

Table 4 determines the root causes and reasons of the major contributor to breakdowns found using the Pareto Chart.

This section shows the production of the company and the prices of the bottles produced that indicates the company's Total Sales if the expected daily production is produced and attained.

Table 5. The Production per Machine and the Prices of the Products in a 24-hour operation

Type of Machine	Type of Bottle Product	Number of Production per packs	Price per pack	Sales

		Produced		
Automatic Pet Bottle Machine	500 mL	90	₱ 550.00	₱ 49,500.00
	300 mL	80	₱ 605.00	₱ 48,400.00
Manual Bottle Machine	1 Liter	70	₱ 430.00	₱ 30,100.00
	500 mL	50	₱ 550.00	₱ 27,500.00
	330 mL	50	₱ 605.00	₱ 30,250.00
Total Sales				₱ 185,750.00

Table 5 shows each machine produces different PET bottles per pack with different prizes. If the daily quota with full production is achieved, the company's total sales are ₱ 185,750.00. Considering that there is an average of 3.28 hours of machine breakdown in the company in a day, the researchers found out that the company loses a sale of ₱ 25,385.83 every day.

Tracking key performance indicators (KPIs) for incident management can assist in identifying and diagnosing problems with processes and systems, provide benchmarks and realistic targets for the team to work toward, and provide a starting point for larger questions.

Table 6. Key Performance Indicator of the current production.

Key Metric	Formula	in hours	in minutes
Machine Uptime	$\frac{\text{Total Time - Machine Downtime}}{\text{Total Time}}$	86%	86%
Mean Time Between Failure	$\frac{\text{Total Working Time - Total Breakdown Time}}{\text{Number of Breakdowns}}$	7.31	438.71
Mean Time to Repair	$\frac{\text{Total Maintenance Time}}{\text{Number of Repairs}}$	0.37	22.44
Mean Time to Resolve	$\frac{\text{Total Hours of Downtime}}{\text{Total Number of Incidents}}$	1.16	69.53
Mean Time to Respond	$\frac{\text{Full Response Time}}{\text{Number of Incidents}}$	0.66	39.60
Mean Time between to acknowledge	$\frac{\text{Time to acknowledge}}{\text{Number of Incidents}}$	0.50	29.93
Mean Time to failure	$\frac{\text{Total Operating time of the products}}{\text{Number of Devices}}$	4.8	288.00
System Availability	$\frac{\text{Mean Time between failures}}{\text{Mean Time Between failures + Mean time to repair}}$	95%	95%

The researchers found that only 86% of the machine is available and actually runs in the total production time with 7.31 hours of mean time between failures. The average time to repair a breakdown is 22.44 minutes, and it takes 1.16 hours to resolve. It is evident that the company takes longer to respond and acknowledge the breakdown, which takes 29.93 minutes and 39.60 minutes, respectively. Furthermore, it is shown that the machines can run up to an average of 4.8 hours before it breaks. The System Availability of the overall production process or the probability of the system performing as expected during a mission as per calculation is 95% - a difference of 9% compared to the total machine uptime.

VI. PROPOSED QUALITY PROCEDURE

This phase presents the proposed Quality Procedure for PMC Bottle King Solutions Services, Inc. After analyzing and studying the case in the company, the following recommended procedures are made by the researchers:

1. Machine Maintenance Ticket

The researchers proposed a Machine Maintenance Ticket to regulate and control the number of machine breakdowns happening in the production area. Corrective actions must be noted if the breakdown exceeds to 30 minutes in each shift. The maintenance manager must thoroughly document the ticket.

MAINTENANCE TICKET

Operator's Name: Date:
Maintenance Manager: Hazard risk:
Machine Type: Serial No.:
Time of Breakdown: _____
Causes and Reasons
_____
_____
Time to acknowledge: _____
Start Time of repair: _____
End Time of repair: _____
INITIAL TEST OF MACHINE
Time: _____
CHANGED OR NEW DEVICE INSTALLED (Must be tested on line)
Date: _____/_____/_____
Manufacturer: _____
Comments: _____
FINAL TEST OF DEVICE (If device fails – must be completed)
Time Tested
DEVICE PASSED:
Time machine back to operation:
Additional comment/s: _____
The above report is certified to be true.

_____
Signature of Maintenance Manager

Fig 6. Machine Maintenance Ticket

2. Machine Maintenance Tag

If a machine breakdown happens, a maintenance repair tag [21] must be answered and hung on the machine, indicating that the machine is still on the repair.

3. Machine Maintenance Manual

The Maintenance Manual [21] for every machine should be displayed near the machine where the operator can see and read the instructions on how to operate the machine properly. If a breakdown happens, the maintenance manual should display instructions on what to do before, during, and after.

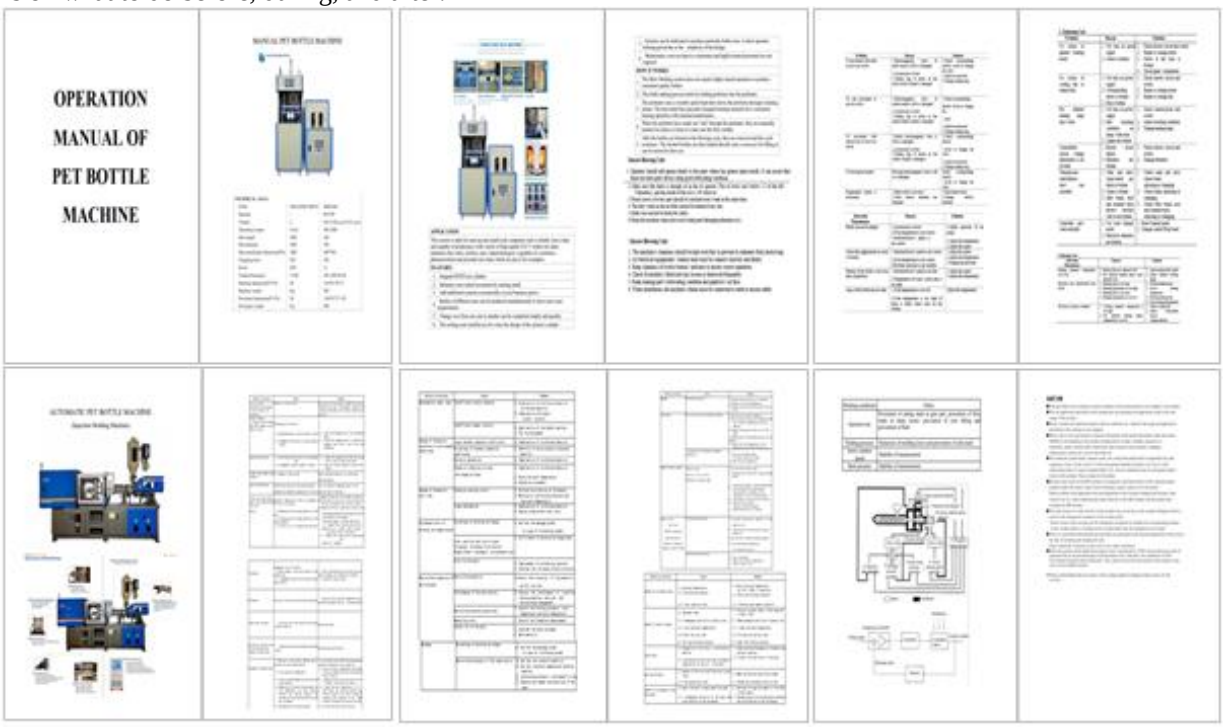

Fig 8. Operation Manual of PET Bottle Machine

4. Heating, Sensor, and Oil Seal Breakdown

After determining the root cause and reasons for machine breakdown, the researchers used the Total Production Maintenance proactive approach according to its concept and pillars. The proposal is provided in the following steps: Corrective maintenance action, Preventive maintenance action, and Predictive maintenance action.

4.1 Corrective Maintenance Action

The breakdown analysis is given with corrective maintenance action depicted in Table 7.

No.	Breakdown	Root Cause	Corrective Maintenance Action
1	Heating	Overuse	Have a daily 2-hour Machine Downtime to lessen the breakdown and regulate the temperature
2	Sensor	Misalignment of device	Be attentive during the bearing installation process and checking of alignment
3	Oil Seal	Improper installation	Establish a regular checking and inspection of oil seal condition and installation of the machines.

Table 7 Corrective Maintenance Action Plan

4.2 Preventive Maintenance Action

The Preventive Maintenance Action Plan shall be done in a check sheet monitored by the operators and maintenance manager daily and weekly.

Table 8 Preventive Maintenance Action Plan Daily Check Sheet

Date:		
Operator's Name:		
Machine:		
Time	**Daily Check List**	**Remarks**
	Rest the Machine for 30-60 minutes (Day shift)	
	Rest the Machine for 30-60 minutes (Night shift)	
	Check the Temperature Settings	
	Check the Oil Seal condition	
	Check Oil Seal and Bearing Alignment	
	Check Sensor condition	
	Check for dust	

Table 9 Preventive Maintenance Action Plan Weekly Check Sheet

Month and Year:										
Machine:										
Weekly Check	**1st Sunday**		**2nd Sunday**		**3rd Sunday**		**4th Sunday**		**5th Sunday**	
List	Time	Remarks	Time	Remarks	Time	Remarks	Time	Remarks	Time	Remarks
Pressure Checking										
Inspect Oil Seal Thickness										
Check Machine Operating Temperature (below 75°)										
Check Sensor alignment										
Date										
Checked by										

4.3 Predictive Maintenance Action

The Predictive Maintenance Action is to be checked by the production-in-charge on a check sheet monthly basis.

Table 10 The Predictive Maintenance Action Plan Monthly Check Sheet

Date:		
Production-in-Charge:		
Machine:		
Monthly Check List	**Time**	**Remarks**

Regulate the ideal temperature of the blow to the bottle		
Changing of wear out oil seal		
Checking of Machine temperature		
Cleaning dust and sand		
Regulate pre-blowing of the bottle with fast cooling		
Optimize the consumption of High-Pressure Air		
Check Sensor rod distance		
Checking of stock materials		

5. Industrial Infrared Thermometer

Fig 9. Industrial Infrared Thermometer

Since one of the major contributors to machine breakdown is overheating, the researchers proposed purchasing and using an industrial infrared thermometer [21] that will help the company monitor and maintain the temperature of the machines to minimize breakdowns.

With the help of this tool, temperature readings can be easily detected to avoid overheating. The device should be 5-15 meters away from the machine to have the exact readings of the temperature.

6. Mean Time to Resolve, Mean Time to Repair, and Mean Time to Acknowledge

Annual training shall be implemented to improve the efficiency and effectiveness of the workers in handling machines and to instruct workers on how to immediately alert the maintenance manager and production-in-charge. This annual training is especially for those new and inexpert workers.

TRAINING PLAN SHEET

Program Title	ANNUAL TRAINING OF PMC BOTTLE KING SOLUTION SERVICES INC.
Today's Training Title	ANNUAL TRAINING ABOUT MACHINE OPERATION AND BREAKDOWN
Total Time	8 AM – 12 PM, every Last Saturday of June
Objective	To train and improve the new and inexpert workers; and aims to improve the quality of work and how to handle machine breakdowns
Assessment Overview	This training planning sheet is intended for new and inexpert workers, they shall be trained by an expert trainer or by experienced personnel of the company and they must be instructed of the production process, how to list breakdowns, and how to alert the maintenance manager in a timely and abrupt manner.
Location	Inside the company specifically at the production area

Sequence	Topic/ Content	Methods of delivery	Time
Introduction	Invocation and the National Anthem	Song	8:00am-8:10am
	Data about the previous breakdowns	Statistical Presentation	8:10am – 8:30am
	Data about the statistical analysis between breakdown and the worker	Comparative Analysis using Graphs	8:30am - 8:45am
	Present reviews from the manager	A discourse from the manager	8:45am-9:00am
Body	How to properly operate the machine?	An actual presentation from the maintenance manager	9:00am-9:25am
	Break		9:25am - 9:35am
	How to identify machine breakdowns?	An actual presentation	9:35am - 9:50 am
	What to do before, during, and after machine breakdown?	An actual and graphic presentation	9:50am-10:50am
Conclusion	Question the workers about their understanding	Question and Answer	10:50am-11:20am
	Activity Application about machine breakdown practices	Apply the machine breakdown discussion through an activity	11:20am-11:40am
	Training Summary	Brief conclusion from the production-in-charge	11:40am-12:00pm
Lunch			12:00 PM

Fig 10. Training Plan Sheet

7. Proposed Quality Maintenance Procedure

Table 11 The Proposal for Quality Maintenance Procedure in a Cost-Benefit Analysis

No	Activity	Person Assigned		Cost (in a year)	Benefit	Remarks
1	Machine Maintenance Ticket	Machine Operator		₱ 2.5x 313 = ₱ 782.5	Regulates the number and duration of breakdowns	
2	Machine Maintenance Tag	Maintenance Manager		₱ 1.25x 313 = ₱ 391.25	To help monitor repair and maintenance	

3	Machine Maintenance Manual	Maintenance Manager or Production-in-Charge		₱ 5 x 5 = ₱ 25	To instruct workers before, during, and after machine breakdowns	
4	Daily Check Sheet	Machine Operator		₱ 1.25x 313 = ₱ 391.25	As a Preventive Maintenance Action Plan	
5	Weekly Check Sheet	Machine Operator		₱ 2.5 x 12 = ₱30		
6	Monthly Check Sheet	Production-in-charge or maintenance manager		₱ 5 x 12 = ₱ 60	As a Predictive Maintenance Action Plan	
7	Annual Training of workers	All Workers		₱ 5,000	Improves efficiency with minimal breakdowns	
8	Purchase Industrial Infrared Thermometer	Production-in-charge or maintenance manager		₱ 1,500	Helps in monitoring the temperature of the machine to avoid overheating	
Total				₱ 8, 180		

Table 11 depicts the actions or activities to reduce the duration of machine breakdown and improve productivity to achieve quality maintenance at PMC Bottle King Solutions Services, Inc. The Total Cost of this proposal is only ₱ 8, 180 per year. The researchers included the designated person, cost, and benefits to achieve the proposed procedures.

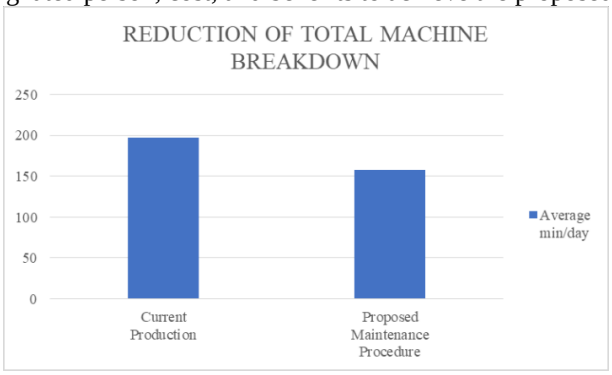

Fig 11. Reduction of Total Machine Breakdown if the proposal is implemented

As shown in the figure above, the current production has a total of 197 min/day of machine breakdown. However, if the proposed maintenance procedure is implemented, the Total Machine Breakdown can decrease up to more or less 39.4 minutes per day, resulting in an average of 157.6 min/day breakdowns. This is based on the study of the Reduction of Breakdown Hours through the Lean Technique in a High-Volume Low Variety Manufacturing Industry which indicates a reduction of up to 20% of the total breakdown hours using TPM [15].

VII. CONCLUSION AND FUTURE SCOPE

The researchers concluded that Lean Production System is a practical analysis to identify the highest value of waste in PMC Bottle King Solutions Services, Inc., specifically machine breakdown resulting in unplanned downtime. It is also an efficient methodology for minimizing the identified waste, significantly reducing total machine downtime when implementing Lean tools and techniques. It is shown in Figure 11 that when the Proposed Quality Maintenance Procedure is implemented, the Total Machine Downtime will decrease by up to 20%, improving the company's production, efficiency, and quality.

The following are recommended for future researchers who want to conduct a study related to Lean Production System Analysis: The researchers recommend studying other lean waste in the company, not just machine breakdown. Furthermore, they also recommend gathering data in a longer timetable. On the other hand, they advised assessing the participants' awareness of the Lean Production System and its correlation to the company's quality implementation status. Lastly, the researchers recommend the future researchers to apply and implement the proposal and recommendation to their prospective study.

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