Sudan University of Science and technology
College of Engineering
School of Mechanical Engineering
(Production Department)

Implementation of Preventive Maintenance Optimization Techniques In (Pasgianos Factory)

(Case Study)

A Project Submitted in Partial fulfillment of the Requirements of the Degree B.Sc. (Honor) in mechanical Engineering

Prepared by:

Albokhary Mohammed Taher Bashir Hamid
Almoatassem Bellah Khalaf Allah Ahmed Ali
Masaad Shawgy Masaad Ali

Supervisor:

Ustaz. Widatalla Alamin Abdalla

October 2017

بسم الله الرحمن الرحيم

قال تعالى:

" قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ "

سورة البقرة الاية 32

إهداء

إلي الذي منني كل ما يملك .. ولم يأخذ جهداً في تقديم الدعم لي ..

حتى صرت نباتاً استوى على سوقه بإذن الله .. وكنت الزرع

الذي يعجب الزراع نباته..

وسر نجاحي ونور دربي ... **والدي**

إلي نبع المحبة والحنان و الوفاء و أغلى ما أملك... **والدتي الحبيبة**

إلي من أحن وأشتاق إليهم دائماً..

إلي من هم عزوتي وسندي في الحياة ... **إخواني**

إلي من كانو لي أوفياء ... **أصدقائي جميعاً**

إلي من ساهم في انجاز هذا العمل المتواضع..

الي الذي وجهنني وصوبني وبذل معي اقصى جهده ... **مشرفي**

الباحثون

الشكـــــر والعرفـــان

ما كان للكلمات أن تفي صاحب الحق حقه ولا العبارات المنمقة إن ترد ولو قليلاً من جميل أشخاص كان لهم عظيم الأثر في انجاز هذا البحث على أننا لا نملك إلا أن نقدم جزير الشكر وجليل الاحترام لمن وقف معنا على طول الدرب وأخذ بيدنا إلى طرقات الخير والعلم وقدم لنا من الدعم المادي والمعنوي , كما نرجو أن نستطيع رده يوم من الأيام.

الى **د. وداعة الله الأمين**, نمد أيدينا بكل ما نستطيع حمله من مودة وعرفان جميل فقد بدأت فكرة البحث من توجيهاته وإرشاداته وكان على طول الطريق الرفيق الأمين الذي لطالما صحح أخطائنا رغم كثرتها , ورفع معنوياتنا . ونحمد الله تعالى على نعمته بأن نور به طريق حياتنا فعسى إن لا نفقده على طول هذا الدرب ولا بد لنا من توجيه شكر جزيل للذي لم يبخل علينا بأي إجابة أو مساعدة بل كان له الفضل الكبير في إبداء النصح في عديد من التفاصيل والمشاكل التي واجهتنا أثناء العمل ولعل ما نقدمه بكل تفاني ابلغ من أي تعبير عن جهدهم المبذول بكل إتقان فلهم جزيل الشكر وعظيم الإمتنان..

Abstract

This research explains how to implement the **Preventive Maintenance Optimization (PMO)** methodology as a new concept of engineering management and puts a practical picture and modern application to develop maintenance departments in terms of performance and efficiency. This was done through a test and application at the Pasgianos soft drink factory.

In this research, we sought to implement a targeted **(PMO)** methodology to one of the most important machines in the production line of soft drink in Pasgianos factory.

The **(PMO)** methodology focuses on faults affecting the most common machine within the Pasgianos production line and the development of a maintenance strategy to reduce these failure and reduce their likelihood of occurrence.

In this study, were identified the problems that cause the machines to stop continuously to avoid future recurrence and avoid them completely using the tools and steps provided by the **(PMO)** method.

By applying the **(PMO)** method, we manage to reduce the downtime and the economic cost, also increase reliability and productivity of the system.

الملخص

هذا البحث يشرح كيفية تطبيق منهجية**Preventive Maintenance Optimization** (PMO) كمفهوم جديد للإدارة الهندسية ويضع صورة عملية وتطبيق حديث لتطوير أقسام الصيانة من حيث الاداء والكفاءة. وتم ذلك من خلال اجراء الإختبار وتطبيقة في شركة ج.د.بيزيانوس للمشروبات الغازية .

وقد سعينا في هذا البحث لتطبيق منهجية (PMO) مستهدفين ماكنتين ضمن اهم الماكينات في خط إنتاج مشروب بزيانوس.

ترتكز منهجية (PMO) على التركيز على الاعطال المؤثرة على الانتاج والأعطال الأكثر شيوعا ضمن خط الإنتاج في شرك ج.د.بيزيانوس و وضع استراتيجية للصيانة للحد من هذه الأعطال وتقليل إحتمالية حدوثها

سعينا من خلال هذه الدراسة لتحديد جزور المشاكل التؤدي الي توقف الماكينات بشكل مستمر لتجنب تكرارها مستقبلا وتفاديها بصورة كاملة مستخدمين الادوات والخطوات التي توفرها منهجبة (PMO).

بتطبيق منهجية (PMO) نستطيع تخفيض زمن توقف الماكينة وايضا تخفيض التكلفة الاقتصادية، وتساعد ايضا في زيادة اعتمادية النظام وزيادة معدل الانتاج.

Table of content

List of Tables

List of Figures

List of Abbreviations

Abbreviation	Stand for
BM	**B**reakdown **M**aintenance
PM	**P**reventive **M**aintenance
PdM	**P**re**d**ictive **M**aintenance
PMO	**P**reventive **M**aintenance **O**ptimization
RCM	**R**eliability **C**entered **M**aintenance
CBM	**C**ondition **B**ased **M**aintenance
FMA	**F**ailure **M**ode **A**nalysis
FMEA	**F**ailure **M**ode and **E**ffect **A**nalysis
FMECA	**F**ailure **M**ode, **E**ffect and Criticality **A**nalysis
RPN	**R**isk **P**riority **N**umber
RCA	**R**oot **C**ause **A**nalysis

CHAPTER ONE

INTRODUCTION

1.1 INTROUDCTION:

With the continuous evolution of the science and technology more machines are continues to show up making our lives easier and more enjoyable. Unfortunately, these machines cannot keep serving without proper care and attention and here rise the importance of maintenance.

In general, maintenance is an action necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition to achieve its maximum useful life.

The main point of maintenance is to make sure that the machine will continue to work with high performance as long as possible. And to reach this, new types and kinds of maintenance has been discovered and developed.

There are five main types of maintenance each one of them has a different time and a different stages but the same result.

These types are breakdown maintenance (BM), preventive maintenance (PM), predictive maintenance (PdM), reliability-centered maintenance (RCM) and preventive maintenance optimization (PMO).

Breakdown maintenance is maintenance that performed to repair the machine after the failure while preventive maintenance is maintenance that performed to prevent the failure of the machine before it is happen.

In other hand, we have predictive maintenance this type of maintenance has two stages, first to predict when the failure might occur and second to prevent the occurrence of the failure by performing the proper action.

Reliability-centered maintenance is the type of maintenance that determine the most effective maintenance should be applied. Reliability-centered maintenance has been developed to become more effective and this lead us straight to preventive maintenance optimization, which it is our current research object.

1.2 Project Problem:

Pasgianos factory follow the traditional method of maintenance such as breakdown maintenance which it depend on waiting the occurrence of the failure then perform the corrective actions. Using this type maintenance have series effect such as reducing the life cycle of the machine or equipment. Also it reduce the reliability of the system and it require high cost, time and effort.

1.3 Project Objective:

1- Analysis of failures

2- Select the proper type of maintenance

3- Make maintenance strategy

1.4 Scope:

Conduct the (PMO) methodology in a pasgianos factory for the production line on Blow Mold and Filler machine.

CHAPTER TWO

Literature Review

2.1 Classify of maintenance

The guiding principle preventive maintenance is the regular and systematic application of engineering knowledge and maintenance attention to equipment and facilities to ensure their proper functionality and to reduce their rate of deterioration. [1]

Before describe predictive maintenance and Reliability Centered Maintenance (RCM) we should first know the old maintenance method and the reasons that direct to develop new strategy for maintenance.

Breakdown maintenance was practiced in the early days of production technology and was reactive in nature. Equipment was allowed to run until a functional failure occurred. Secondary damage was often observed along with a primary failure.

This led to time-based maintenance, also called preventive maintenance. In this case, equipment was taken out of production for overhaul after completing a certain number of running hours, even if there was no evidence of a functional failure. The drawback of this system was that machinery components were being replaced even when there was still some functional lifetime left in them. This approach unfortunately could not assist to reduce maintenance costs.

Due to the high maintenance costs when using preventive maintenance, an approach to rather schedule the maintenance or overhaul of equipment based on the condition of the equipment was needed.

This led to the evolution of predictive maintenance. It requires continuous monitoring of equipment to detect and diagnose defects. Only when a defect is detected, the maintenance work is planned and execute.

Predictive maintenance in the actual sense is a philosophy – an attitude that uses the actual operating conditions of the plant equipment and systems to optimize the total plant operation. It is generally observed that manufacturers embarking upon a predictive maintenance program become more aware of the specific equipment problems and subsequently try to identify the root causes of failures. [2]

2.2 Preventative maintenance (PM)

Preventative maintenance (or preventive maintenance) is maintenance that is regularly performed on a piece of equipment to lessen the likelihood of it failing. Preventative maintenance is performed while the equipment is still working, so that it does not break down unexpectedly.

Preventative maintenance is planned so that any required resources are available.

The maintenance is scheduled based on a time or usage trigger. A typical example of an asset with a time based preventative maintenance schedule is an air-conditioner which is serviced every year, before summer. A typical example of an asset with a usage based preventative maintenance schedule is a motor vehicle, which might be scheduled for service every 10,000km.

Preventative maintenance is more complex to coordinate than run-to-failure maintenance because the maintenance schedule must be planned. Preventative maintenance is less complex to coordinate than predictive maintenance because monitoring strategies do not have to be planned nor the results interpreted[3]

2.2.1 Assets suitable for preventative maintenance

Include those that:

- have a critical operational function
- have failure modes that can be prevented (and not increased) with regular maintenance
- have a likelihood of failure that increases with time or use

Unsuitable applications for preventative maintenance include those that:

- have random failures that are unrelated to maintenance (such as circuit boards)
- do not serve a critical function

2.2.2 Advantages of preventative maintenance:

Planning is the biggest advantage of preventative maintenance over less complex strategies. Unplanned, reactive maintenance has many overhead costs that can be avoided during the planning process. The cost of unplanned maintenance includes lost production; higher costs for parts and shipping, as well as time lost responding to emergencies and diagnosing faults while equipment is not working. Unplanned maintenance typically costs three to nine times more than planned maintenance. When maintenance is planned, each of these costs can be reduced. Equipment can be shut down to coincide with production downtime. Prior to the shutdown, any required parts, supplies and personnel can be gathered to minimize the time taken for a repair. These measures decrease the total cost of the maintenance. Safety is also improved because equipment breaks down less often than in less complex strategies.

Preventative maintenance does not require condition-based monitoring. This eliminates the need (and cost) to conduct and interpret condition-monitoring data and act on the results of that interpretation. It also eliminates the need to own and use condition-monitoring equipment.

2.2.3 **Disadvantages of preventative maintenance**:

Unlike reactive maintenance, preventative maintenance requires maintenance planning. This requires an investment in time and resources that is not required with less complex maintenance strategies.

Maintenance may occur too often with a preventative maintenance strategy. Unless, and until the maintenance frequencies are optimized for minimum maintenance, too much or too little preventative maintenance will occur.

The frequency of preventative maintenance is most likely to be too high. This frequency can be lowered, without sacrificing reliability when condition monitoring and analysis is used. The decrease in maintenance frequency is offset by the additional costs associated with conducting the condition monitoring.[3]

2.3 Predictive Maintenance

Predictive maintenance is defined as a tool used to schedule maintenance on the concurrent periods, and uses the vibrations and analysis of oils infrared or continuous lubrication to determine need to take corrective maintenance.

We used predictive maintenance to Monitoring detects degrading conditions and Most cost failures result from degrading conditions.

A comprehensive predictive maintenance program utilizes a combination of the most cost-effective tools to obtain the actual operating conditions of the equipment and plant systems. On the basis of this collected data, the maintenance schedules are selected.[2]

It is very important that the management supports the maintenance department by providing the necessary equipment along with adequate training for the personnel. The personnel should be given enough time to collect the necessary data and be permitted to shut down the machinery when problems are identified.[1]

2.3.1 The benefits of predictive maintenance

1-Increase in machine productivity.

2-Extend intervals between overhauls

3-Minimize the number of 'open, inspect and repair if necessary' overhaul routines

4-Improve repair time

5-Increase machine life

6-Resources for repair can be properly planned.

7-Improve product quality

8-Save maintenance costs[2]

2.3.2 Condition-based maintenance (CBM)

The basic concept of condition based maintenance is" if the condition of the item can be monitored continuously or even frequently, PM actions will be implemented only when failure is judged to be imminent"[4]

This philosophy consists of scheduling maintenance activities only when a functional failure is detected.

The most Advantages that it allows for some lead-time to purchase parts for the necessary repair work and thus reducing the need for large inventory of spares increase production capacity.

A possible disadvantage is that maintenance work may actually increase due to an incorrect assessment of the deterioration of machine.[2]

2.3.3 Techniques:

The specific techniques used depend on the type of plant equipment and their impact on production or other key parameters of plant operation.[2]

These techniques are:

1. Vibration monitoring
2. Thermography inspection
3. Oil analysis
4. Electrical insulation
5. Ultrasonic, etc..[1]

TABLE (2.1) : Typical Predictive Techniques[1]

Monitoring Techniques	Use	Problem Detection
Vibration	Rotating-machinery A-pumps ,B-turbines, C- compressors, D- gear boxes	1-Misalignment 2-,imbalance, 3-defective bearings, 4-defective rotor blades, 5-broken gear teeth
Fluid Analysis	A-Lubrication, B-cooling, C-hydraulic D- power systems	1-Excessive wear of bearing 2-surfaces fluid contamination
Infrared Thermography	A-Boilers, B-steam system components, C- motor controllers, D- diesel engines	,1-boiler refractory cracks, 2- deteriorated insulation, 3-hot or cold firing cylinders
Electrical insulation	A-Motor and generator windings, B-electrical distribution equipment	1-Trends of electrical insulation condition, 2-reversed coils or turns
ultrasonic	A-Hull structure, B-shipboard C-machinery and associated piping D-systems and mechanical Components	1-Corrosion, 2-erosion, 3-fatigue 4-cracking, delamination’s, wall 5-thickness reduction

2.4 Reliability Centered Maintenance (RCM):

A set of tasks generated on the basis of a systematic evaluation that are used to develop or optimize a maintenance program[5].

A reliability-centered maintenance (RCM) is a process systematically identifies all of the functions and functional failures of assets. It also identifies all causes for these failures then it proceeds to identify the effects of these failure modes and in what way those effects matter.

(RCM) considers all asset management options: on-condition task, scheduled restoration task, scheduled discard task, failure-finding task, and one-time change to hardware design, operating procedures, personnel training, or other aspects of the asset outside the strict world of maintenance.

This consideration is unlike other maintenance development processes.[6]

2.4.1 (RCM) phases:

(RCM) has three phases to it

The first phase is to identify the equipment that requires preventive maintenance.

The second phase is to specify the different types of preventive maintenance activities and tasks, including predictive maintenance (PM) techniques that need to be performed on the identified equipment.

The third phase is ensuring that the preventive maintenance tasks that were specified are properly executed in a timely manner

It has been estimated that more than 60 percent of all (RCM) programs initiated have failed to be successfully implemented.[5]

2.4.2 Cornerstones of (RCM):

1. Know when a single-failure analysis is acceptable and when it is not acceptable.
2. Know how to identify hidden failures.
3. Know when a multiple-failure analysis is required[5]

2.4.3 SEVEN QUESTIONS ADDRESSED BY (RCM):

Fundamentally, the (RCM) process seeks to answer the following seven questions in sequential order.

1. What are the functions and desired performance standards of each asset?
2. How can each asset fail to fulfill its functions?
3. What are the failure modes for each functional failure?
4. What causes each of the failure modes?
5. What are the consequences of each failure?
6. What can and/or should be done to predict or prevent each failure?
7. What should be done if a suitable proactive task cannot be determined?[7]

2.4.4 (RCM) Steps:

Step 1: Selection of equipment for (RCM) analysis

The first step is to select the piece of equipment for reliability centered maintenance analysis. The equipment selected should be critical, in terms of its effect on operations, its previous costs of repair and previous costs of preventative maintenance.

Step 2: Define the boundaries and function of the systems that contain the selected equipment

The equipment belongs to a system that performs a crucial function. The system can be large or small, but the function of the system, and its inputs and outputs, should be known. For example, the function of a conveyor belt system is to transport goods. Its inputs are the goods and mechanical energy powering the belt, while its outputs are the goods at the other end. In this case, the electric motor supplying the mechanical energy would be considered as part of a different system.

Step 3: Define the ways that the system can fail (failure modes)

In step 3 the objective is to list all of the ways that the function of the system can fail. For example, the conveyor belt may fail by being unable to transport the goods from one end to the other, or perhaps it does not transport the goods quickly enough.

Step 4: Identify the root causes of the failure modes

With the help of operators, experienced technicians, (RCM) experts and equipment experts, the root causes of each of the failure modes can be identified. Failure of the conveyor could include a lack of lubrication on the rollers, a failure of a bearing, or a loosened belt.

Step 5: Assess the effects of failure

In this step the effects of each failure mode are considered. Equipment failures may affect safety, operations and other equipment. Criticality of each of these failure modes can also be considered.

There are various recommended techniques that are used to give this step a systematic approach. These include:

1. Failure, mode and effects analysis (FMEA)
2. Failure, mode, effect and criticality analysis (FMECA)
3. Hazard and operability studies (HAZOPS)
4. Fault tree analysis (FTA)
5. Risk-based inspection (RBI).

Step 6: Select a maintenance tactic for each failure mode

At this step, the most appropriate maintenance tactic for each failure mode is determined. The maintenance tactic that is selected must be technically and economically feasible.

Maintenance is selected when it is technically and economically feasible to detect the onset of the failure mode.

Time or usage-based preventative maintenance is selected when it is technically and economically feasible to reduce the risk of failure using this method.

Step 7: Implement and then regularly review the maintenance tactic selected

Importantly, the (RCM) methodology will only be useful if its maintenance recommendations are put into practice. When that has been done, it is important that the recommendations are constantly reviewed and renewed as additional information is found[7]

2.5 Preventive Maintenance Optimization (PMO):

(PMO) is a means of rationalizing all the Preventive Maintenance work to ensure that all the work adds value and there are no duplications of effort.[8]

2.5.1 Need of (PMO):

Taking any plant as a sample, we can notice that as the plant goes into full operation more breakdowns occur thus more maintenance tasks would be performed and others would be created. Unfortunately, many of these new tasks only repeat the existed one.

Often, in an attempt to be seen to be doing something about high profile reliability problems, maintenance personnel create and perform tasks supposed to prevent the failures but in reality, serve no realistic purpose.

Performing all these tasks consumed the resources that available for (PM) thus (PM) is missed.

The failures that should be prevented start to show up and more unplanned maintenance performed, the maintenance program become out of control.

The vicious circle of breakdown maintenance, temporary repair, and reduced (PM) gains momentum and becomes well entrenched.

Management consultants started to reduce the staff and cut off the budgets. The result is a huge pressure on the maintenance department and a low performing plant.

Some of maintenance organizations start to use (RCM) in aim of regaining the control but (RCM) is not a rationalization tool it consumes excessive amounts of valuable resources.[8]

2.5.2 Step of (PMO):

Step 1: Task Compilation.

Step 2: Failure Mode Analysis (FMA).

Step 3: Rationalization and (FMA) Review.

Step 4: Functional Analysis (Optional).

Step 5: Consequence Evaluation.

Step 6: Maintenance Policy Determination.

Step 7: Grouping and Review.

Step 8: Approval and Implementation.

Step 9: Living Program.

STEP 1- Task Compilation:

What maintenance tasks are being undertaken by the operations and maintenance personnel (task compilation)?

Task compilation is a simple matter of writing down what the people are doing and listing the maintenance program functions into a database.

Step 2 - Failure Mode Analysis (FMA):

a) What are the failure modes associated with the plant being examined (failure mode analysis)?

b) What is (are) the failure mode(s) that each existing task is meant to prevent or detect?

c) What other failure modes have occurred in the past that have not been listed or have not occurred and could give rise to a hazardous situation?

A team of cross-functional members should identify what each maintenance task is aimed for.

Step 3 - Rationalization and Failure Mode Review:

What functions would be lost if each failure were to occur unexpectedly (functions)? [Optional question]

Using the data from failure modes, we can reduce the task duplication and the wasted effort on it.

We may use the technical documentation or the experience of the team to help creating this list.

Step 4 – Functional Analysis:

What happens when each failure occurs (failure effects)?

In this step, any lost function due to failure modes can be established. This task is optional, and may be justified for analyses on highly critical or very complex equipment items

Step 5 - Consequence Evaluation:

In what way does each failure matter (failure consequences)?

Each failure mode is analyzed to determine whether the failure is hidden or evident. For evident failures, a further determination of hazard or operational consequence is made.

Step 6 - Maintenance Policy Determination:

What should be done to predict or prevent each failure (proactive tasks and task intervals)?

What should be done if a suitable proactive task cannot be found (default actions)?

In this step, each failure mode is analyzed using Reliability Centered Maintenance (RCM) principles. This step establishes new or revised maintenance policies

Step 7 - Grouping and Review:

This step is about teamwork to produce more efficiency and productivity.

Step 8 - Approval and Implementation:

The analysis must pass on the local stakeholders for the final review and comment by performing a presentation and a report including data from the (PMO) software.

Step9 - Living Program:

In this step, it is the intention to create an organization that constantly seeks to improve its methods by continued appraisal of every task it undertakes and every unplanned failure that occurs. To achieve this requires a program where the workforce is adequately trained in analysis techniques and is encouraged to change practices to improve their own job satisfaction and to reduce the unit cost of production.

During this step, several vital processes for the efficient management of assets can be devised or fine-tuned as the rate of improvement accelerates.

These processes include the following:

- Production / maintenance strategy,
- Performance measurement,
- Failure history reporting and defect elimination,
- Planning and scheduling,
- Spares assessing, and
- Workshop and maintenance practices.[8]

2.5.3 Functional Differences between (RCM) and (PMO):

1- (RCM) was designed to develop the initial maintenance program during the design stages of the asset life cycle Whereas (PMO) has been designed for use where the asset is in use.

2- (PMO) is a method of review whereas (RCM) is a process of establishment.

3- (PMO) is far more efficient and flexible in analysis than (RCM).

2.5.4 Methodology differences between (RCM) and (PMO):

The central difference between (RCM) and (PMO) is the way in which failure modes are generated.

1- (RCM) generates a list of failure modes from a rigorous assessment of all functions, a consideration of all functional failures and then an assessment of each of the failure modes that relate to each functional failure.

2- (PMO) generates a list of failure modes from the current maintenance program, an assessment of known failures and by scrutiny of technical documentation.

2.5.5 Strengths and benefits of (PMO) compared with (RCM):-

1-(PMO) is a method with enormous flexibility:

(RCM) analysis cannot regulate or filter which failure modes are analyzed at which time therefore (RCM) analysis requires the presence of all trades simultaneously as the failure modes come out in a rather random manner.

With (PMO), it is possible to review the activities of a particular trade on a particular piece of equipment or site because (PMO) begins with maintenance tasks, which can be filtered on the field, trade.

2-(PMO) is self-regulating in terms of investment and return:

(PMO) is highly effective where equipment has numerous failure modes but where the vast majority of these are either random, instantaneous or not of high consequence.

The other point here is that (RCM) would require the input of specialist electronics engineers to define the failure modes properly whereas PMO would require only the operators.

3-(PMO) is six times faster than (RCM):

The positive effect of deploying a process of maintenance analysis that is six times faster than (RCM) for the same given outcome cannot be overstated.

2.5.6 Weaknesses of (PMO):-

The only valid weakness of (PMO) compared to (RCM) for plants that have been in operation for some time, is that (PMO) does not list the complete set of failure modes. This may be important from a spares assessing perspective. However, if the motivation for performing maintenance analysis is to generate a focused and effective (PM) program, then this weakness is irrelevant.[8]

CHAPTER THREE

METHEDOLOGY

3.1 Introduction:

The fault analysis process is one of the steps necessary to neutralize the quality of the machine and also helps in determining the quality of the maintenance, and I help predict the expected failures and the processes necessary to avoid them.

The fault analysis process helps in developing the strategy for preventive maintenance, scheduling, and proper maintenance.

3.2 Failure modes and effects analysis (FMEA)

The (FMEA) is a proactive approach to solving potential failure. It is an established reliability engineering activity that also supports fault tolerant design, testability, safety, logistic support, and related functions.[9]

3.2.1 The purpose of (FMEA) :

The purpose of (FMEA) is to analyze the design characteristics relative to the planned manufacturing process to ensure that the resultant product meets customer needs and expectations. When potential failure modes are identified, corrective action can be taken to eliminate or continually reduce the potential for occurrence.[9]

3.2.2 Types of (FMEA)

The three most common types of

1. System FMEA
2. Design FMEA
3. Process FMEA
4. Service FMEA[10]

3.2.3 (FMEA) Process

Priorities on the failure modes can be set according to the (FMEA)'s risk priority number (RPN) system, a concentrated effort can be placed on the higher (RPN) items based on the Pareto analysis obtained from the analysis. As the equipment proceeds through the life cycle phases, the (FMEA) analysis becomes more detailed and should be continued. [9]

3.2.4 Basic information required for the (FMEA) process.

1- What does the System do? Mission.

2- What is its function? Function

3- How could it fail to perform its function? Failure Mode.

4- What happens if it fails? Effect of Failure.

5- What is the Likelihood of failure? Occurrence (O)

6- What is the consequence of failure? Severity (S)

7- What is the predictability of failure? Detectability (D)

8- What is the Risk Priority Number (RPN)? (RPN = O x S x D) [11]

3.2.5 Failure Mode Analysis and Preparation of Worksheets

Table (3.1) : FMEA Worksheet

Item	Function	Potential failure mode	Potential Effect (s) of Failure	Potential Cause (s) of Failure	Severity	Occurrence	Detection	RPN	Failure rate	Current Design Controls (Prevention)	Current Design Controls (Detection)	Recommended Actions
1	2	3	4	5	6	7	8	9	10	11	12	13

Column 1: Item

- An "item" is the focus of the (FMEA) project.
- it consist a unique reference number to each item or just the name of the item [12]

Column 2: Function

- A "function" is what the item or process is intended to do, usually to a given standard of performance or requirement.
- There can be many functions for each item or operation.

Column 3: Failure Mode

- A "failure mode" is the manner in which the item or operation potentially fails to meet or deliver the intended function and associated requirements.

Column 4: Effect

- An "effect" is the consequence of the failure on the system or end user.

Column 5: Cause

- A "cause" is the specific reason for the failure, preferably found by asking "why" until the root cause is determined. .
- If a cause occurs, the corresponding failure mode occurs.
- There can be many causes for each failure mode

Column 6: severity

- "Severity" is a ranking number associated with the most serious effect for a given failure mode
- Based on the criteria from a severity scale.[12]

Table (3.2) : Severity ranking [10]

Rank	Description
1–2	Failure is of such minor nature that the customer (internal or external) will probably not detect the failure.
3–5	Failure will result in slight customer annoyance and/or slight deterioration of part or system performance
6–7	Failure will result in customer dissatisfaction and annoyance and/or deterioration of part or system performance.
8–9	Failure will result in high degree of customer dissatisfaction and cause non-functionality of system
10	Failure will result in major customer dissatisfaction and cause non system operation or non-compliance with government regulations

Column 7: Occurrence

- The probability that a failure will occur during the expected life of the system can be described in potential occurrences per unit time.
- Individual failure mode probabilities are grouped into distinct, logically defined levels[10]

Table (3.3) : Occurrence ranking [10]

Rank	Description
1	An unlikely probability of occurrence during the item operating time interval. Unlikely is defined as a *single failure mode (FM) probability* < *0.001* of the overall probability of failure during the item operating time interval
2–3	A remote probability of occurrence during the item operating time interval (i.e. once every two months). Remote is defined as a *single FM probability* > *0.001 but* < *0.01* of the overall probability of failure during the item operating time interval
4–6	An occasional probability of occurrence during the item operating time interval. Occasional is defined as a *single FM probability* > *0.01 but* < *0.10* of the overall probability of failure during the item operating time interval.

Column 8: Detection

Detection” is a ranking number associated with the best control from the list of detection-type controls, based on the criteria from the detection scale. [12]

Table (3.4) : Detection ranking[10]

Rank	Description
1–2	Very high probability that the defect will be detected. Verification and/or controls will almost certainly detect the existence of a deficiency or defect
3–4	High probability that the defect will be detected. Verification and/or controls have a good chance of detecting the existence of a deficiency or defect.
5–7	Moderate probability that the defect will be detected. Verification and/or controls are likely to detect the existence of a deficiency or defect.
8–9	Low probability that the defect will be detected. Verification and/or controls not Likely to detect the existence of a deficiency or defect.
10	Very low (or zero) probability that the defect will be detected. Verification and/or controls will not or cannot detect the existence of a deficiency or defect

Column 9 Risk Priority Number (RPN)

- "RPN" is a numerical ranking of the risk of each potential failure mode cause, made up of the arithmetic product of the three elements:
  1-Severity 2- occurrence 3- detection
- **RPN=SEVERITY x OCCURANCE x DETECTION [12]**

Column 10: failure rate

- Failure rates for each failure mode are listed.

- In many cases it is more suitable to classify the failure rate in rather broad classes [13]

Column 11& 12: Controls

- “Controls” are the methods or actions currently planned, or are already in place, to reduce or eliminate the risk associated with each potential cause.[12]

Column 11: Prevention-type Controls

- describe how a cause, failure mode, or effect in the product design is prevented based on current or planned actions
- They are intended to reduce the likelihood that the problem will occur, and are used as input to the occurrence ranking.

Column 12: Detection-type Controls

- describe how a failure mode or cause in the product design is detected, based on current or planned actions before the product design is released to production, and are used as input to the detection ranking.
- They are intended to increase the likelihood that the problem will be detected before it reaches the end user

Column 13: Recommended Actions

“Recommended actions” are the tasks recommended by the (FMEA) team to reduce or eliminate the risk associated with potential causes of failure

. They should consider

- Existing controls
- Relative importance (prioritization) of the issue
- Cost and effectiveness of the corrective action.
- There can be many recommended actions for each cause.[12]

3.3 Pareto Analysis

Is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule) the idea that by doing 20% of the work you can generate 80% of the benefit of doing the whole job. Or in terms of quality improvement, a large majority of problems (80%) are produced by a few key causes (20%).[14]

A Pareto Diagram is a good tool to use when the process investigated produces data that are broken down into categories and you can count the number of times each category occurs.

A Pareto diagram puts data in a hierarchical order, which allows the most significant problems to be corrected first[14]

Among the examples they give include:

- 20 percent of the input creates 80 percent of the result
- 20 percent of the workers produce 80 percent of the result.[15]

3.3.1 Pareto analysis benefits:

First is that it can categorize and stratify such things as errors, defects, delays so we can identify different classes or types of problems.

Second, is that it graphically displays the results in a Pareto chart or Pareto diagram so that the significant few problems emerge from the general background. [15]

3.3.2 Pareto chart

How to make:

1. Collect data about the contributing factors to a particular effect (for example, the types of errors discovered during surgical setup).

2. Order the categories according to magnitude of effect (for example, frequency of error). If there are many insignificant categories, they may be grouped together into one category labeled “other.”

3. Write the magnitude of contribution (for example, frequency of error) next to each category and determine the grand total. Calculate the percentage of the total that each category represents.

4. working from the largest category to the smallest, calculate the cumulative percentage for each category with all of the previous categories.

5. Draw and label the left vertical axis with the unit of comparison (for example, “Number of
Occurrences of Error,” from 0 to the grand total).

6. Draw and label the horizontal axis with the categories (for example, “Type of Error”), largest to smallest from left to right.

7. Draw and label the right vertical axis “Cumulative Percentage,” from 0 to 100 percent, with the 100 percent value at the same height as the grand total mark on the left vertical axis.

8. Draw a line graph of the cumulative percentage, beginning with the lower left corner of the largest category (the “0” point).

9. Analyze the diagram to indicate the cumulative percentage associated with the “vital few” (for example, three error type’s account for 80 percent of all errors). [16]

3.4 Root Cause Analysis (RCA):

(RCA) are designed to provide a cost-effective means to isolate all factors that directly or indirectly result in the myriad of problems that we face in the plants and facilities

Used to resolve any problem that has serious, negative impact on effective management, operation, maintenance, and support of our plants and facilities [6]

3.3.1 Root Cause Analysis capability:

(RCA) has the capability to

1- identify incipient problems;

2- isolate the actual cause or forcing function that directly resulted in the problem,

3- identifies all factors that directly or indirectly contributed to the problem [6]

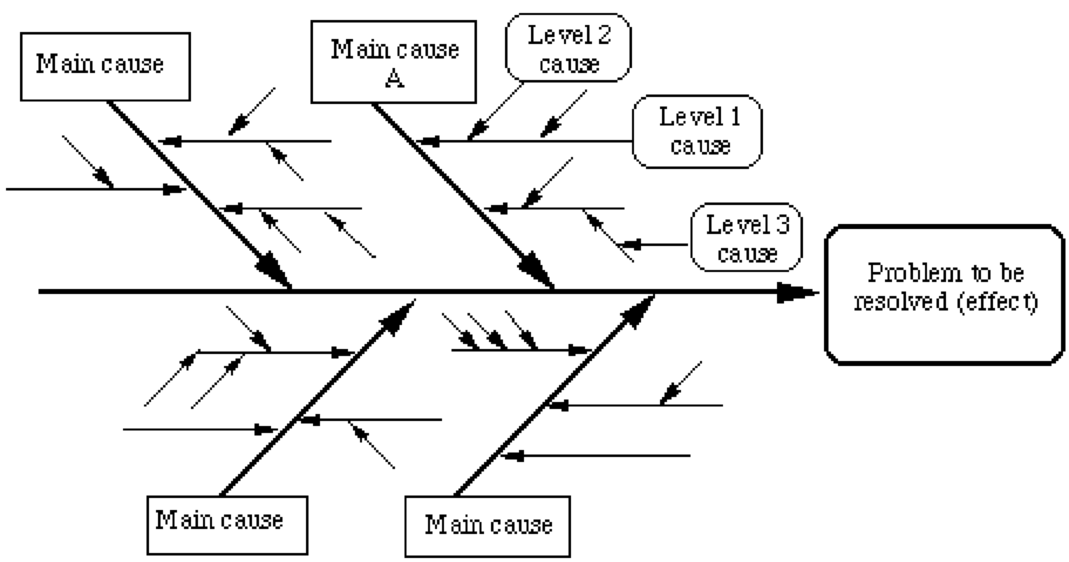

Figure (3.2): cause and effect diagram

3.5 Failure modes, effects, and criticality analysis (FMECA):

(FMECA) is a methodology to identify and analyze all potential failure modes of the various parts of a system and the effects of these failures may have on the system .And also how to avoid the failures, and/or mitigate the effects of the failures on the system

It is like FMEA The (C) in (FMECA) indicates that the criticality (or severity) of the various failure effects are considered and ranked [13]

3.5.1 (FMECA) WORKSHEET

Table (3.6) : FMECA Worksheet [13]

description of unit			description of failure			effect of failure		failure rate	severity ranking	risk reducing measures	Comments
ref no	Function	operational mode	failure mode	failure causes or mechanism	detection of failure	on the subsystem	on the system function				

CHAPTER FOUR

Implementation

4.1 Introduction:

Pasgianos factory is one of the leading factories in the industry, working as an advanced manufacturer within the production line of the factory.

Blow molds and Filler machines were selected to conduct the study and determine the maintenance strategy needed to reduce their downtime. Any stop in any machine stops the production line.

4.2 Blow mold machine:

Its basic function is to punch the raw material (pre-molds). The machine receives the raw material and transfer it through the conveyor to the heating furnace where it is heated to certain temperature and then transferred to the molds.

The formation process is carried out by blowing the raw material by an air source until it forms and take the form of the mold. Finally, the ready-made bottle is transferred by the conveyor to the juice filling machine.

4.2.1The main parts of Blow Mold machine:

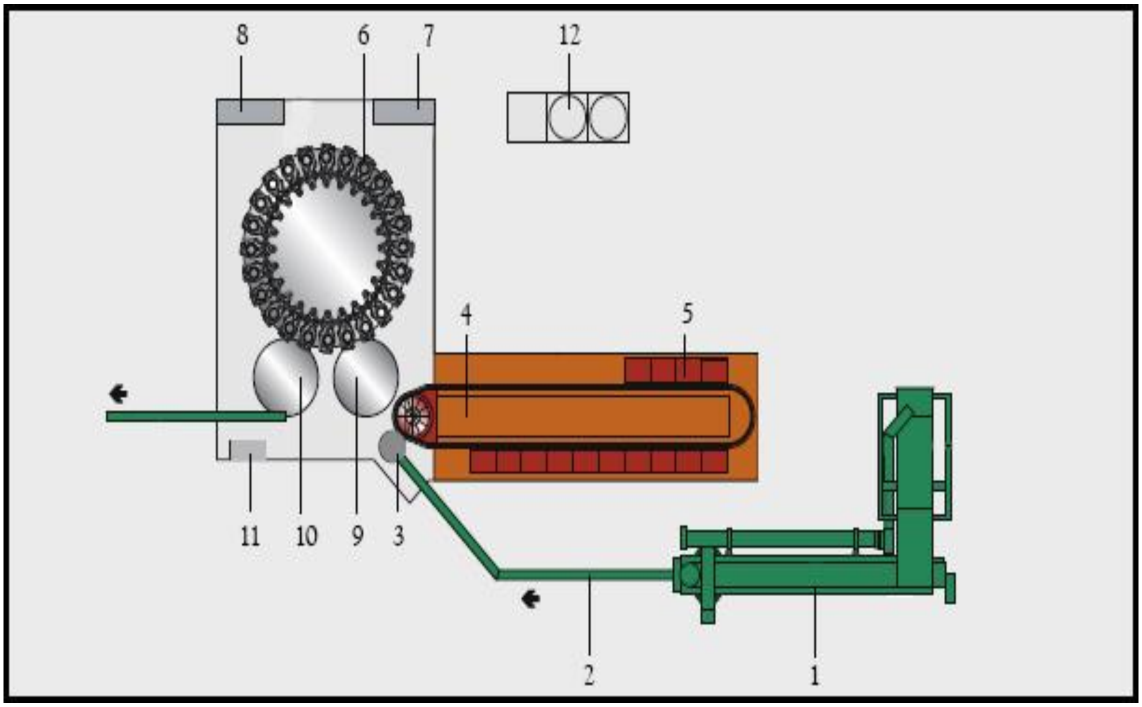

Figure (4.1): Blow Mold machine

1-perform supply
2-perform feed rail
3-infeed starwheel
4-linear oven
5-heaters
6-blowing stations
7-water supply
8-air supply
9-perform transfer wheel
10-bottle transfer wheel
12-chiller

4.2.2 FMEA for Blow Mold machine

Table (4.1) : FMEA for Blow Mold machine

Item	Function	Potential failure mode	Potential Effect (s) of Failure	Potential Cause (s) of Failure	Severity	Occurrence	Detection	RPN	Failure rate	Current Design Controls (Prevention)	Current Design Controls (Detection)	Recommended Actions
Perform Conveyor belt	moving the product from the hopper to the supply system	1- Conveyor belt deviation 2-poor operation of roller	Direct effect on delaying production process	Rotation of the roller is not flexible or poor rack rigid	4	2	2	16	0.0002	adjusting the position of the roller bearing , using high manufactured equipment	Visual check	The failure has direct effect on the production line also simple to prevent , there for preventive maintenance
Perform supply	moving the product to the blow molder	Problem with perform supply infeed	Reduce the a mount of bottles entering the molds	adjust in the parameter	3	1	4	12	0.0002	Check parameters settings	Simple mentoring to the production line	The failure has low sev\occ\det , so it will be better to wait the failure then perform maintenance
Linear oven	Heating the product before the blowing process	Problem in the heaters	Wrong temperature setting thus issues in the blowing process	Old filters	4	1	5	20	0.0002	Filters replacement	Sensors reading	either preventive or corrective maintenance since the failure is easy to fix with very low occurrence

Starwheels	Transfer the product between system components	Closing cam	Bottles will fall down making deformation and delaying production	Damaged pin	3	1	2	6	0.0002	Always check for wear and clamp replacement	Missing bottles in the line	the failure is rare to happen and easy to repair thus corrective maintenance
Molds	The blowing process	1- Unclosed Molds no(5) 2-Bottle deformation 3- wrong temperature setup in base mold	1- preventing the blow in the Molds 2- unaccaptable bottles	1- mold locking pin 2- temperature setup and blowing angle 3- temperature setup	4	3	4	48	0.002	1-Rain off the condensation water 2-check the screw connection 3-check the operation before starting the production	Sensors reading	the failure will cause a small down time but it has high occurrence number thus the down time will increase ,there for preventive maintenance is recommended

Chiller	Cooling the product after the blow process	1-Oil failure trip 2- Low and high pressure trip	Bottle deformation , issues with filling process	low superheat, oil pump damage, low refrigeran t, condenser has poor or no flow	5	1	2	10	0.0002	Weekly check for leakage and proper operation	Sensors reading	The failure has a lot of causes ,trying to prevent the failure may be an issue also the failure is rare, thus corrective maintenance is suitable
Encoder	keep the synchronizatio n between the BM and the filler	Problem with the infeed between the filler and BM	Lose the timing between the two machines	Damaged gear	6	1	7	42	0.0002	Check for wear and lubrication	Fail in the infeed synchron izing between the machines	With high severity and detection numbers predictive maintenance should be implement

4.2.3 Pareto Analysis for Blow Mold:

Table (4.2): Pareto table Blow Mold Machine

Failure	Count	Cumulative Count	Cumulative %
problem in Molds	9	9	69.2
Problem in Perform Conveyor belt	1	10	76.9
Problem in the heaters	1	11	84.6
problem in the cam	1	12	92.3
Problem with the infeed between the filler and BM	1	13	100.0

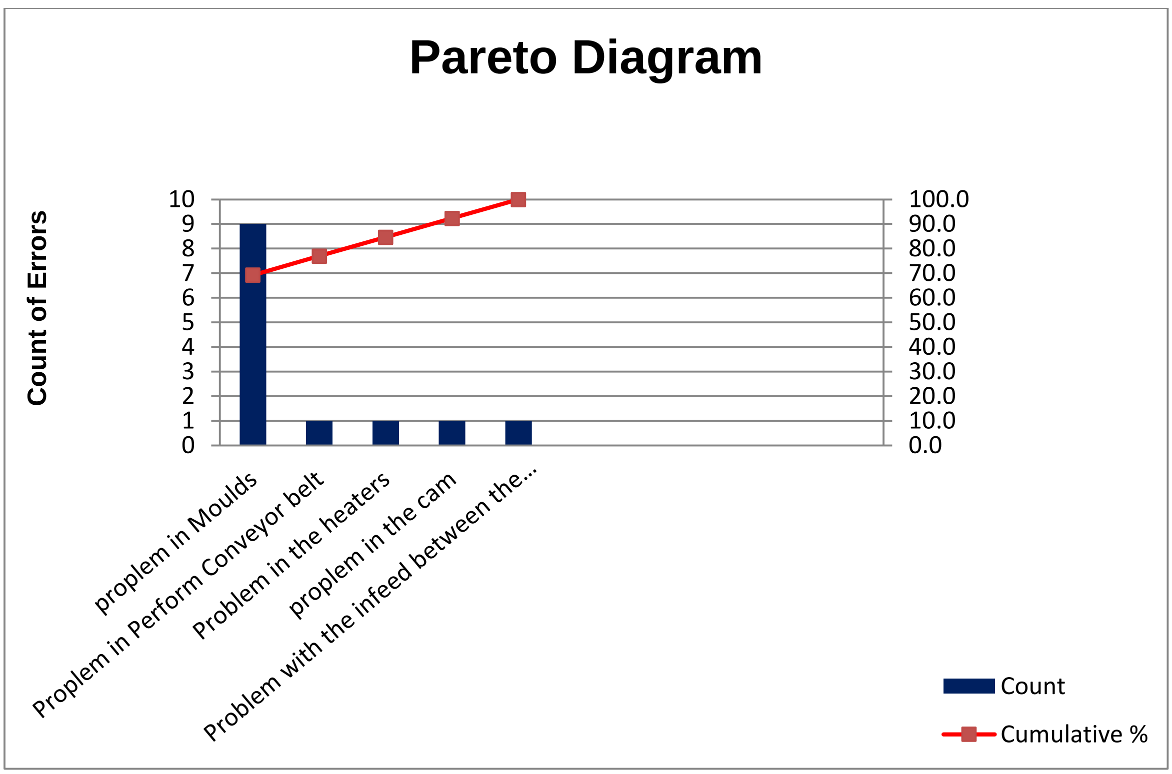

Figure (4.2) : Pareto diagram for Blow Mold machine

4.2.4 Root causes analysis for Blow Mold:

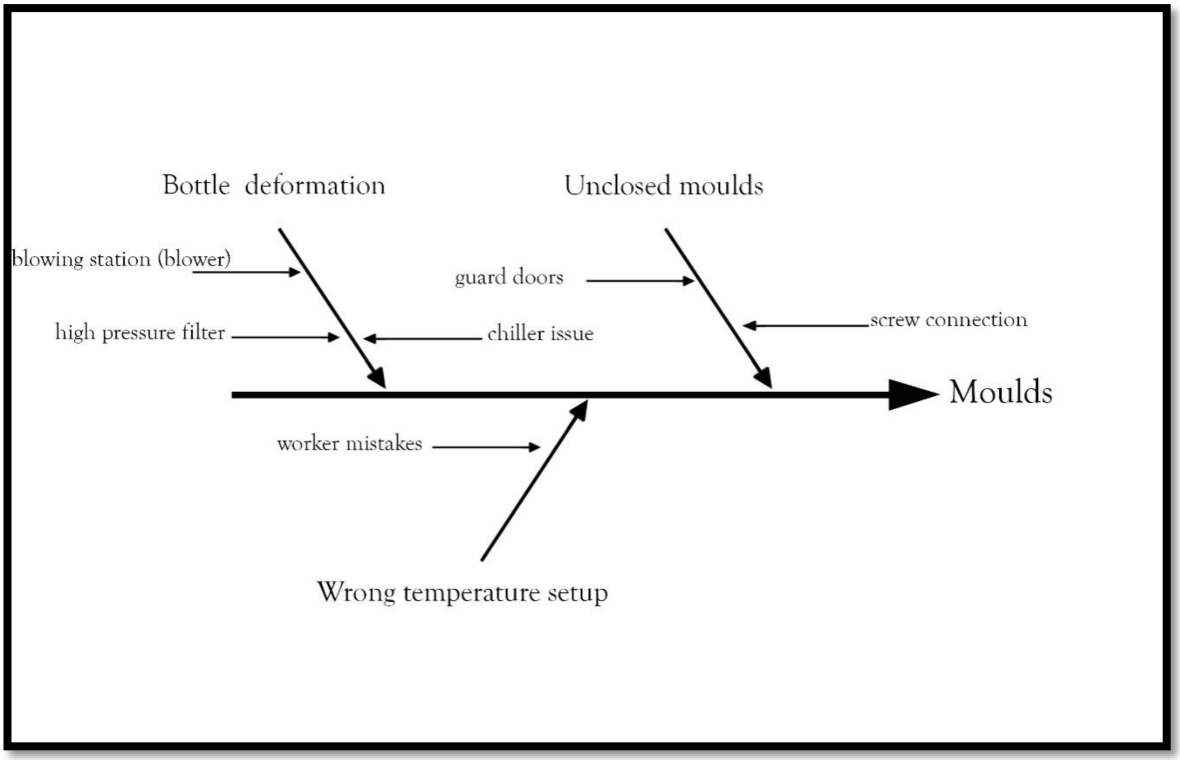

Figure (4.3) : Mold root cause tree

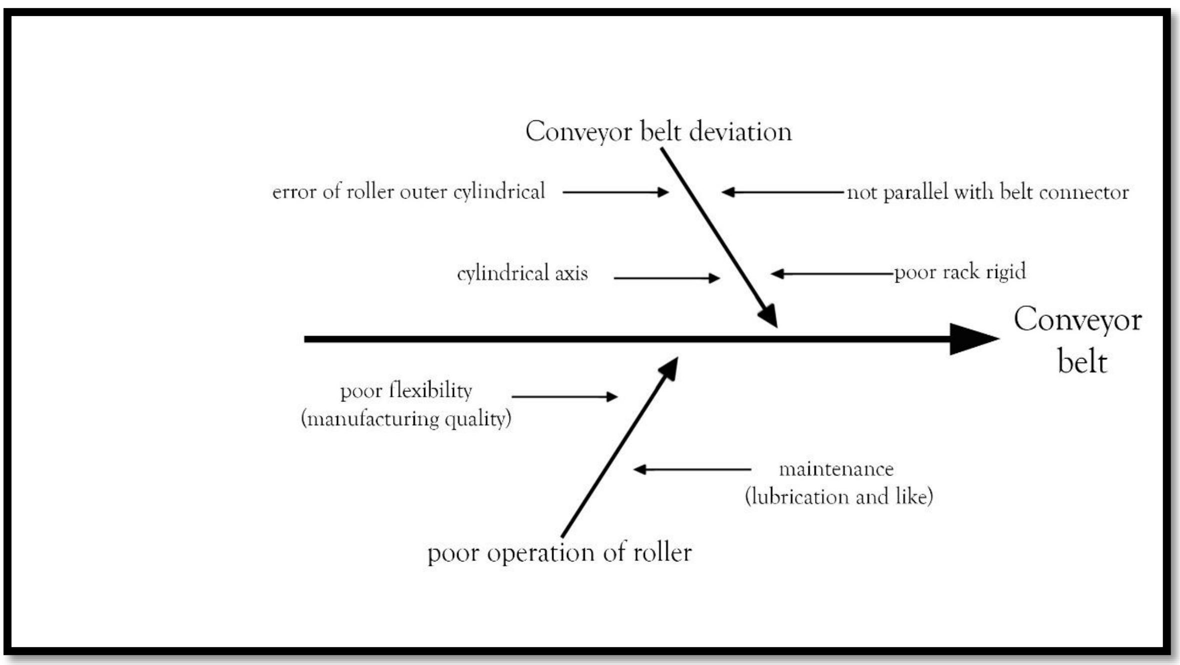

Figure (4.4) : Conveyor belt root cause tree

4.2.5 (FMECA) for Blow Mold machine

Table (4.3) : FMECA for mold

description of unit			**description of failure**			**effect of failure**		**failure rate**	**severity**	**risk reducing measures**	**comments**
ref no	**Function**	**operational mode**	**failure mode**	**failure causes or mechanism**	**detection of failure**	**on the subsystem**	**on the system function**				
Molds	The blowing stage	Running	1-Unclosed mold	1- mold locking pin	Simple check for the molds	preventing the blow in the mold, unacceptable bottles	stop the production line, damage in bottle	high	4	2-check the screw connection	the failure will cause a small down time but it has high occurrence thus the down time will increase ,there for preventive maintenance is recommended every week
			2-Bottle deformation	2- blowing angle	Check bottles shape					1-Rain off the condensation	
			3- wrong temperature setup in base mold	3- temperature setup	Check the control adjustment					3-check the operation before starting the production	

Blowing station (blower)	The blowing process	Running	Low blowing pressure	No or low air supply	Sensors reading	Bottle deformation	error in blowing	high	4	Check the compressors component , check the presser from blower	The failure will effect on the machine production directly therefore preventive maintenance every week
Chiller	Control the temperature	running	1- Low and high pressure trip	1-low superheat, ,low refrigerant , condenser has poor or no flow	Sensor reading	Bottle deformation and wrong temperature setup	error in bottle dimension	low	4	1-check the refrigeration liquid	These failures has a lot of causes ,trying to prevent the failure may be an issue also the failure is rare, thus corrective maintenance is suitable
			2-Oil failure trip	2-oil pump damage, refrigerant leak	Poor cooling					2-check for setting the temperature	

Filter	Clean the air for the blowing stage	Running	Dust penetration/blinding	Overusing the same filter , incorrect design	Sensor reading	Bottle deformation	1-error in bowing bottle 2-bad product	low	2	Replace them by time	Low severity , breakdown maintenance
Screw connections	Holds down the machine component	All modes	1-break and deformation	overload on the connection	Sensor reading	Unclosed mold	1-error in blow molds 2-stop the production line	low	2	Check for wear and replace if its need	Low severity, breakdown maintenance

Table (4.4) : FMECA for conveyor belt

description of unit			**description of failure**			**effect of failure**		**failure rate**	**severity ranking**	**risk reducing measures**	**comments**
ref no	**Function**	**operational mode**	**failure mode**	**failure causes or mechanism**	**detection of failure**	**on the subsystem**	**on the system function**				
Perform Conveyor belt	moving the product from the hopper to the supply system	running, idle	1- Conveyor belt deviation	Rotation of the roller is not flexible	Position check	The infeed to the machine will stop	Direct effect on delaying production process	low	4	adjusting the position of the roller bearing	The failure has direct effect on the production line also simple to prevent , there for preventive maintenance every month
			2-poor operation of roller	poor rack rigid	Low operation					, using high manufactured equipment	
cylinder	transmission and change of direction	running	1-error of roller outer cylindrical	Low quality of the equipment, over load on the cylinder,	Visual check for the operation	deviation when the conveyor belt is running	The movement system will stop	low	4	Using better surface manufacture equipment	The failure is simple to repair thus breakdown maintenance is recommender
			2- error of cylindrical axis	High parallelism error between cylindrical axis and	Check the position for the axis					deviation ends should adjustment to the conveyor	

				roller axis						belt running Direction ,adjusting deviation angle	
belt connector	Connect between the conveyor components	Running	1-Error in parallel with belt connector	connection error is too big	Check the position of the belt	belt deviation	A slight downtime on the transfer to the BM	Low	3	improve installation connection accuracy	Breakdown maintenance
			2- Poor rack rigid	overload on the belt	Check the belt surface and connection						
roller	Support movement of the device	Idle	1- poor flexibility	Manufacturing quality of roller, not enough bearing stiffness ,	Check for damage on the roller	poor operation of roller	A slight downtime on the transfer to the BM	low	4	Using good lubricating Materials and ball bearings support	Preventing the failure is possible by normal activities , so preventive maintenance every month
			2- sealing and bearing lubrication problem	wrong seal Form and poor lubrication materials	Visual check						

4.2.6 strategy of maintenance for Blow Mold machine

Table (4.5) : strategy of maintenance for Blow Mold machine

Operation Time	Item	Work
Daily	Entire machine	Check for safety, dirt and damage
Weekly Or every 150 operation hours	Molds	Cleaning and check for proper operation
	Blowing station	Check for leakage and proper operation , check the filters for dirt
	High pressure filter	Drain of the condensation water, clean or replace
	Chiller	Check the pressure and refrigerant and proper operation
Monthly Or every 500 operation hours	Molds	______
	Blowing station	______
	High pressure filter	______
	Chiller	______
	Conveyor belt	Check for proper tension and wear if necessary replace them
	Cylinders	Check for wear, surface and proper fitting if necessary replace them
	Roller	Check for wear
	Belt connecter	Check for proper tension and wear if necessary replace them
Yearly Or every 5000 operation hours	Entire machine	General inspection

4.3 Filler Machine

It core function is tired liquid (juice). The flask and blowing mold machine are received by a receiving star: bottle are inserted into the filling machine where the juice is filled from the juice container by filling method.

The vial is then transferred to the vending machine where the vials are tightly covered and transferred to the subsequent machine.

4.3.1 The main parts of Filler machine:

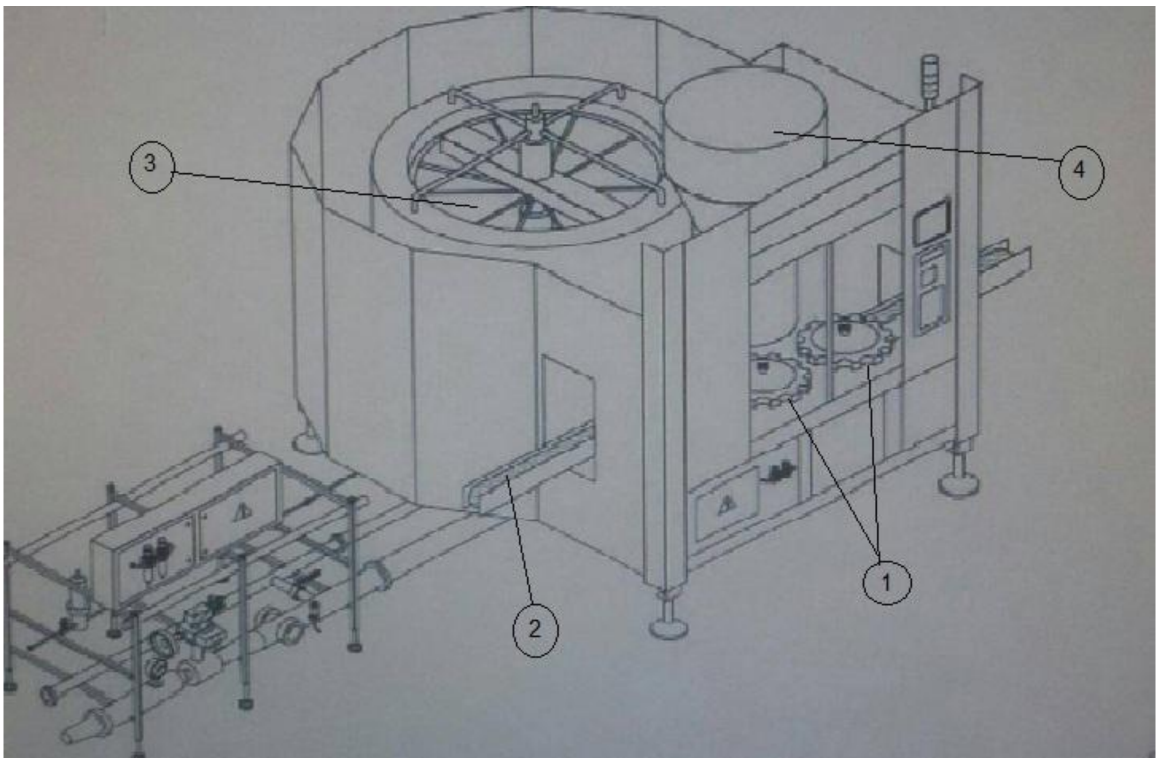

Figure (4.5): Filler machine

1- Starwheel,
2- Conveyor belt
3- juice container
4- caps container,

4.2.2 (FMEA) for filler machine

Table (4.6) : FMEA for filler machine

Item	Function	Potential failure mode	Potential Effect (s) of Failure	Potential Cause (s) of Failure	Severity	Occurrence	Detection	RPN	Failure rate	Current Design Controls (Prevention)	Current Design Controls (Detection)	Recommended Actions
Conveyor belt	Moving the bottles from the BM to the filler	1- Conveyor belt deviation 2-poor operation of roller	Direct effect on delaying production process	Rotation of the roller is not flexible or poor rack rigid	4	2	2	24	0.00116	check for the correct tension	Mentoring the production line	The failure has direct effect on the production line also simple to prevent , there for preventive maintenance
Starwheels	Transfer the bottles between the system components	Wrong bottle receiving	Delay in production	Damaged clamp	3	3	2	30	0.00116	Clamp replacement and check wear	Falling bottles in the ground	With high occurrence number thus a lot of down times preventive maintenance should be applied

soft drink containers	Fill the bottles with soft drink	Problem with valve no 37	Empty bottles	Broken valve leader	5	1	6	30	0.00023	Leader replacement every specific period	Sensors reading	This failure has low occurrence but high severity and detection thus either corrective or preventive maintenance will be suitable
Caper	Close the bottles using the caps from the container	Un closed bottles	Unacceptable products	Shorten in cap supply	5	1	2	10	0.00023	Check sensors before starting	Sensors reading	Corrective maintenance since the failure is rare (low occurrence)
caps containers	Supply the caper with the caps	Problem in cap supply runner	Un closed bottles	Missing screw and the runner need to be expand	6	2	5	60	0.00046	Expand the cap run and check the screw connection	Sensors reading	The failure down time is small and it is easy to repair thus corrective maintenance is suitable
Encoder	keep the synchronization between the BM and the filler	Problem with infeed synchronizing	Lose the timing between the filler and B.M	Damaged gear	7	1	8	56	0.00069	Check for wear and lubrication	Fail in the infeed synchronizing between the BM and the filler	With high severity and detection numbers predictive maintenance should be implement

4.3.3 Pareto analysis for Filler machine

Table (4.7): Pareto analysis for filler machine

failure	Count	Cumulative Count	Cumulative %
Wrong bottle receiving	5	5	38.5
Problem with infeed synchronizing	3	8	61.5
Problem in cap supply runner	2	10	76.9
Problem with valve no 37 in soft drink container	1	11	84.6
problem in filler sensors	1	12	92.3
bottles out without caps	1	13	100.0

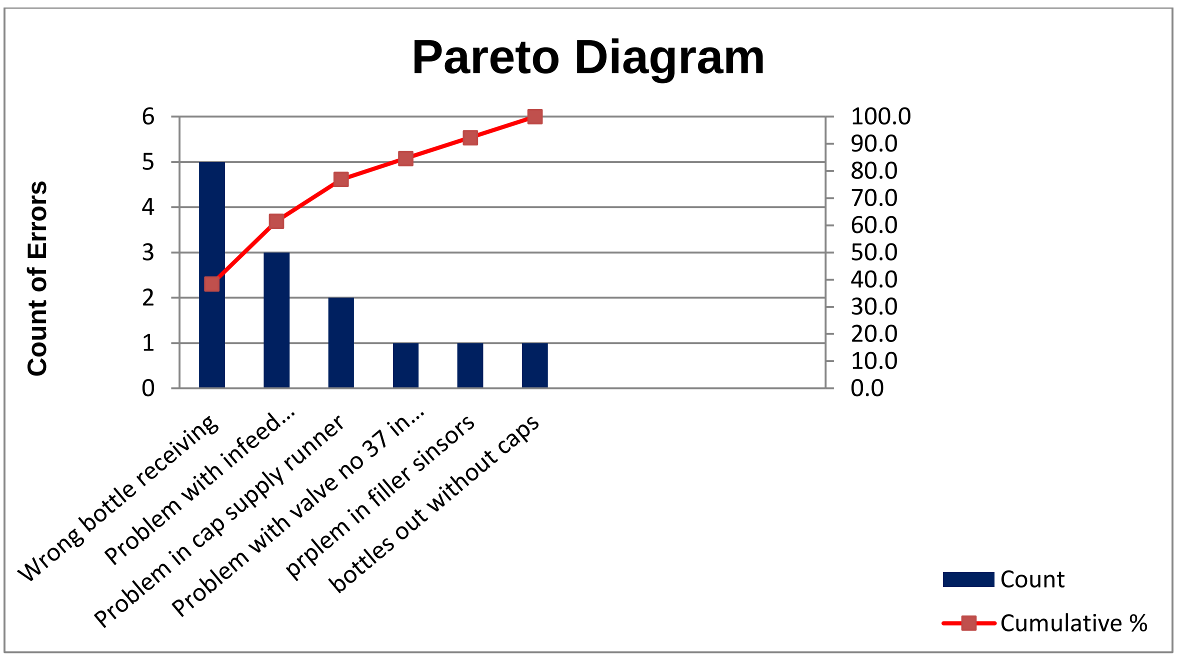

Figure (4.6) : Pareto diagram for filler machine

4.3.4 Root Cause Analysis for Filler machine

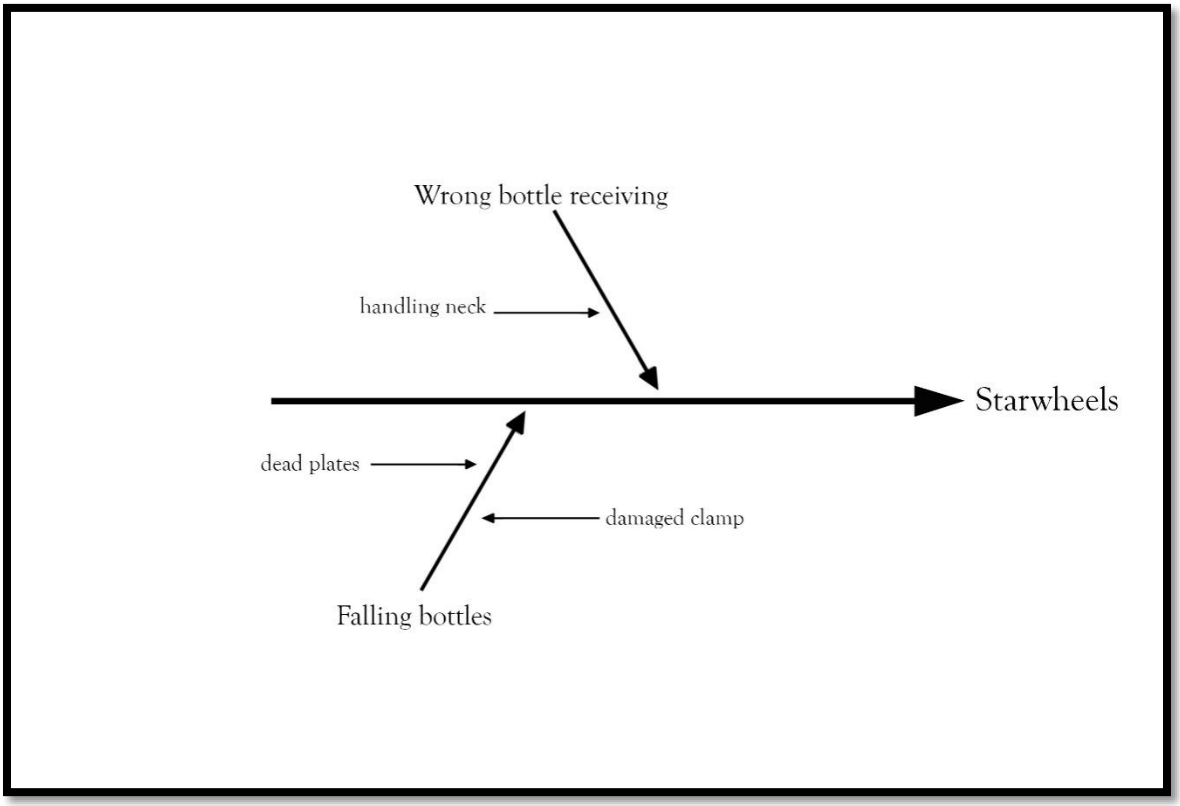

Figure (4.7): Starwheel root cause tree

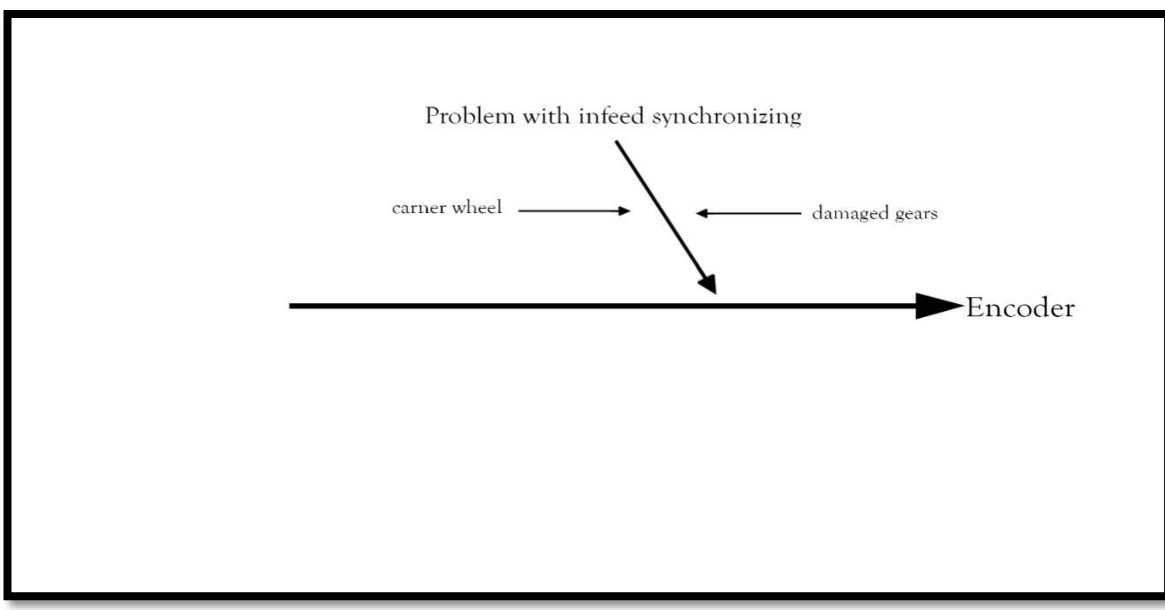

Figure (4.8) : Encoder root cause tree

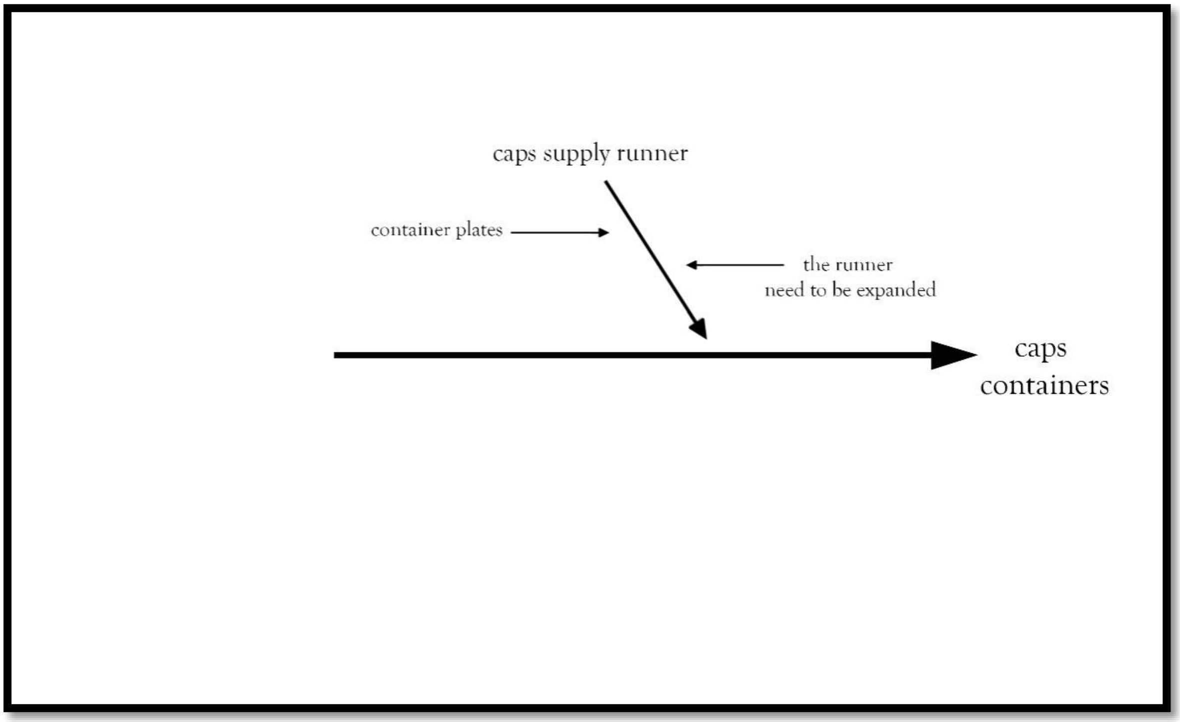

Figure (4.9) : Caps container root cause tree

4.3.5 (FMECA) for filler machine

Table (4.8): FMECA for starwheel

description of unit			description of failure			effect of failure		failure rate	severity	risk reducing measures	comments
ref no	**Function**	**operational mode**	**failure mode**	**failure causes or mechanism**	**detection of failure**	**on the subsystem**	**on the system function**				
Clamp	To grab bottle and	Running	Clamp damaged	Bearing and holding device when a lateral pivoting range	1.stop of the machine 2.maintenance worker experience	Falling bottles	Extensive damage can be done to whole installation transfer area	HIGH	5	Continued check for operation and damage	Since the failure can be prevent easily therefor preventive maintenance
			Gripper destroyed	Force is exceeded	Fall of bottles					Use better materials to avoid the damage	
Connecting screw	Synchronizing And move the wheel to take bottles	Running	Connecting screw damaged	1.friction 2.missalignment	1.stop of the machine 2.maintenance worker experience	Falling bottles	Make secondary damage in transfer area	LOW	5	1.Oil 2.Verify the proper alignment of the screw position	Low failure rate , low effect and easy to repair thus corrective maintenance
			Screw wear	High pressure on the screw	Fall of bottles						

Table (4.9): FMECA for encoder

description of unit			description of failure			effect of failure		failure rate	severity	risk reducing measures	comments
ref no	**Function**	**operational mode**	**failure mode**	**failure causes or mechanism**	**detection of failure**	**on the subsystem**	**on the system function**				
encoder	keep the synchronization between the BM and the filler	running	Problem with infeed synchronizing	Damaged gear, timer issue	Fail in the infeed synchronizing	Lose the timing between the filler and B.M	The work between the two machine will missed up	High	7	Check for wear and lubrication	With high severity and detection numbers predictive maintenance should be implement
the transmission gear	Support the movement with belt between the two machines	running	Surface damaged	Excessive Wear of continued operation	Visual check surface of the gear	Continued operation may lead to breakage	Lose the synchronization	low	7	Stop the overload on the equipment	predictive maintenance
The timer	Control the work timing	running	Timing lose	Damaged gear	Visual check for the gear	Wrong filler infeed	Lose the synchronization	low	7	Check for damage	predictive maintenance

Table (4.10): FMECA for caps container

description of unit			description of failure			effect of failure		failure rate	severity ranking	risk reducing measures	comments
ref no	**function**	**operational mode**	**failure mode**	**failure causes or mechanism**	**detection of failure**	**on the subsystem**	**on the system function**				
Container plates	Handle the caps	Running	Falling caps	Screw connections	Simple mentoring	Unclosed bottles	Delaying the filling stage	low	4	Check and replace the connections if need to	The failure is rare to happen and easy to repair ,there for breakdown maintenance
The cap runner	The supply path	Running	Hold the caps	Small space inside the runner	Low infeed to the caper	Unclosed bottles	Delaying the filling stage	high	4	Check connection , expand the runner	The failure will cause totally unacceptable products thus preventive maintenance every month

4.3.6 Strategy of maintenance of filler machine

Table (4.11): Strategy of maintenance of filler machine

Time	Item	Work
Daily	Entire machine	Check for safety, dirt and damage
Monthly Or every 500 operation hour	The wheel clamp	check for wear, damage
	Wheel plates	check for wear, dirt adjustment
	Handling neck	check for wear, damage
	The cap runner	Check connection and proper operation
	Container plates	check for wear
	All gears	check for wear, bearing and lubrication
Yearly Or every 5000 operation hour	Entire machine	General inspection

4.4 Strategy of maintenance for uncritical component in Blow Mold machine and Filler machine

Table (4.12) : Strategy of maintenance for uncritical component in both Blow Mold machine and Filler machine

Time	Item	Work
Daily	Entire machine	check for safety, the lubrication system and connections
Monthly Or every 500 operation hours	Encoder	Visually check the dive wheels and the cam wheel.
	Perform Conveyor belt	Check the screw connections and the lubrication process.
	Perform supply	Check the rotary joint and prober lubrication.
	Linear oven	Check for cleanliness, damage and proper operation.
	Caper	Check the handling parts neck, plates, and clamps and check the filling units for wear, adjustment and damage.
Yearly Or every 5000 operation hours	Entire machine	General inspection.

CHAPTER FIVE

Conclusion and Recommendations

5.1 CONCLUSION

1- All failure that have been or may have occurred in the machines and the appropriate maintenance type have been analyzed and identified
2- The appropriate maintenance plan has been determined for each machine
3- By analyzing the two machines, the failures had taken place in the molds. Although the molds failures has the highest occurrence rate, but its only effect on the products, there is no effect on the production process.
4- On the other hand, the conveyor belt and the encoder failures, these failures has no effect on the products, but it has always caused the production process to stop. Thus, it is responsible of most of the system downtime.
5- Although the aim of (PM) is to prevent occurrence of the failure, some failures including caper, star wheel and the containers failures has small effect and low occurrence therefor it’s better to wait for the failure then repair it.

5.2 RECOMMENDATIONS

1- Apply the maintenance plan obtained to minimize the possibility of failures.
2- We recommend that complete the research by entering the cost of maintenance and the cost of spare parts to find the best maintenance strategy
3- In our previous analyzing, we notice that some failures has low severity, occurrence and no place among the critical failures, but it has cumulative impact on the system. Thus, for the upcoming researches we recommend that to take this type of failure between the critical failures.
4- We recommend that to take the safety as factor in the analysis.

Refrences

1. Preventive and Predictive Maintenance. 8/1/2017 07:27PM]; Available from: https://www.lce.com/pdfs/The-PMPdM-Program-124.pdf.
2. Scheffer, C. and P. Girdhar, Practical machinery vibration analysis and predictive maintenance. 2004: Elsevier.
3. Preventative Maintenance (PM). 15/10/2017 9:30AM]; Available from: http://www.fiixsoftware.com/maintenance-strategies/preventative-maintenance.
4. ETI, M., S. OGAJI, and S. PROBERT, Development and implementation of preventive-maintenance practices in Nigerian industries. Applied Energy, 2006. 83(10): p. 1163-1179.
5. Bloom, N.B., Reliability centered maintenance. New York: Mac Graw-Hill, 2006.
6. Mobley, K., L. Higgins, and D. Wikoff, Maintenance engineering handbook. 2008: McGraw-Hill Prof Med/Tech.
7. Reliability centered maintenance (RCM). 18/2/2017 8:10AM]; Available from: https://www.fiixsoftware.com/maintenance-strategies/reliability-centered-maintenance.
8. Altona, V. and R. van Dullemen, Introducing PM OPTIMISATION.
9. Villacourt, M., Failure mode and effects analysis (fmea): A guide for continuous improvement for the semiconductor equipment industry. International Semetech Inc., Austin, USA, 1992: p. 10.
10. Haapanen, P. and A. Helminen, Failure mode and effects analysis of software-based automation systems. 2002.

11. Failure Mode Effects and Criticality Analysis (FMECA) Procedure 30/4/2017 9:30PM]; Available from: https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdq2/~edisp/dd_046414.pdf.
12. Carlson, C., Effective FMEAs: Achieving safe, reliable, and economical products and processes using failure mode and effects analysis. Vol. 1. 2012: John Wiley & Sons.
13. Chapter 3 FMECA. 15/10/2017 3:22 AM]; Available from: http://frigg.ivt.ntnu.no/ross/srt/slides/chapt03-fmeca.pdf.
14. PARETO ANALYSIS. 6\5\2017 9:29AM]; Available from: http://www.improhealth.org/fileadmin/Documents/Improvement_Tools/Pareto_Analysis.pdf.
15. Brooks, c. What Is a Pareto Analysis? 6/5/2017 10:32AM]; Available from: http://www.businessnewsdaily.com/6154-pareto-analysis.html.
16. Pareto Diagram 2004 6\5\2017. 2:50 PM]; Available from: http://www.health.state.mn.us/divs/opi/qi/toolbox/docs/paretodiagram_ihi.pdf.
17. Pareto Analysis Template. 6/5/2017 3:00PM]; Available from: https://www.projectsmart.co.uk/docs/pareto-analysis.xlsx.

Appendix

Appendix A: Blow Mold machine failures

Date	Failure	Total maintenance time
23/1/2017	Problem with perform supply inf**eed**	60 min
27/1/2017	Unclosed mold no(5)	15 min
1/3/2017	Un closed mold no(5+1)	5 min
6/3/2017	Bottle deformation (temperature setup and blowing angle)	25 min
8/3/2017	wrong temperature setup in base mold	25 min
9/3/2017	Problem in the heaters	15 min
12/3/2017	Bottle deformation (temperature setup and blowing angle)	20 min
14/3/2017	Bottle deformation (temperature setup and blowing angle)	10 min
19/3/2017	Un closed mold no(5+6)	30 min
21/3/2017	temperature setup and mold 5 issue	15 min
22/3/2017	Damaged pin	10 min
2/4/2017	Problem in mold no 6 (temperature setup and blowing angle)	10 min
3/4/2017	Problem with the infeed between the filler and BM	40 min

Appendix B: Blow Mold machine failures count

Failure	Count
problem in Molds	9
Problem in Perform Conveyor belt	1
Problem in the heaters	1
problem in the cam	1
Problem with the infeed between the filler and BM	1

Appendix C: Filler machine failures

Date	Failure	Total maintenance time
23/1/2017	Wrong bottle receiving	10 min
6/2/2017	Wrong bottle receiving	15 min
23/2/2017	Problem with infeed synchronizing	120 min
1/3/2017	Problem with valve no 37	50 min
2/3/2017	Clamp issue	35 min
5/3/2017	Wrong bottle receiving	30 min
7/3/2017	Problem in cap supply path	15 min
13/3/2017	Problem in cap supply path	10 min
14/3/2017	Bottles fall down inside the filler	10 min
14/3/2017	Bottles fall down inside the filler and infeed issue	25 min
19/3/2017	Unclosed bottle	10 min
3/4/2017	Problem with infeed timing	15 min
17/4/2017	Problem with sensor reading	45 min

Appendix D: Filler machine failures count

Failure	Count
Wrong bottle receiving	5
Problem with infeed synchronizing	3
Problem in cap supply runner	2
Problem with valve no 37 in soft drink container	1
problem in filler sensors	1
bottles out without caps	1